INVESTIGATING THE ROLE OF SENSOR BASED TECHNOLOGIES TO SUPPORT DOMESTIC ACTIVITIES IN SUB-SAHARAN AFRICA

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ABSTRACT

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In sub-Saharan Africa (SSA), homes face various challenges including insecurity, unreliable power supply, and extreme weather conditions. While the use of sensor-based technologies is increasing in industrialized countries, it is unclear how they can be used to support domestic activities in SSA. The availability of low-cost sensors and the widespread adoption of mobile phones presents an opportunity to collect real-time data and utilize proactive methods to monitor these challenges. This dissertation presents three studies that build upon each other to explore the role of sensor-based technologies in SSA. I used a technology probes method to develop three sensor-based systems that support domestic security (M-Kulinda), power blackout monitoring (GridAlert) and poultry farming (NkhukuApp). I deployed M-Kulinda in 20 Kenyan homes, GridAlert in 18 Kenyan homes, and NkhukuProbe in 15 Malawian home-based chicken coops for one month. I used interview, observation, diary, and data logging methods to understand participants' experiences using the probes. Findings from these studies suggest that people in Kenya and Malawi want to incorporate sensor-based technologies into their everyday activities, and they quickly find unexpected ways to use them. Participants' interactions with the probes prompted detailed reflections about how they would integrate sensor-based technologies in their homes (e.g., monitoring non-digital tools). These reflections are useful for motivating new design concepts in HCI. I use these findings to motivate a discussion about unexplored areas that could benefit from sensor-based technologies. Further, I discuss recommendations for designing sensor-based technologies that support activities in some

Kenyan and Malawian homes. This research contributes to HCI by providing design implications for sensor-based applications in Kenyan and Malawian homes, employing a technology probes method in a non-traditional context, and developing prototypes of three novel systems.

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CHAPTER ONE: INTRODUCTION

Homes in rural parts of Sub-Saharan Africa (SSA) face various challenges including frequent power blackouts, domestic insecurity, and rising temperature conditions that affect poultry farming practices. SSA is a region in Africa that lies to the south of the Sahara Desert (Kampala, 2019). Some of the countries within this region include Tanzania, Malawi, Kenya, and Zimbabwe. As of 2019, the region had a population of 1.07 billion people from 46 different countries (United Nations, 2019). The World Bank reports that every year, an average home in SSA experiences 700 hours without electricity compared to one hour in industrialized countries (The World Bank, 2016). Over 50% of crimes in this region involve theft of domestic property (Grote & Neubacher, 2016). Further, 68% of poultry farmers in SSA are negatively affected by climate change (Liverpool-Tasie et al., 2019). These are examples of significant challenges that require attention within SSA. Sensors present an opportunity to design technological solutions that can address these challenges.

In industrialized countries, sensor-based technologies—such as smart security systems, virtual assistants, and sleep monitors—have been used to support people's domestic needs. Further, these technologies are used commercially to support medical systems (S. Zhang et al., 2020), efficiency of energy sources (Kjeldskov et al., 2012), security for homes (Brush et al., 2011), and environmental monitoring (Moore et al., 2018). The United Nations define industrialized countries as countries that have a Gross National Income (GNI) per capita of more than $12,375, and these countries generally have a high quality of life, a developed economy, and advanced technological infrastructure (United Nations, 2020). Some of the industrialized countries include the United States (U.S.), the United Kingdom (U.K.), Canada, Denmark, and Germany.

The adoption of these technologies continues to grow in industrialized countries; however, their adoption is low in SSA. By 2016, there were 14.87 billion sensor-based devices world-wide (Microsoft Dynamics 365, 2019), but only four percent of these devices were being used in SSA (Serrenho & Bertoldi, 2019). One reason contributing to this small percentage is that commercially available sensor-based systems require high-speed Wi-Fi/Cable Internet connection and high voltage electricity supply; these are resources that are considered 'for the upper-class' in SSA (McDonald, 2011; Sebbar et al., 2016). Generally, the upper-class have financial resources to buy these devices and are located in wealthy urban areas that have good network coverage and electricity supply (Choi et al., 2019). A second reason for SSA's low access to sensor-based technologies is that existing systems are generally not designed to solve the challenges SSA homes face, such as frequent power blackouts. The availability low-power sensors and micro-controllers that transmit data through cellular networks presents an opportunity to design sensor-based technologies that support domestic activities in SSA.

Despite this opportunity, prior research on the role of sensors in homes has mostly been conducted in industrialized countries; yet, "homes are not the same across the globe" (Bell et al., 2005). Homes around the globe are significantly different in terms of scale, size, and history (Dourish & Bell, 2011). Even within a country, homes have varied social and cultural practices, dysfunctions, and aspirations (Miller, 2008). Further, the ways people adopt and use technology in homes is influenced by where they live. Bell et al. (2005) suggest that the design of technologies for homes should use traces of histories and specific cultural meanings to inform culturally rich designs. Similarly, Dourish and Bell (2011, p. 166) argue that "to design meaning making domestic technologies, one must begin with an awareness of cultural context, accrued social meanings, and everyday experiences".

Designing domestic technologies should start with understanding existing home experiences, then augment them with digital technologies and infrastructures (Dourish & Bell, 2011). This increases the likelihood of designing domestic technologies that appropriately support peoples' everyday needs. Scholars have found that the transfer of technology from one region to another can introduce unintended consequences that negatively affect peoples' lives (Ahmed, Guha, et al., 2017). For example, Ahmed et al., observed that the transfer of technological products from industrialized countries to the Global South carried threats associated with privacy in Bangladesh (Ahmed, Guha, et al., 2017). The Global South broadly refers to low-income countries that are mostly located in "the regions of Latin America, Asia, Africa and Oceania" (Dodos & Connell, 2012, p. 1). Irani et al. (2010, p. 2) underscored that "efforts to migrate technologies from industrialized countries to other parts of the world have foundered either on infrastructural differences or social, cultural, political or economic assumptions that do not hold".

Instead of importing sensor-based technologies from one region to another, it is important to understand different roles sensors can play, peoples' reflections about using them in their domestic space, and how they should be specifically designed for a given region. Sengers et al. (2005) argued that unconsciously held thoughts are not rationally known, but they are part of our identity and the way we experience the world. These unconsciously held thoughts are necessary to understand peoples' relationship with technology. So, in this dissertation, reflection means "bringing unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice" (Sengers et al., 2005, p. 2). By understanding peoples' reflections, researchers and designers learn about potential opportunities of using technology to solve challenges.

The goals of this dissertation are to explore the role of sensor-based technologies in SSA homes and peoples' reflections about using them to support their activities. I used research through design (RtD) methodology to pursue these goals in three sites within SSA: Bungoma and Kisumu in Kenya, and Nsaru in Malawi. This dissertation does not attempt to generalize its findings to larger populations throughout SSA, but rather to draw attention to pluralistic aspects of how participants in the study sites want to use sensor-based technologies in their homes. Pluralism encourages designing technological systems that resist a universalized or generalized point of view (Bardzell, 2010). This design research approach is important as it responds to concerns within Human Computer Interaction (HCI) and Information and Communication Technologies for Development (ICTD) where technological experiences among SSA users have been universalized (Winschiers-Theophilus & Bidwell, 2013). Instead of focusing on universalizing findings, RtD focuses on generating knowledge that can be used to design technologies that meet people's specific needs (Zimmerman & Forlizzi, 2014).

This research draws from my experiences growing-up in Malawi and exploratory research (conducted in 2016) where I studied technology use and sustainable practices in rural Kenyan homes (S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018). This study's findings suggest that participants face domestic security challenges and people use technology, such as security lights, to deter thieves from breaking into their homes (S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018). These findings are aligned with prior research in HCI/ICTD that suggest that homes in SSA face challenges and people are interested in using technology to support their needs (Castle et al., 2016; Chetty et al., 2015; S. P. Wyche et al., 2010).

HCI/ICTD researchers have conducted research to explore how technology, especially mobile phones, can be used to support people's needs in SSA (Chidziwisano, Wyche, & Kisyula, 2020; E. Oduor et al., 2016; S. Wyche et al., 2015; S. Wyche & Steinfield, 2015). However, most ICT-based research in SSA focuses on using mobile phone applications to provide people with information. Dell and Kumar's (2016) review of the technologies studied in ICTD suggests that researchers focus on mobile phones, desktop and laptops, video technologies, and paper. Among the 259 papers they reviewed, 147 papers focused of mobile phone applications. These include social media applications (S. P. Wyche et al., 2013), financial management applications (Castle et al., 2016), and mobile applications for accessing agricultural pricing information (S. Wyche & Steinfield, 2016). Mobile applications alone usually require manual user-input, and they typically lack the capability to collect real-time data from the surrounding environment. I build upon my exploratory research and mobile phone research in SSA by using sensor-based technologies to provide opportunities for people to access real-time information about their daily challenges and take proactive measures to control them (Moshin et al., 2009; H. Phiri, 2018; S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018).

I situate my research in the fields of HCI, ICTD, and Ubiquitous Computing (UbiComp). More specifically, I situate my research HCI's third paradigm, which provides methodologies and methods for designing, developing, and evaluating computing systems that meet users' needs (Grudin, 2012). As Harrison et al. (2007) argued that HCI's three paradigms can coexist; my research also draws from the theory of distributed cognition which was introduced in the second paradigm. Distributed cognition extends what is considered cognitive "beyond the individual to encompass interactions between people with resources and materials in the environment" (J. Hollan et al., 2000, p. 3). This theory guided my research by using early design methods to understand peoples' interactions with sensors in the presence of the resources they use to support different activities in their homes. My research views cognition as a process that goes beyond an individual brain to include resources and practices surrounding them.

The field of ICTD specifically applies HCI methodologies and methods to support global development (Dell & Kumar, 2016). UbiComp applies them to design, develop, and deploy pervasive technologies (including sensor-based technologies) that integrate information in the everyday physical world (Weiser, 1994). These fields provide an appropriate methodological background to pursue my research goals. My research contributes to these fields by broadening the domestic technologies typically explored in HCI/ICTD research to include sensors.

1.1 Motivation

This dissertation examines how to design sensor-based technologies to support domestic activities in SSA, because sensors afford real-time data collection and event detection, foster inter-user engagement (users introduce new technologies to their neighbors and use them as tools for experimentation) and are affordable. The collection of real-time data offers an opportunity to continuously monitor and reduce the challenges people face, such as environmental conditions that negatively affect poultry farming (Nyoni et al., 2019). Prior research suggests that data collected from sensors can provide real-time chicken coop conditions thereby helping poultry farmers to take proactive measures to control adverse effects, like heat stress (H. Phiri, 2018). Further, the implementation of sensor-based solutions presents an alternative to inadequate extension services in rural areas because modern sensors are integrated with micro-controllers thereby enabling local computations (Arora et al., 2004). This means that sensor-based applications can process and analyze the data they collect then provide feedback to famers without the presence of extension officers.

In relation to real-time data collection, sensors can also afford real-time event detection; that is, they record events as they happen and provide feedback to users (Dutta et al., 2005). This is important as there are many events in SSA, such as power blackouts and domestic robbery, that require continuous monitoring (Grote & Neubacher, 2016; Klugman et al., 2019). Automatic event detection, using sensors, can improve accuracy and precision of existing manual methods as prior research conducted in Tanzania, Malawi and Zambia suggests that sensor-based technologies can improve water quality monitoring systems (Adu-Manu et al., 2017).

Further, the cost of sensors has significantly decreased over time. Between 2004 and 2018, the average cost of a sensor dropped nearly 200%, from $1.30 to an average cost of $0.44 (Microsoft Dynamics 365, 2019). Further, these low-cost sensors require low-voltage input that can be easily supplied by a small power bank (Dutta et al., 2005; A. Raj & Steingart, 2018). These factors increase the potential of using sensor-based applications in regions that have poor electricity reliability.

Sensors also provide new ways for users to observe, explore, reflect, and discuss their local surroundings. This generate new ideas about how technology can be used to support people's needs (Dema et al., 2019; Moore et al., 2018; Segura et al., 2019). Dema et al. (2019, p. 1) suggests that "sensors provide new ways for communities to see and discuss their local environment, fostering them to share and grow their knowledge together". This encourages users' awareness of their environment, knowledge sharing, and reflections about the role of technology in their lives (Dema et al., 2019; Moore et al., 2018). It is important to understand users' reflections about new technologies, because they provide new opportunities to design technologies that support their needs (W. Odom et al., 2014; Sengers et al., 2005). However, there is little research exploring peoples' reflections about the role of sensor-based technologies in SSA homes. This dissertation broadens existing research in HCI, ICTD, and UbiComp by providing peoples' reflections about the role of sensor-based technologies in some Kenyan and Malawian homes.

1.2 Research Questions

This research is guided by the following questions:

1) What is the role of sensor-based technologies in supporting domestic activities in Kenya and Malawi? Research on the application of sensor-based technologies in homes has primarily taken place in industrialized countries (Desjardins, Wakkary, Odom, et al.,

2015; Kidd et al., 1999). Yet, the existing infrastructure and the challenges SSA homes face are different. It is unclear how sensors can be used to support domestic activities in SSA. By answering this research question, I provide empirical evidence about how people in some regions of SSA experience and interact with sensor-based technologies to support their existing needs.

2) What are the reflections of people in Kenya and Malawi about using sensor-based technologies to support domestic activities? Participants' reflections are a core principle of technology design for "identifying blind spots and opening new design spaces" (Sengers et al., 2005, p. 2). These reflections can inform requirements for designing sensor-based applications that meet the needs of some people living in Kenyan and Malawian homes. It is important to design technological applications based on user needs to solve existing challenges.

1.3 Methodology, Findings and Contributions

To answer these questions, I used RtD methodology, because it "draws on design's strength as a reflective practice of continually reinterpreting and reframing a problematic solution through a process of making and critiquing artifacts that function as proposed solutions" (Zimmerman & Forlizzi, 2014, p. 167). RtD encourages researchers to design artifacts that users interact with to reconsider different aspects of their world (Zimmerman & Forlizzi, 2014). To do this, I designed three technology artifacts: M-Kulinda for supporting domestic security activities, GridAlert for monitoring power blackouts, and NkhukuProbe for monitoring poultry farming activities. I independently developed M-Kulinda and worked collaboratively with local technicians in Kenya and Malawi to develop GridAlert and NkhukuProbe. I describe these artifacts as technology probes because they combine "the social science goal of collecting data about the use of technology in a real-world setting, the engineering goal of field testing the technology and the design goal of inspiring users (and designers) to think of new kinds of technology" (Hutchinson et al., 2003).

I deployed these probes in 53 homes in Kenya and Malawi to understand participants' experiences using sensor-based technologies to support different activities. The technology probes method has been widely used in HCI to design family communication technologies (Brereton et al., 2015; Hutchinson et al., 2003; W. T. Odom et al., 2014), new sensing technologies for conserving endangered species (Dema et al., 2019), and inspirational educational technology for children (Wyeth et al., 2006). However, to date, there have been few studies that use this method in SSA. This method is appropriate to answer my research questions because it introduces new technologies to users, inspiring them to reflect on different ways of using technology in their homes (Hutchinson et al., 2003). Technology probes are introduced early in the design process, so users can become partners in the design of new technologies (Hutchinson et al., 2003).

I conducted the first and second studies that took place in Bungoma and Kisumu, Kenya and worked remotely with research assistants for the study conducted in Nsaru, Malawi due to the COVID-19 pandemic. Each study had two phases: pre-probe deployment (Phase I) and evaluation (Phase II) phases. During these phases, I complemented the technology probes method with other methods including semi-structured interviews, observations, diary studies, and data logging. During Phase I, I conducted in-depth interviews to understand the various tools that participants use in each of the areas I focused on: domestic security, power blackout monitoring, and poultry farming. I complemented these interviews with observations of different tools that participants had in their homes.

Following this, I conducted an evaluation of the probes; that is, I asked participants to use them for one month. During the deployment period, participants documented their experiences using the diary method. I also used the data logging method to collect data about participants' interactions with the probes. After a month, I conducted follow-up semi-structured interviews with participants to learn more about how they used the probes.

I analyzed qualitative data using the affinity diagramming technique (Beyer & Holtzblatt, 1999) that allowed me to extract meaning from the data I collected and use that meaning to answer my research questions. I used Python to analyze data logs. Python is an "interpreted interactive object-oriented programming language" (Sanner, 1999, p. 3). It is used for data analysis and visualization, because it has numerous libraries that support computational data analysis (McKinney, 2012). My analysis of the data logs generated descriptive statistics regarding participants' interactions with the probes. These statistics include how often participants interacted with the probe on daily basis and over time. Understanding how frequently participants used the probes during the deployment was necessary to validate data provided using the diaries.

My analysis suggests that sensor-based technologies can potentially secure participants' homes, monitor power blackouts and their poultry farming activities. Participants' interactions with the probes prompted detailed reflections of how some people in Kenya and Malawi want to use sensor-based technologies in their everyday lives. For example, participants used the probes beyond the three domains they were designed for, like monitoring the amount of time their children spent watching television. They also thought of other ways to use sensors, including air quality and water outage monitoring.

Findings from these studies also draw attention to the unintended consequences which can accompany the deployment of sensor-based technologies in some homes. The deployment of sensor-based technologies seemed to exacerbate patriarchal norms that negatively affect women's privacy in homes. My analysis suggests this was common in patriarchal homes compared to matriarchal homes. More specifically, men in Bungoma and Kisumu, Kenya used the probes to monitor their daughters and wives unlike men in Nsaru, Malawi. This might be due to the nature of the sensors I deployed in these study sites, however a key distinction between these field sites is that most homes in Kisumu and Bungoma are guided by patriarchal norms compared to homes in Nsaru, Malawi, which are guided by matriarchal norms (Maseno & Kilonzo, 2011; Ong'ayi et al., 2020; K. M. Phiri, 2009). From a distributed cognition perspective, participants' understanding of how the probes could be used was guided by their existing cultural norms, because culture itself is within the boundaries of a cognitive process (J. Hollan et al., 2000). These findings suggest future research opportunities in HCI/ICTD to explore how sensor-based technologies can be designed to reduce amplifying patriarchal norms, which tend to be unfavorable, especially for women and girls.

My research outcomes contain design implications for sensor-based technologies that can potentially support domestic activities in some Kenyan and Malawian homes. Further, my findings motivate a discussion about the benefits of using the technology probes method to design new technologies in Kenya and Malawi. Participants' interactions with the probes inspired them to think of other ways of using technologies in their homes. The ways participants used the probes inform research ideas for future exploration.

My dissertation makes three contributions to the fields of HCI, ICTD, and UbiComp. First, it provides empirical evidence about the potential of using sensor-based technologies to support domestic activities in rural Kenya and Malawi. Findings from my three studies provide detailed accounts of participants' interactions with the probes to support their everyday domestic activities. These accounts provide opportunities for designing other sensor-based technologies for some Kenyan and Malawian homes. Participants' interactions with the probes unveiled four areas of interest where sensors can be applied in these homes. These included automating non-digital tools, designing sensors to support neighborhood cohesion, designing sensors to support occult practices, and designing privacy-aware sensors.

Second, this research makes a methodological contribution by using a technology probes method in SSA—a new context where this method has not been used. The use of the technology probes method in this context draws attention to recommendations for designing sensor-based technologies. This alternative method to design research is different from other methods, such as interviews, focus group discussion, surveys, and usability studies (Anokwa et al., 2009; Dell & Kumar, 2016), that have been used to study technology use in ICTD contexts. My research contributes to ICTD by demonstrating the benefits of using technology probes method in SSA. The technology probes method's open-ended nature provided flexibility for participants to reflect on the role of sensor-based technologies in their everyday activities. Further, this dissertation extends other studies that have used technology probes outside ICTD contexts by demonstrating the value of collaborating with local technicians when designing technology probes for SSA.

Finally, the probes themselves also represent a contribution. Over the course of my dissertation, I designed and built three prototype systems: M-Kulinda ("Kulinda" is a Swahili word for security), GridAlert, and NkhukuProbe ("Nkhuku" is a Chichewa word for chicken). These prototype systems are a contribution to UbiComp as they illuminate how pervasive and everyday computing applications can be used to support domestic activities in some Kenyan and Malawian homes.

1.4 Overview of Dissertation

In the next chapter, I review related studies in the fields of HCI, ICTD, and UbiComp. This chapter includes the history of sensor-based technologies followed by a review of how these technologies have been used in industrialized countries. Then, I review infrastructural differences between industrialized countries and SSA. Next, I provide a review of how technology has been used to solve problems related to domestic security, power blackout monitoring, and poultry farming in SSA. I conclude Chapter Two with a review of the technology probes method, to further explain why I use this method to answer my research questions.

In Chapter Three, I describe RtD, and how I used this methodology to answer my research questions. I also describe my positionality, and how this influenced my research. Following this, I detail the methods I used to collect data and how I analyzed it. Chapters Four, Five, and Six are dedicated to my three studies. In each chapter, I describe how I developed the technology probes, including the technical details. Then, I give an overview of the study sites and participants. Following this, I present key findings from each of the studies and conclude with a summary.

Chapter Four focuses on the M-Kulinda probe for domestic security. Findings from this study suggest that participants want to use sensors to monitor power blackouts and poultry farming (Chidziwisano & Wyche, 2018). In Chapter Five, I build upon findings from the M-Kulinda deployment to design GridAlert and explore the role of sensor-based technologies to support power blackout monitoring in Kisumu County, Kenya (Chidziwisano, Wyche, & Oduor, 2020). In this study, I collaborated with local technicians to design GridAlert using locally available materials, because prior research suggests that local resources have a high impact on the sustainability of a technology (Klugman et al., 2019). Chapter Six builds on findings from the two previous studies by using a similar approach to explore the role of sensor-based technologies in supporting poultry farming—another area that was suggested by participants in the M-Kulinda study. To explore this topic, I collaborated with local technicians to design NkhukuProbe and deploy it in Nsaru, Malawi (Chidziwisano et al., 2021).

In Chapter Seven, I discuss how sensor-based technologies can be used to support different activities in some Kenyan and Malawian homes and how participants' reflections about using sensors in their homes provide future opportunities for technology design. My research findings suggest that the integration of sensors with non-digital tools in homes can potentially support domestic activities, and participants are interested in using sensors beyond the extent of how they have been used in industrialized countries. However, my findings also suggest that introducing sensors into patriarchal homes can potentially exacerbate patriarchal norms and jeopardize women's privacy. In Chapter Eight, I discuss the limitations of this dissertation, and propose future research directions. I conclude this dissertation in Chapter Nine where I discuss the contributions of this research in HCI/ICTD.

CHAPTER TWO: RELATED WORK

In this chapter, I present related research from the fields of HCI, ICTD, and UbiComp. I also draw from the fields of criminology and agriculture to provide a foundation of domestic security and poultry farming research in SSA. First, I provide a background of research in HCI, ICTD and UbiComp—the fields of study that my research contributes to. I demonstrate how HCI research evolved from studying user interaction on desktop computers primarily in controlled environments, to studying technology use in a real-world settings. Then, I provide a background of how HCI research expanded into new subfields—including ICTD and UbiComp—to account for technology use in different contexts and the development of new technological systems. This background suggests that HCI research within ICTD has primarily focused on mobile phone technology use with little focus on sensor-based applications in SSA homes. The integration of sensor-based applications in SSA homes is important to monitor different challenges that some households face.

Since my research focuses on sensor-based applications, I review the history of sensors followed by a review of UbiComp literature about the application of sensors in industrialized countries' homes. This review demonstrates how HCI research transitioned from studying technology use in office settings, to studying domestic technology use in industrialized countries. Though this prior research provides a deep understanding of domestic technology use, it does not account for homes outside industrialized countries. Despite this, homes across the globe have different infrastructures and constraints. A review of these differences suggests the need for HCI research on domestic technologies to diversify its scope into SSA homes.

Although there exists a gap about the role of sensors in SSA homes, some scholars have explored this topic. However, they primarily focused on how sensor-based technologies can support industrial activities rather than domestic ones. Further, sensor-based deployments in

SSA domestic settings have primarily focused on collecting information and providing it to utility companies rather than end users. I discuss how sensors are currently being used in SSA and their potential to support domestic security, power blackout monitoring, and poultry farming activities. Prior studies that explored these issues in SSA are mostly from the fields of criminology, electrical engineering, and agriculture (Bunei et al., 2013; Klugman et al., 2014; H. Phiri, 2018). These studies primarily use research methods, such as surveys, that are not suited to understanding peoples' practices and developing technological solutions to meet their needs. HCI research methods (e.g., technology probes) are specifically designed to understand user needs, test technological artifacts, and explore other ways of using technologies. My dissertation research uses technology probes to understand how some people in Kenya and Malawi would use sensor-based technologies to support their domestic activities. I distinguish my research from prior studies by using non-traditional HCI methods that focus on understanding people's unique experiences rather than generalized experiences. I conclude this chapter with a review of related work about technology probes and how they have been used to study peoples' reflections on different technologies.

2.1 Research in Human-Computer Interaction

Human-Computer Interaction (HCI) is a "discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (Hewett et al., 1992, p. 6). HCI focuses on human interaction with computing technologies as they become widely used, reflected in the spread of systems and applications (Grudin, 2012). Early research in HCI focused on evaluating computer mediated systems to measure task completion rates (Hutchins et al., 1985). The goal of early research in HCI was to optimize man-machine relationships (Harrison et al., 2007). Harrison et al. (2007) refers to this as HCI's first paradigm (wave)—designing desktop computers for a single user in an office setting. For example, Card et al. developed the Model Human Processor (MHP) to predict systems' performance in relation to how long it takes a user to complete a particular task (Card et al., 1986). The MHP calculated the rate at which a user can read text based on how much the user sees whenever they move their eyes. Early research in HCI tended to overlook larger social, cultural, and environmental factors that influence users' interaction with computers (J. Hollan et al., 2000).

To account for this gap, HCI scholars developed theories that are used to explore factors that influence user interaction with computing systems (J. Hollan et al., 2000). For example, the theory of distributed cognition provides an understanding of the computing world's transition from a single computer to a complex networked world of information and computer mediated interactions (J. Hollan et al., 2000). Distributed cognition theory is meant to understand interactions between people and technologies around them. Unlike previous theories, it extends the understanding of what is considered cognitive beyond a confinement of the human mind to include the interactions between people and materials around them (J. Hollan et al., 2000). Distributed cognition theory underscores that computing elements are used in a complex cultural environment, and it is important to understand existing constraints when designing technological systems (J. Hollan et al., 2000).

The theory of distributed cognition and other HCI theories developed at this time were important sources for theoretical reflection on the relationship between computing elements and the human mind (Bødker, 2006). Describing this as HCI's second paradigm, Harrison underscored that information processing is analogous to computation signal processing and that human interaction enables communication between the computer and the human mind (Harrison et al., 2007). The second paradigm broadened the use of a computer to include "group working, shaped by ideas about situated and social action together with Scandinavian approaches to participatory design" (Rogers, 2004, p. 30). This is generally referred to as Computer Supported Cooperative Work (CSCW)—a conference that emerged in 1986 by bringing together researchers from Information Systems, Office Information Systems, HCI, distributed Artificial Intelligence, and Anthropology to discuss issues of communication, information sharing, and coordination (Grudin, 2012).

Over time, the complex networked world consist of technologies that have become smaller, more affordable, and leverage sensing and network technologies to monitor objects of interest (e.g., our bodies, home appliances, and weather conditions) (Grudin, 2012; Schaller, 1997). This changing nature and complexity of computing technologies motivated researchers to introduce more specialized sub-fields in HCI, including UbiComp (Grudin, 2012). The field of Ubiquitous Computing specifically focuses on enhancing computer use by making many computers available throughout the physical environment while making them effectively invisible to the user (see section 2.1.1 for detailed review of UbiComp) (Weiser, 1994).

These computing technologies, such as mobile phones, have become widely available beyond the office space; as such, HCI research has expanded further to focus on "non-work, non-spaces and non-purposeful engagements where notions of culture, emotion, reflexivity and multiple mediation have center stage" (Rogers, 2004, p. 30). This is called HCI's third paradigm, where interaction is not analogous to information processing and transmission, but it is a form of meaning making in which the artifact and its context are mutually defining and subject to multiple interpretations (Harrison et al., 2007). The third paradigm is characterized by three elements: 1) a focus on meaning and meaning creation; 2) a basis on human experience; and 3) a representation of multiple perspectives and their relationships. These multiple perspectives include different elements of human life such as culture, gender, emotion, and experience (Bødker, 2006). The third paradigm embraces design and research directions that account for multiple perspectives by using methods that emerge from "theoretical lenses and what happens practically at a scene of action" (Harrison et al., 2011, p. 5). These methods include technology probes, and the probes are particularly useful because their construction avoids asking direct questions that limit discoveries to what is suggested by researchers (Boehner et al., 2007). As the third paradigm has provided new methods for understanding peoples' experiences using technologies, and the meaning they attach to them based on their context (Harrison et al., 2011), this dissertation is situated within this paradigm at the intersection of three fields: HCI, ICTD and UbiComp.

2.2 Research in the Field of Information and Communication Technologies for Development.

Today, computing technologies are widely available in almost all regions of the world, including SSA. Researchers argue that HCI can never be complete without the study of technologies in SSA (Ho et al., 2009). As such, researchers introduced a specific field to address the "distinctive needs of users in the Global South" (Ho et al., 2009). This broad area of study is referred to as Information and Communication Technologies for Development (ICTD). With a focus on understanding, developing, and evaluating technological systems in the Global South (Anokwa et al., 2009), my dissertation is well situated in this growing field. Here, I review major trends and highlights of ICTD research that are relevant to my research.

The field of ICTD draws attention to the "unexplored territory for HCI research" a terrain which has become relevant in HCI (Toyama, 2010, p. 7). From the early 1990s, scholars started conducting research on ICT usage and developing technological systems that targeted the Global South (Burrell & Toyama, 2019; Ho et al., 2009), such as health information systems. These research projects primarily targeted issues in education, microfinance, government, and health (Chetty & Grinter, 2007). For example, health information systems for the Global South were first deployed in South Africa, and were adopted in other countries such as Mozambique, India, and Ethiopia (Braa, 1996). By the first decade of the 21st century, interest in the field grew; universities and research institutions started participating in the field (Ho et al., 2009). For example, in 2001, Massachusetts Institute of Technology (MIT) and the government of India established Grassroots ICT Projects to study factors that influence the effectiveness of ICT use in India (Keniston, 2002). At the same time, the U.S. National Science Foundation (NSF) funded the University of California to conduct large multidisciplinary projects that evaluate ICTs in the Global South (Ho et al., 2009).

This growing interest from academia facilitated the introduction of specific journals and conference venues for the field. In 2003, Michael Best—a professor at Georgia Institute of Technology—founded the Information Technologies and International Development journal (ITID) to publish articles from ICT observers and ICT interventionists (Bar & Best, 2010; Ho et al., 2009). This was followed by the first ICTD conference that took place in 2006 at the University of California, Berkeley (Burrell & Toyama, 2019; Ho et al., 2009). This conference published research by technologists who examined "the link between information and communication technologies and socio-economic development" (Burrell & Toyama, 2019, p. 1). In 2007, Chetty and Grinter (2007) suggested that traditional HCI methods should be adapted within ICTD to support evaluation methods. These methods primarily included qualitative research methods (e.g., focus groups, semi-structured interviews, and observations) that are suitable for understanding people's practices and behavior (Anokwa et al., 2009; Ho et al., 2009; Toyama, 2010). The incorporation of these methods supported cross-cultural HCI research by investigating how cultures relate to system design and usage in the Global South (Ho et al., 2009). Further, the utilization of traditional HCI methods in ICTD expanded researchers' understanding of different activities that shape people's behavior (Toyama, 2010).

These methods are applied in ICTD to study newly introduced systems in the Global South (Anokwa et al., 2009) and investigate ways of designing systems so that they meet user and infrastructural requirements. Toyama (2010) suggests there are problems in ICTD research that can only be answered using HCI methods. For example, he asks whether mobile phones should be designed in such a way that even illiterate users can use them (Toyama, 2010). Without HCI's early design methods, like technology probes, it is difficult to find better ways of developing systems for users in the Global South.

Though a significant amount of ICTD research has used HCI's design methods, a majority of these studies have been conducted in Asia (Dell & Kumar, 2016). In 2016, Dell and Kumar conducted a literature review of 259 papers that were published in HCI and ICTD fields between 2009 and 2014. They found that 94 of these studies were conducted in SSA compared to 140 studies that were conducted in Asian countries (Dell & Kumar, 2016). Within SSA, several countries are under-represented as most of ICTD research takes place in few countries like South Africa (Dell & Kumar, 2016). Further, ICTD/HCI4D studies that have been conducted in SSA primarily focused on mobile phone usage. Notable examples include Oduor et al.'s (2014) research about how technology supports family communication in Kenya, Heimerl (Heimerl et al., 2009) et al.'s research on the role of SMS for cellular users who live in areas with poor network coverage in Uganda, Donner's (2008) research about research approaches to mobile phone use in the developing world, and Wyche et al.'s (2016) research about mobile phones as amplifiers of inequality in rural Kenya. Existing research in these fields broadened the field of HCI by making stories outside industrialized countries visible and offered recommendations for designing technologies for SSA.

Despite these contributions to ICTD, significant gaps remain; there is little research that has focused on sensors in SSA domestic spaces. Research about domestic technology primarily takes place in industrialized countries (Desjardins, Wakkary, & Odom, 2015). Desjardins et al. describes this as a limitation of existing research on domestic technology design because it "creates a western view of the home" (Desjardins et al., 2015, p. 2). I begin filling this gap by exploring the role of sensor-based technologies in Kenyan and Malawian homes.

2.3 History of Sensors

Sensors have been used for over hundred years and are a key component of this dissertation research. In this section, I provide a background of sensors from their invention to their transformation in size, weight, and cost, with the purpose of informing ubiquitous applications that support people's everyday activities.

A sensor is a "device that receives signals and responds to them in a distinctive manner, thus converting any physical or biological quantity into a measurable output signal" (Islam & Haider, 2009). The history of sensors (Figure 1) dates back to the nineteenth century when mechanical sensors—sensors that detect an event based on mechanical deformation that is translated into an electrical signal—were used in measuring instruments (e.g., aneroid barometer) (Schütze, Helwig, & Schneider, 2018; Zhang & Hoshino, 2014). The first electrical sensors (which eventually gave rise to today's smart sensors) were developed to improve defense applications during World War I and II (Corsi, 2010; Rogalski, 2012). During these wars, infrared sensors were used to improve the quality of astronomical observations, thermo-vision, surveillance, and warning systems (Corsi, 2010). For example, in 1939 an IR sniperscope—a display unit for optical sighting—was developed to improve visibility at night time (Rogalski, 2012). These applications were primarily implemented in industrialized countries, and it is unclear whether the developers of sensors considered using them in SSA.

A decade later, researchers developed biosensors—sensors that are used to detect the concentration of bio-chemical substances (Palchetti & Mascini, 2010). In 1956, researchers in the field of biochemistry developed a sensor-based oxygen probe which was used to measure oxygen in biochemical sample solutions (Palchetti & Mascini, 2010). These sensors were large, expensive, and they also required high voltage input which limited who had access to them and the purposes for which they could be used.

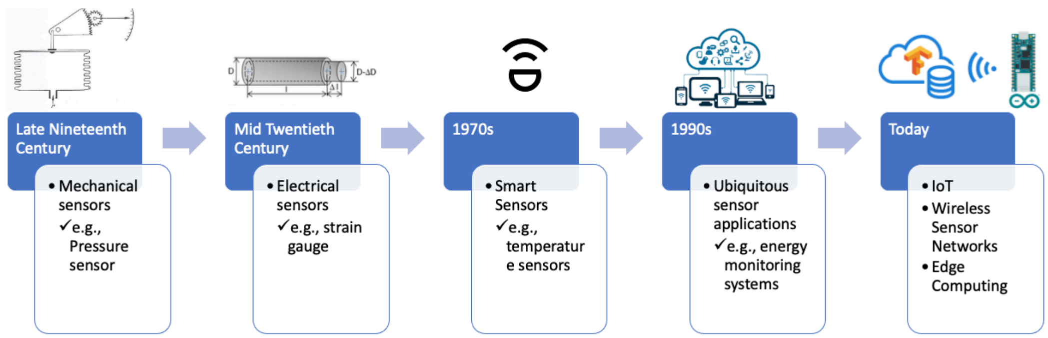


Figure 1: An illustration of the evolution of sensors (diagram made by author)

By the 1970's researchers made substantial progress towards developing sensors that were smaller in size, lighter, and affordable (Corsi, 2010). The term "smart sensors" was coined to refer to sensors that were implemented on a single chip with a signal processing unit (Kanoun, 2009; Prosser & Schmidt, 1997). Researchers leveraged silicon technology to develop numerous types of sensors which could be commercialized and used in public applications, such as the environment, health, transport, and security (Corsi, 2010). In 1982, a digital infrared imaging (DII) machine was developed for hospital use to measure body temperature from the breast area and automatically compute overall body temperature distribution (Corsi, 2010). The DII machine also consisted of highly sensitive cameras that were used to detect early signs of breast cancer. These breakthroughs, as well as efforts to use silicon technology and the Internet to develop portable computers that are connected through a wireless network led to a new field of computer science, UbiComp, that "speculates on a physical world filled and invisibly interwoven with sensors, actuators, displays and computational elements embedded seamlessly in everyday objects of our lives" (West, 2011, p. 1).

2.3.1 Sensors in Ubiquitous Computing

The progress made on reducing sensors' size, weight, and cost significantly contributed to Mark Weiser's vision of ubiquitous computing. Mark Weiser was a computer scientist and chief technology officer at Xerox PARC and is widely considered a foundational scholar in the field of UbiComp. In 1993, he speculated the role sensors will play in fulfilling the idea of ubiquitous computing. By this time, sensors were already used in office spaces to support different activities such as controlling heating and cooling systems (Weiser, 1993). Weiser envisioned that small sensors could be used in office spaces to switch on/off lights, computer displays, and other appliances.

A decade after Weiser introduced his vision for UbiComp, Abowd and Mynatt (2000) reviewed the field's history in three areas: natural interfaces, context-aware computing and automated capture and access for live experiences. Their review suggested that there had been progress to develop computers beyond the desktop. These advancements primarily focused on developing computer technology that was aware of its environment to help humans remember important information about their activities. Abowd and Mynatt's (2000) early review of these accomplishments opened-up a new area of research on ubiquitous applications called "everyday computing".

Everyday computing "results from considering the consequences of scaling ubiquitous computing with respect to time" (Abowd & Mynatt, 2000, p. 14). This idea is central to everyday computing because it moves computing from a localized traditional desktop to a model that supports the informal and unstructured activities of people's everyday lives. These are activities that happen continuously in peoples' lives, such as communicating with family and friends (Abowd & Mynatt, 2000). Everyday computing suggests that the design of UbiComp applications should acknowledge that multiple activities can occur concurrently. Further, Abowd and Mynatt (2000) proposed that UbiComp research should focus on connecting events in the physical and virtual worlds and designing continuously present computer interfaces. UbiComp's progress towards fulfilling this proposition largely contributed to HCI research's transition into domestic spaces.

2.4 Domestic Technology in Industrialized Countries

HCI researchers have studied technology use in homes since the 1990s (Desjardins et al., 2015). During this time, HCI researchers turned their attention away from studying the office environment to studying technology use in homes (Bell et al., 2005). Researchers studied a range of topics including how people consume resources at home (Pierce et al., 2010), technology use in the kitchen (Bell et al., 2005), and how family members negotiate communication (Anderson et al., 1999). The study of these topics was inspired by the transition of technology from office spaces into homes.

Bell and Kaye (2002) conducted an ethnographic study in the U.S. and Europe to investigate the issues related to technology design in domestic spaces—especially the kitchen. Their findings raised concerns about how technology in homes prioritized efficiency rather than experience, affect, and desire. This is because most of domestic technologies were primarily imported from office spaces (Bell & Kaye, 2002). They also suggested that designers should understand what people are already doing in their domestic spaces and design around those activities. This requires methods for understanding present systems and how they can be integrated in people's everyday lives.

Despite the need to understand peoples' interests, practices and desires, the majority of domestic technology studies in HCI were primarily conducted in industrialized countries (Desjardins et al., 2015). So, Bell et al. (2005) proposed moving beyond the U.S. setting to consider domestic technology in other regions of the world. They used ethnographic techniques to study domestic spaces in India, Malaysia, Singapore, China, and Indonesia. Findings from these studies suggest that homes in different regions have different infrastructures. For instance, not everyone has broadband Internet especially in the Global South (Bell et al., 2005). For this reason, domestic technology in SSA needs to be studied to understand how it can be designed to fit within existing infrastructure and meet people's needs.

2.4.1 Research on Sensors for Domestic Use in Industrialized Countries.

Since 2000, sensor-based technologies have informed the design of new applications that improve people's domestic lives in industrialized countries, including systems for energy monitoring, home surveillance, activity tracking, and air quality monitoring (Brereton et al., 2015; Goel et al., 2015; Laput & Harrison, 2019). The Aware Home at the Georgia Institute of Technology (Georgia Tech) is a prominent example of this research. It is described as a "living laboratory" for ubiquitous computing and consists of two bedrooms, two bathrooms, an office, a kitchen, a dining room, a living room, and a laundry room (Kidd et al., 1999; Kientz et al., 2008). Research conducted in the Aware Home demonstrates that sensors can be used in computational environments (e.g., smart homes) to interpret and understand its occupants' contextual cues through various applications such as support for the elderly, finding lost objects, and specialized activities in kitchens (Kidd et al., 1999).

Sensors provide "convenient, personalized information and entertainment services at any time and in any context" (Kidd et al., 1999, p. 4). Further, they are an enabling tool for knowing 'who is where' and 'what they are doing'—central aspects of intelligent behavior in ubiquitous systems (Kidd et al., 1999). For example, these aspects of sensors are applied in the Aware Home to support the elderly in locating lost objects (Kientz et al., 2008). The Aware Home uses the "Memory Mirror"—a sensor-based technology that specifies details about an object's use over time (Kientz et al., 2008). These objects include knives, spoons, phones, and plates.

When an object is lost, users can simply trace how they used the object to locate it (Kientz et al., 2008). The Memory Mirror provides a useful example of how sensors can support life in domestic spaces.

The Aware Home also consists of the Cook's Collage—a sensor-based technology that provides a visual summary of a recent cooking activity (Kientz et al., 2008). It consists of a display that shows a list of activities that were completed with the most recent one highlighted in yellow. The purpose of this technology is to provide reminders about what one was doing to easily resume activities in case of any interruptions, such as answering a phone call while cooking. The Aware Home is also equipped with other technologies for monitoring children's development, archiving family videos and saving audio files (Kientz et al., 2008). These technologies provide examples of how UbiComp research, in industrialized countries, informed the designing sensor-based technologies that can be implemented in real homes. For example, power monitoring system that started with UbiComp research at Georgia Tech were commercialized through a startup company called Zensi (Pais, 2011). However, the single focus on homes in industrialized countries does not account for infrastructural differences between industrialized countries and SSA.

2.4.2 Commercially Available Sensor-Based Technologies in Industrialized Countries

Sensor-based technologies are widely available in industrialized countries for commercial purposes. For example, between 2014 and 2019, the percentage of homes that own a sensor-based device in the U.S. increased from 10% to 38% (Parks Associates, 2020). These sensor-based devices included cameras, smart door locks, sprinkler systems, leak detectors, and energy monitors (Parks Associates, 2020). Here, I review commercially available sensors for domestic security, power blackout monitoring and poultry farming, because they are directly related to sensor-based technologies discussed in this dissertation.

As of 2021 there were 85 million domestic security sensors, mostly cameras, installed in the U.S., representing a 71% increase since 2015 (Ilic-Godfrey, 2021). Some of the popular home surveillance sensor-based technologies include the Honeywell and SimpliSafe home security systems (Alam et al., 2020; HoneyWell, 2021; SimpliSafe, 2021). These sensor-based technologies consist of cameras, smart alarms, and motion sensors that are installed in homes, and they require a Wi-Fi connection to provide updates to users' mobile app (HoneyWell, 2021; SimpliSafe, 2021). Scholars who have studied these technologies suggest privacy and security threats as one of the downsides of using them in homes (Kafle et al., 2021; Zeng et al., 2017; Zheng et al., 2018). To account for this problem, researchers and technology industries have introduced devices that are used to alert users about possible tracking (Mayberry et al., 2021). These include Apple Airtags which are used to track lost objects and alert users about possible tracking (Mayberry et al., 2021). .

There are also commercially available power outage detection devices that are used in the U.S. These include MySpool—a power outage system that uses email and text messages to provide feedback to users (MySpool, 2021). Like other sensor-based applications that are available in industrialized countries, MySpool requires Wi-Fi connection to send email and text alerts. Despite the presence of these devices, there are no statistics about their adoption rate in industrialized countries homes. Further scholars have only explored the potential of using social media data to detect power blackouts in industrialized countries (Bauman et al., 2017; Sun et al., 2016).

In the poultry industry, sensor-based technologies are developed to monitor the internal chicken coop conditions such as temperature, humidity, lighting, and then convey the information to farmers (Chowdhury & Morey, 2019). Notable off the shelf sensor-based poultry farming tools include Big Dutchman DOL 53 sensor system that is used to measure ammonia concentration in chicken coops (Big Dutchman, 2022) and SKOV's Tunnel used to control temperature and humidity conditions in chicken coops (SKOV, 2022). Further, sensor-based technologies in industrialized countries are used for monitoring water usage, counting eggs, weighing chickens, measuring growth, and detecting diseases. These sensor-based technologies have been studied by scholars; for example, researchers at the University of Georgia evaluated the Big Dutchman DOL 53 sensor and found that it successfully measures ammonia concentration in a poultry house with 95% accuracy (Czarick et al., 2018).

2.5 Industrialized Countries and SSA Infrastructure Differences.

Sensor-based technologies have their own infrastructural requirements that need to be satisfied to successfully deploy them in peoples' homes. Infrastructure refers to a set of equipment that is required to support human activities (Bowker et al., 2010). Infrastructure can include a wide range of resources, such as buildings, communication networks, electricity services, and roads. Technological infrastructure consists of digital resources that support the utilization of computing services (Bowker et al., 2010). The Internet, mobile phones, computers, and electricity are some of the technology infrastructural requirements for successful deployment of sensor-based technologies (Ndubuaku & Okereafor, 2015). In this section, I review infrastructure differences between industrialized countries and SSA, as they are related to how people adopt and use sensor-based applications.

While 87% of homes in industrialized countries have access to the Internet, only 17.8% of homes in SSA have access to the Internet (International Telecommunications Union, 2019). For example, in the U.S., 87% of the homes have Internet access compared to 17.9% in Kenyan homes, and 11.1% in Malawian homes. Among Internet users in the U.S., 92% access the higher speed network compared to only 38% in Kenya, and 30% in Malawi (International Telecommunications Union, 2019; KNBS, 2019). Within SSA, the digital gap between rural and urban homes widens as only 6.3% of rural homes have access to the Internet compared to 28% of homes in urban areas (International Telecommunications Union, 2021). In Kenya, 6.9% of rural homes have access to the Internet compared to 35.4% of the homes in urban areas (KNBS, 2019). In Malawi, only 4.3% of the homes in rural areas have access to the Internet compared to 19.4% in urban areas (Malawi National Statistical Office, 2019).

In addition to the low penetration of Internet services in SSA homes, these services are expensive for most people in SSA. As of 2020, the cost of 2 GB mobile data, voice calls, and SMS alerts in Kenya was $10 per month, which is 7.5% of the GNI per capita (International Telecommunications Union, 2021). In Malawi, the cost of the same services was $22 per month, which is more than 20% of the GNI per capita (International Telecommunications Union, 2021). The poor network infrastructure and high cost of Internet services make it difficult to import off-the-shelf sensor-based products that require broadband Internet to provide service to users.

Despite these drawbacks, the high penetration of GSM network in SSA presents an opportunity for researchers to design sensor-based technologies that can transmit data through this network and provide feedback to users. The ITU estimates that 88.4% of the population in SSA live within the reach of a GSM signal (International Telecommunications Union, 2021). For every 100 inhabitants, there are 80 mobile phone subscriptions in SSA (International Telecommunications Union, 2019). Out of these subscribers, only 34 have access to broadband Internet. This is because 80% of the mobile phone subscribers do not have smartphones that support broadband Internet connection (Kshetri, 2017; Poushter, 2016). In Kenya and Malawi, 80% and 52% of the households have at least one mobile phone respectively (KNBS, 2019; Malawi National Statistical Office, 2019).

Electricity reliability is another factor that influences the usage of sensor-based technologies. Though electricity is one of the most important infrastructures to support technological advancement, most countries in SSA struggle to extend grid power to all areas of their countries, especially rural areas. According to the International Energy Agency (IEA), SSA has 75% of the world's population without electricity (IEA, 2020). For instance, 23% of the households in Kenya have access to the national grid electricity and only 11.4% of the households in Malawi access the national grid electricity (Malawi National Statistical Office, 2019; Olang et al., 2018). This infrastructural challenge makes it difficult for people in SSA to use sensors that depend on the availability of high voltage electricity supply.

These infrastructural challenges negatively affect the adoption of existing sensor-based technologies in SSA. For example, high-cost of WiFi Internet negatively affected the usability of an emergency care system in Tanzania (Greenberg et al., 2021). In South Africa, poor network connectivity and unreliable electricity supply contributed to the failure of environmental conservation projects (Kshetri, 2017). In this dissertation, I design and develop sensor-based technology probes that communicate using the GSM network that is widely available in SSA. Further, the probes are powered by solar batteries that can be recharged without using grid electricity.

2.6 The Organizational Structure of Some Households in SSA

Homes consist of a "wide range of physical, infrastructure, legislative contexts and they are embedded with highly varied systems of meaning" (Dourish & Bell, 2011, p. 164). The variations between homes present significant challenges when designing technological systems for domestic use. Further, homes are shaped by different cultures that significantly depend on "distinctive spiritual, material, intellectual, and emotional features that characterize a society or social group" (Maseno & Kilonzo, 2011, p. 5). These features influence how people adopt and use technologies to support their needs. The theory of distributed cognition underscores that the interpretation of computing systems depends on culture, because agents live in a complex cultural environment (J. Hollan et al., 2000). This suggests that culture is part of the cognitive process thereby contributing to how people reflect on technological systems. Here, I focus on describing the structure and organization of extended homes in rural Kisumu and Bungoma, Kenya, and rural Lilongwe, Malawi. I focus on these homes because they are the dominant type of households in the areas I conducted the studies (Ibisomi & De Wet, 2014). As such, the participants in my research also lived in extended homes.

An extended home comprises of several members from different generations sharing the same household (El-Islam, 1982). Extended homes in SSA mostly consist of a compound with multiple houses serving different purposes. These include houses for boys, girls, livestock, and a main home for parents (Abuya et al., 2019; Mason et al., 2013). Household members are often from several different generations, because when children get married, they build their own separate home within their parent's compound (Ankrah, 1993). Family members within a compound maintain ties by offering social economic support. They support each other by sharing the basic needs of life including food and shelter (Dinisman et al., 2017).

2.6.1 Organizational Structure of Extended Households in Bungoma

Bungoma county is situated in western Kenya. The Luhya, a Bantu ethnic group that consists of 18 sub-tribes, each speaking a different dialect, constitutes over 90% of the county's inhabitants (KNBS, 2019; Ong'ayi et al., 2020). The Luhya ethnic group is the second most populous ethnic group in Kenya. They depend on livestock farming, crop production, and running small scale businesses (Ong'ayi et al., 2020).

Similar to every culture, the Luhyas are guided by customary laws and traditional beliefs. For example, they believe in "witchcraft which operates in the same realm with spirits" (Lagat, 2018, p. 8). Luhya households are dominantly patriarchal; that is, a man rules other household members including women (Maseno & Kilonzo, 2011). Patriarchal norms among the Luhyas favor men over women. For example, women are required to do most of household chores including cooking, fetching water, washing clothes as well as taking care of children (Maseno & Kilonzo, 2011).

Luhya households consist of a compound that is demarcated with fencing (Ong'ayi et al., 2020). These compounds constitute more than three structures on it, including a main house. Other structures in these compounds typically include livestock kraals, a kitchen, a latrine, and houses for other household members (e.g., children who are older than 15). Today, structures are typically constructed out of brick, mud, and/or thatch, and corrugated sheet metal roofs (Maseno & Kilonzo, 2011).

2.6.2 Organizational Structure of Extended Households in Rural Kisumu

Kisumu is predominantly inhabited by the Luo people (Abonyo, 2005). The Luo ethnic group is the third largest group in Kenya and is found on the eastern shore of Lake Victoria, in Western Kenya (Abonyo, 2005). The people living in this area have multiple sources of income such as farming, fishing, running small scale business, and livestock herding (Potter, 2004).

Like the Luhyas, Luo people have their own beliefs. The Luos primarily believe that their members should take responsibility and adhere to existing customary laws (Abonyo, 2005). These customary laws include patriarchal norms which consider men as superior to women and situate them as heads of their households (Maseno & Kilonzo, 2011). In this way, men are considered superior over women. Luos also promote polygamous families; that is, a man can have more than one wife. Men and women share different responsibilities in their homes. Men are primarily responsible for building homes and finding casual jobs to earn money (Maseno & Kilonzo, 2011). On the other hand, women are considered caretakers of their homes and are expected to prepare meals, look after children, plant and weed family farms, and fetch water (Abonyo, 2005).

Also like the Luhyas, Luo people live in extended homes that accommodate houses for multiple generations (Abonyo, 2005). This is because when children grow up within a homestead, their father builds a separate home for them on the same compound. Luo homesteads also consist of chicken coops, cattle kraals, granaries, and courtyards. These homesteads are mostly demarcated by hedges with two gates—one in the front of the homestead and the other at the back (Abonyo, 2005).

2.6.3 Organizational Structure of Extended Households in Rural Lilongwe

Nsaru, Lilongwe is in the central region of Malawi, which is dominated by the Chewa people—the largest ethnic group in Malawi (Malawi National Statistical Office, 2019). The Chewa people, living in rural areas, rely on farming, rearing animals, and selling their farm produce for income (K. M. Phiri, 2009).

Unlike the Luhyas and the Luos, Chewa people practice matriarchy; that is, the wife has more power over the husband and other family members (K. M. Phiri, 2009). Generally, the woman depends on her brother to lead other members within her household. In this way, the wife's brother "becomes the guardian to his sister and her offspring, and the sustainer of their social, economic, and legal interests" (K. M. Phiri, 2009, p. 259). For this reason, the husband moves from his parent's home to live at his wife's extended home upon marriage. However, like the Luos and Luhyas, the Chewa also live in extended households and eat from a single unit (Abbot & Homewood, 1999). The Chewas have their own cultural practices and traditional beliefs. Some notable practices include initiation ceremonies, which are organized to induct boys and girls into adulthood and traditional dances that are organized during specific celebrations (K. M. Phiri, 2009).

Despite some similarities, it is clear that there are some differences in terms of the structure and organizations of homes in these three locations. Generally, these homes are significantly different from homes in industrialized countries. For example, in North America, a home can be “a house in the suburbs, a downtown apartment, a cottage in the country, a single room at the end of the hall, a duplex, a farmhouse, a houseboat or a mansion in the hills” (Friedman & Krawitz, 2005). Unlike extended homes in Bungoma, Kisumu, and Nsaru, a typical home in North America consists of a kitchen, a bathroom, a living room, a dining room, a toilet, and bedrooms—all in a single unit (Friedman & Krawitz, 2005). Differences in terms of living conditions (safety, food, and shelter), culture, home appliances, and other factors play a role on how people use technology in their homes (Dillahunt et al., 2009). Despite this, HCI research on the role of these technologies in homes has been conducted in industrialized countries. Studying how sensor-based technologies can be used in SSA opens-up a space for critical reflection about the design of domestic technologies (Bell et al., 2005). By focusing on some homes in Kenya and Malawi, which have not been given much attention within HCI, my research contributes to this field by making visible the ways inhabitants want to use sensor-based technologies to support their everyday activities.

2.7 Application of Sensors in Sub-Saharan Africa

Despite little research on how sensor-based technologies can support domestic activities, sensors have been used for other activities outside the home environment in SSA. In particular, sensor-based technologies have been used by public and private companies in SSA to improve agricultural and food systems, health-care systems, electricity reliability, and resource conservation (Kshetri, 2017). For example, Kilimo Salama (Swahili term for safe agriculture), is a company that sells seeds and provides agricultural inputs insurance in Kenya and Rwanda. This company installed 32 weather stations that use sensors to collect weather information and provide it to farmers (Kshetri, 2017; Mohtasin, 2021). The weather stations also aggregate rainfall patterns throughout the year to determine areas that had excessive or little rainfall. If data from the weather stations suggest that farmers in a particular area received more or less rainfall, the company pays back farmers who bought seeds during that season (Kshetri, 2017). In this way, the system helps farmers reduce crop losses due to unfavorable weather conditions.

In Zambia, Uganda, Benin, and Kenya, VaxTrac (a US-based non-profit organization) deployed a sensor-based registry system in hospitals that allowed patients to access their vaccination records by touching a biometric sensor (Jain et al., 2016). Sensor-based technologies have also been used in South Africa to facilitate surveillance against poachers in national parks by tracking movements in the park and sending GPS coordinates to a central operation office (Kshetri, 2017).

Though sensor-based technologies are used in SSA industries, these companies have not focused on designing applications to support domestic activities. Researchers that have deployed sensors in SSA homes focus on collecting real-time data (like frequency of power blackouts) and providing that information to companies, not household members (Klugman et al., 2019; Klugman et al., 2014). In Ghana, Klugman et al. (2019) designed DumsorWatch and GridWatch—a sensing technology and smartphone application that crowd-sources power blackout data and sends it to electricity companies. This helps electricity companies distribute power across different regions proportionately; however, little is known about how this data could help end-users to monitor power blackouts (Klugman et al., 2019; Kulugman et al., 2014).

These studies suggest that sensors can be used to support activities in SSA; however, it is unclear how residents in SSA can access and utilize the benefits of sensor-based technologies in their everyday lives. Homes face various challenges—including domestic security, power blackouts, and negative environmental conditions that affect poultry farming. Sensor-based technologies provide opportunities to monitor these challenges and reduce their negative impacts. Further, there are many activities that take place in homes of SSA that go unnoticed, such as patterns of electrical appliance usage and domestic animal rearing practices. Understanding these activities in detail can provide insights for designing systems for SSA homes. My work extends prior research by designing, developing, and evaluating sensor-based systems for homes. My research is different from these studies because it focuses on designing sensor-based technologies to support people's domestic activities rather than designing sensor-based systems to improve productivity across different companies.

2.7.1 Technology for Domestic Security, Power Blackout Monitoring, and Poultry Farming in SSA

Here, I review related work about how technology can support domestic security, power blackout monitoring and poultry farming. This review suggests that there is little research that has used technology to support domestic security and monitoring power blackouts and poultry farming activities in SSA. My research is distinguishable from prior studies because their focus on sensors in SSA targeted companies rather than end users. Further, most of prior studies are different from my research because they did not focus on using early design methods to design and evaluate sensor-based technologies for domestic use.

2.7.1.1 The Role of Technology on Domestic Security

People living in SSA homes consistently raise concerns about burglars breaking into their homes, poultry theft, cattle rustling and theft from grocery stores (Bunei et al., 2016; S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018). Though this topic is understudied within HCI, ICTD, and UbiComp, researchers in criminology recognize its importance. Prior research suggests that homes in rural areas of SSA are targeted by thieves more than urban ones, because rural areas do not have close supervision and lack social services like police stations (Bunei et al., 2013; C. Oduor et al., 2014). In these areas, neighborhoods are monitored using community policing—local authorities who oversee domestic security.

In Kenya, these groups are known as “nyumba kumi” (Swahili for ten houses), because each group consists of ten houses (Kioko, 2017). While these initiatives have proven to be successful at reducing crime, few studies in SSA have explored the role of technology in supporting domestic security (Bunei et al., 2016; C. Oduor et al., 2014; Sidebottom, 2012). Researchers have studied using smartphone applications to report crime and suggested that participants prefer using online platforms (e.g., Facebook groups) to report crime (Ngugi, 2013). Despite this, over 80% of mobile phone owners in SSA rely on basic phones, so the outcome of using smartphones in research may not be representative (GSMA, 2020). Criminology research suggests that preventive mechanisms against burglary should be attuned to solve local problems based on the availability of resources (Sidebottom, 2012). Sensor-based technologies can be integrated with basic phones’ Short Message Service (SMS) and Unstructured Supplemental Service Data (USSD) to collect crime-related data and provide alerts to homeowners.

In industrialized countries, HCI scholars have studied ICT’s potential in deterring crime. Erete (2013) studied crime convicts to understand whether burglar-detecting technologies, such as alarms, are effective in preventing crime. Her findings suggest that these technologies are ineffective at preventing crime despite reinforcing community activism. She proposed that technology should be designed to encourage neighborhood cohesion; that is, encouraging collective action among community members (Erete, 2013).

Building on this study, Lewis and Lewis (2012) analyzed 865 posts from a community web forum to understand the role of technology in community policing. They found these technologies are used to strengthen social ties, encourage discussions among residents, disseminate information, and regulate neighborhoods’ social norms. Their study suggests that crime prevention technology should be designed to encourage communication and problem solving discussions among residents (Lewis & Lewis, 2012).

At the same time, research suggests that technology can play an integral role in promoting civil liberties for people with differing socio-economic backgrounds around the world (Erete, 2013). Inequalities that influence crime are perpetuated by local policies which have mostly been shaped by community members with political power (Erete, 2013). This notion is also evident in SSA where, for the most part, the poor have no say in formulating policies (Kimalu, 2002). This results in policies that tend to favor the rich, thereby inciting crime and violence from the poor (Kimalu, 2002). Erete (2013) proposed that HCI researchers should consider the broader ecological infrastructure that affects social issues. These opportunities should also be extended to SSA. This presents an opportunity for HCI researchers to investigate the role technology can play in crime prevention.

2.7.1.2 Power Blackout Monitoring in SSA

Power blackout monitoring is another significant problem facing SSA homes. This is a topic of interest in the discipline of computer science (Breda & Taneja, 2018; Klugman et al., 2019, 2014; Raj et al., 2018; Taneja, 2016) because of unreliable electricity in SSA (The World Bank, 2016). Computer science researchers have used sensors and smartphones to collect data about power blackouts and report this information to electricity companies. Klugman et al. (2014) designed GridWatch—a mobile application that crowd-sources power blackout data and sends it to electricity companies in SSA. This helps electricity companies distribute power across different regions more proportionately (Klugman et al., 2014). In a related study, Correa et al. (2018) evaluated strategies for deploying GridWatch. Their findings suggest that power outage detection improves dramatically by increasing the density of sensors per transformer (Correa et al., 2018). The higher the number of sensors that detect electricity blackout within a transformer, the higher the confidence of blackout detection. I adopt this prior work's strategy and use it to deploy GridAlert in Kenyan homes.

In industrialized countries, data mining and machine learning techniques have been used to analyze social media data to detect power outages (Bauman et al., 2017). Social media users report data about power blackouts when they occur. This provides large datasets that can be used to develop predictive machine learning models (Bauman et al., 2017). Bauman et al. (2017) relied on social media users as social sensors for detecting blackouts. This approach was based on identifying keywords related to power blackouts in Twitter discussions. Their findings suggest that integrating this approach with other methods like phone calls can complement power blackout detection systems. However, their findings also suggest that many people—especially those living in rural areas—do not regularly tweet about power blackouts (Bauman et al., 2017). Social sensors integrated with other methods for detecting blackouts are effective in areas with high population density where social media data are available at large volume (Hultquist et al., 2015).

To understand the challenges of deploying sensor-based power monitoring systems, Klugman et al. (2019) designed and deployed DumsorWatch and PowerWatch—a mobile app and sensing technology that detects the absence of electricity—in Ghana. Their findings suggest that "local service providers were more likely to provide high quality service in Ghana compared to U.S.-based companies with only nominal ability to operate globally" (Klugman et al., 2019, pp. 9–10). They suggest that technologists should collaborate with local technicians when deploying power monitoring systems. I build upon their work by collaborating with local technicians in the design and deployment of GridAlert and NkhukuProbe.

Prior studies conducted in SSA primarily used technology to provide information about blackouts to electricity companies (e.g., Kenya Power) (Klugman et al., 2014, 2019). However, these studies rarely considered end users of electricity. Other studies that explored Internet usage with end users suggest that providing users with feedback motivates them to use power in a cost-effective manner (Chetty et al., 2015; Sambasivan et al., 2015). Chetty et. al (2015) conducted a study in South Africa, India, and the United States to understand how users manage Internet data. Their findings suggest that developing usable tools that provide consumers visibility and control over Internet usage is an important area of research in HCI (Chetty et al., 2015). I build upon these studies by focusing on the electricity's end users, so that they have greater access to information to support their activities between episodes of power blackouts and power restorations.

2.7.1.3 Using Sensors to Support Poultry Farming in Sub-Saharan Africa

In this section, I review prior research that focused on using sensor-based technologies to support poultry farming activities in SSA. First, I provide an overview of poultry farming in SSA then discuss key conditions (temperature, humidity, and light) that affect poultry farming. Following this, I discuss how scholars have studied the possibility of using sensor-based technologies to optimize these conditions.

In SSA countries, poultry farming remains a significant source of food and income (Alders & Pym, 2009; Beesabathuni et al., 2018). Prior research suggests that the income level of homes that practice poultry farming is 2.3 times more than homes that do not practice poultry farming (Beesabathuni et al., 2018). The difference in income levels between homes is attributed to the fact that poultry farmers generate more income when they sell their chickens and eggs. Income generated from poultry farming is used to buy domestic property (e.g., furniture and radios) (Alders & Pym, 2009) and to pay for children's tuition fees. Farmers also benefit from eating poultry (chicken and eggs) as it is a primary source of protein and vitamins B12, K, and A (Alders & Pym, 2009).

Poultry farming is common among homes in rural SSA—in Malawi, approximately 83% of rural homes raise poultry compared to approximately 15% of urban homes (Maganga, 2013;

Mkwambisi et al., 2008). As rural areas are resource constrained, it is difficult for agricultural and veterinary extension officers to travel to remote areas to give advice to poultry farmers (H. Phiri, 2018). Agricultural extension services are important for providing technical advice to poultry farmers in order to increase their agricultural production (Nyoni et al., 2019). Prior research suggests that inadequate agricultural and veterinary extension services lead to poor poultry farming practices which have caused a decline in egg production in rural homes of SSA (Beesabathuni et al., 2018; Maganga, 2013; Tebug et al., 2012). Further high temperatures—which can exceed 50°C—and humidity conditions in parts of SSA make it difficult for farmers to realize maximum egg production (Guta et al., 2016).

Researchers have proposed different sensor-based technologies to support poultry farming in SSA, many of which are intended to monitor and modify the environment within chicken coops (Afeez et al., 2019; Halachmi et al., 2019; Kutsira et al., 2019; H. Phiri, 2018). The major conditions that affect chicken production are temperature and humidity (Moshin et al., 2009). Chickens best thrive at an environment that is 33°C with a relative humidity of 50%. However, many places in SSA experience high humidity and temperatures (Guta et al., 2016), making it difficult for farmers to realize maximum egg production. Phiri and Phiri (2018) proposed using sensors to detect the presence of intruders in a chicken coop. Poultry farmers would receive alerts via a mobile app, SMS, or web-based application. Afeez et al. (2019) proposed a similar system to regulate environmental factors automatically. Although both systems address poultry farming challenges, they were never evaluated in a chicken coop to understand how farmers would actually use the system or whether it would improve their poultry farming practices.

Proper lighting is also important for chicken rearing Lighting influences physiological and behavioral processes during chicken development, stimulates feed intake, and makes it easier for farmers to inspect their coops (Patel et al., 2016). The optimal light duration in chicken coops depends on the chickens' age; for laying chickens (chickens raised for egg production), it is recommended that chicken coops have 15 hours of constant light (Patel et al., 2016). Unlike temperature and humidity, the importance of light is not as intuitive among farmers and is therefore less likely to be a parameter among inexperienced farmers (Patel et al., 2016). Furthermore, manually controlling chicken coop lighting to comply with this specification can be difficult because farmers might forget to toggle the lights. Sensor-based technologies can potentially address this challenge by automatically controlling lighting conditions in chicken coops.

My research builds upon these prior studies by exploring how farmers in Malawi interact with a sensor-based technology (in participants' natural setting environment) for supporting poultry farming activities. My formative research findings suggest that poultry farmers in SSA have unique coop configurations and tools that they use to monitor activities in their chicken coops (Chidziwisano et al., 2021). My analysis of prior research draws attention to three challenges in SSA households: domestic security, monitoring power blackouts, and monitoring poultry farming activities. Sensor-based technologies provide opportunities to design technological systems that can potentially address these challenges. However, there is little research focussing on how end users can use sensor-based technologies to solve these challenges. The main distinction between prior studies and my dissertation research is that I focus on how end-users would use sensor-based technologies in their homes. Further, these studies did not use non-traditional HCI methods that are useful to understand peoples' reflections on the role of technology in their homes. My research deploys technology probes in some Kenyan and Malawian homes to understand how people want to use sensor-based applications to support their needs.

2.8 Technology Probes

In this section, I review research on technology probes and studies that have used this method in HCI. I provide a background of technology probes, their distinguishing features, and how researchers have used them in the early design process. Following this, I discuss how technology probes are appropriate to study peoples' reflections on the role of technology in their lives. I conclude this section with a justification of why I adopt this research method to pursue my research questions.

The term technology probes was coined by HCI researchers at the University of Maryland (Browne et al., 2001). The method was inspired by Bill Gaver's (1999) cultural probes. Cultural probes are designed objects, physical packets containing open-ended, provocative and oblique tasks to support early participant engagement with the design process (Gaver et al., 1999). They are used in design projects to provoke inspirational responses from participants (Gaver et al., 1999). Browne et al. (2001) used digital technology rather than non-digital objects to gain an understanding of communication needs rather than social norms; they called these "technology probes". Building on this research, Hutchinson et al. (2003, p. 2) defined a technology probe as a design tool that has "the social science goal of understanding the needs and desires of users in a real-world setting, the engineering goal of field-testing the technology, and the design goal of inspiring users and researchers to think about new technologies".

Technology probes are simple, flexible, and adaptable technologies that are deployed in the field to introduce users to new types of technologies and support them in becoming partners in the design of new technologies (Hutchinson et al., 2003). Hutchinson et al. designed the videoProbe—a technology probe for sharing images among family members living in different homes. The probe was deployed in two French homes in Summer 2002 (Hutchinson et al., 2003). Findings from this deployment were used to develop two prototypes that reflected participants' interests in supporting coordination and playful interaction among family members. The features of these prototypes were informed by participants' interactions (e.g., family members making funny faces at each other over a distance) with the videoProbe. The videoProbe helped reveal practical needs and playful desires between distributed families. It also provided a real-world example to motivate interviews and workshops. Further, it introduced families to a new type of technology which encouraged them to consider more creative uses of technology in their homes.

Over the past decade, HCI researchers have used the technology probes method to understand participants' experiences using technologies and inspire them to think of new ways of using technologies (Dema et al., 2019; Odom et al., 2014; Odom et al., 2019). Technology probes have also been used to complement other methods like interviews and observations and to test the potential of new technologies in industrialized countries. For example, Odom et al. (2014) designed and deployed the PhotoBox—a domestic technology that prints random pictures each month—in three homes for 14 months. They investigated the impact of the PhotoBox on participants' anticipation and re-visitation of the past and how their reflections changed over time. They used in-depth interviews and observations to understand how participants used the PhotoBox. Their findings suggest that participants changed their attitudes towards the PhotoBox over time (Odom et al., 2014). They suggested that new technologies are received with excitement. As time passes, the novelty wears off and people may be frustrated. However, if the experiences improve with time, people find ways of using the technology and finally accept it into their everyday lives.

In another study, Dema et al. (2019) used a combination of participatory design and technology probes to understand how sensor-based technologies can be used to conserve endangered species in Bhutan. They conducted a series of contextual inquiry interviews, focus group discussions and observational studies with multiple stakeholders (Dema et al., 2019). Outcomes from these early interventions were used to design a technology probe—a Raspberry-PI computer-based system that plays media that encourages participants to identify and discuss bird sounds. Outcomes from participants' reflections on the bird sounds were used to design prototypes that informed the final version of a system for saving endangered species in Bhutan. Findings from this study pointed to the wider design opportunities that comes with involving all stakeholders at every stage of designing technological systems. They suggested that design intervention must account for power relations in local collaborator's social practices and beliefs that influence conservation (Dema et al., 2019).

These studies provide examples of how technology probes have been used to complement other methods to test the impact of new technologies. Similarly, my proposed research uses this method together with qualitative methods to understand participants' reflections about using sensor-based technologies to support domestic activities in SSA. Further, these studies provide evidence that technology probes' open-ended nature inspires participants to think about their own ways of using new technologies. The focus of technology probes on participants' reflections helps to inform salient issues during early stages of design (Odom et al., 2014). In this research, I adopt this method to understand participants' reflections about using sensor-based technologies and their role in supporting domestic activities in parts of Kenya and Malawi.

2.8.1 Understanding People's Reflections with Technology Probes

Sengers et al. (2005) suggested that "building a technology as a probe" is one of the strategies for understanding people's reflections on technology. They argued that technology probes stimulate an understanding of larger social practices, such as how communication patterns evolve. For example, Brereton et al. (2015) deployed a technology probe, the "Messaging Kettle", in the U.K. to explore how technology might foster social connection with an elderly friend or relative who lives some distance away. Participants' interactions with the probe suggested that simple and varied interaction modalities that allow asymmetric forms of communication are important for long distant communication, especially when people are in different time zones (Brereton et al., 2015). These reflections contain not only users' understandings of the effects of technology use, but also how they see the practices of technology design and evaluation. In the case of the Messaging Kettle, participants reflected upon simplicity as a design principle.

Hutchinson et al. (2003) underscored that a successful technology probe requires reflection by both participants and researchers. Technology probes are an extension of cultural probes, which are adopted from participatory design techniques that regard users as partners in the design process (Beaudouin-Lafon & Mackay, 2012; B. Gaver et al., 1999). Sengers et al. (2005, p.7) underscored that designers should support users in reflecting on their lives. They suggest that technology can be designed to "highlight the choices one makes in everyday activities and to offer up new choices that may not have been in the user's awareness." Similar to cultural probes, technology probes are meant to "inspire users to reflect on their everyday activities in different ways" (Hutchinson et al., 2003, p. 2) and inform recommendations for designing new technological systems (Dema et al., 2019). Unlike other methods, such as interviews and observations, users interact with technology probes during deployment. These interactions play an important role by providing users with new ways of experiencing and reflecting on their activities, making technology probes suitable for exploring users' reflections about using sensor-based technologies in SSA homes (Hutchinson et al., 2003).

2.9 Summary

My dissertation is situated in the fields of HCI, ICTD, and UbiComp. Since the early days of HCI research, scholars have studied the interactions between humans and computing systems.

These two components change over time. Researchers have used various methodologies to understand people's practices and design technologies that meet their needs. The changing nature of technological systems as well as their adoption in different parts of the world motivated HCI researchers to introduce narrower sub-fields, such as ICTD and UbiComp.

Similarly, sensing technologies have become smaller, more affordable, and capable of operating with low power supply. These developments led to new ideas in the field of UbiComp that contributed to the transition of technology from office spaces into homes. Research on sensors in industrialized countries suggests that these technologies can support various activities in homes. Despite these opportunities, the application of sensors to support activities in SSA's domestic space have been underutilized. Homes in SSA face various challenges—including domestic security, power blackouts, and rising temperatures that affect poultry farming activities—that can be monitored using sensor-based technologies. I take advantage of existing mobile phone infrastructure to design sensor-based solutions for monitoring challenges facing some homes in Kenya and Malawi. By using the technology probes method, I encourage users to reflect on the role of sensors in their homes thereby illuminating other ways of using them in Kenya and Malawi.

CHAPTER THREE: METHODOLOGY AND METHODS

In this chapter, I describe the methodology that guided my research. I describe why I used RtD to answer my research questions. RtD encourages researchers to deploy technological artifacts, so I describe how I used the technology probes method to understand participants' experiences using sensor-based technologies. Then, I describe my positionality and how it influenced this dissertation research. Following this, I describe the methods that complemented technology probes to collect data. These methods include semi-structured interviews, observations, diary studies, and data logging. I conclude this chapter with a section about data analysis. I describe how I used affinity diagramming technique to analyse qualitative data, and Python to analyse data logs.

3.1 Methodology

The goals of my dissertation are to investigate the role of sensor-based technologies in SSA homes and householders' reflections about using them in their everyday activities. Based on the theory of distributed cognition, I view these householders as part of a larger social-technical system where their actions are influenced by other components, such as culture, resources, and the environment (J. Hollan et al., 2000). An understanding of the role of sensor-based technologies requires a consideration of all the components that influence peoples' cognitive processes in a real-world setting. This guided me to choose RtD—a methodology that explores and evaluates technology use outside a controlled setting. The term RtD was first used by Christopher Fraying who described it as a research methodology that is used by stakeholders to reflect on their experiences to speculate on what the future could be (Frayling, 1994). Fraying described RtD as a research practice that focuses on improving the world by making things that disrupt or transform the current state of the world (Frayling, 1994). Zimmerman and Forlizzi (2014, p. 167) defined RtD as a methodology "for conducting scholarly research that employs the methods, practices, and proposes of design practices with the intention of generating new knowledge". RtD frames research as a design inquiry that contributes to HCI as long as it has a form of practice, evaluation, and outcome (Zimmerman & Forlizzi, 2014). The practice, evaluation, and outcomes should be documented not for the purposes of reproducing similar outcomes or final product but rather to allow other researchers reproduce the process (Zimmerman & Forlizzi, 2014). This supports the fact that RtD should not be generalizable across different contexts.

RtD is useful for answering my research questions because homes have existing practices, values and norms that are observed by inhabitants. There is no single answer to what role sensor-based technologies can play in SSA; this makes the generative and constructive nature of RtD appropriate to pursue my research questions. In the process of generating this new knowledge, a designer can be thought of as a "self-organized system with constructive as well as reflective skills" (Fallman, 2003, p. 2). The new knowledge generated help to identify new opportunities for designing technologies (Zimmerman & Forlizzi, 2007). Further, RtD's knowledge generating nature helps to discover unanticipated effects and provides a template for solving a specific problem (Zimmerman & Forlizzi, 2007). .

Gaver (2012) suggests taking pride in RtD's aptitude for reflecting, particularizing, and diversifying its ability to manifest results in a form of new, conceptually rich artifacts. This encourages researchers to make "provocative artifacts," and ask people to reflect on them and reconsider the aspects of their world (Zimmerman & Forlizzi, 2014). These artifacts allow people to "think about the world they inhabit, and to notice aspects too often overlooked" (Zimmerman & Forlizzi, 2014, p. 169). To practically implement this, I use technology probes, which are open-ended in nature. This aspect of technology probes allows participants to use them depending on their situation. It also motivates them to think of other ways of using new technologies. The process of reflecting on a technology probe and imagining other ways of using it generates new design requirements (Sengers et al., 2005). This is aligned with RtD because it is oriented towards knowledge-generation (Zimmerman & Forlizzi, 2014); that is, the probes are not end products but a means to generate findings. Further, people in SSA rarely use sensor-based technologies to support their domestic activities. Thus, technology probes helped me introduce sensors to them. This aspect was necessary as it allowed participants to think beyond the core functionality of the probes and provide recommendations on the role of sensors in their homes.

The technology probes method acknowledges intersectional aspects—frameworks for engaging complexity of users' and researchers' identities beyond one facet of identity at a time (Boehner et al., 2007; Schlesinger et al., 2017). Further, this account resonates with the constructivist philosophy of science which posits that reality is socially constructed and the interaction between participants and researchers is important in understanding participants' lived experience (Moses, J.W. & Knutsen, 2019). For this reason, it is important to acknowledge my positionality.

3.1.1 Researcher Positionality

Positionality situates one's identity in relation to a research agenda and subject; it establishes how one's identity—in terms of race, nationality, age, gender, social and economic status, and sexuality—might influence data collection and analysis (Scheyvens, 2014). Here I acknowledge my positionality and how it influences research conducted in this dissertation. I was born and raised in Magombo Village, Thyolo District, Southern Malawi. Malawi is a landlocked country in Southern Africa. Through the course of my childhood, I have lived in rural, semi-urban, and urban areas within Malawi. As a Sena[1], I have participated in various cultural activities (e.g.,

[1] Sena is an ethnic group of people found Mozambique, Malawi, and Zimbabwe. Sena people speak Sena Language—a Bantu language that has many dialectics.

traditional dances and herding cattle) that have shaped who I am. I have also observed people from other tribes participating in their own traditional activities.

I have directly witnessed and experienced the challenges facing Malawian homes including domestic insecurity, power blackouts, and environmental conditions that affect poultry farming activities. I have been a victim of domestic robbery and I have lived in households that frequently experienced more than three power blackouts a day. Further, my mother's poultry farming business of 200 chickens ended without profit because egg production exponentially declined with time and, over 50% of the chickens died in less than 24 weeks due to high temperature conditions that led to heat stress. These experiences increased my interest to study this topic.

My undergraduate education was in computer science and physics at the University of Malawi. Like other universities within Africa, computer science studies at the University of Malawi rarely focus on HCI courses that encourage students to think of users as part of the design process. This is one of the reasons why I decided to pursue graduate studies in HCI. Despite my experience growing up in Malawi, my education differentiates me from a majority of people living in SSA. Further, I realize that, as an HCI researcher, I have some level of power that influences how technological systems are designed. My involvement in the studies presented in this dissertation influenced how the technology probes were designed.

3.2 Data Collection Methods

Here, I describe the methods I used in the three studies presented in Chapters Four, Five and Six. For the studies presented in Chapters Four and Five, I was physically present during data collection. Due to the COVID-19 pandemic, I remotely collaborated with local research assistants in Malawi to conduct the study presented in Chapter Six. All the studies received approval from Michigan State University's (MSU) Institutional Review Board (Appendix D). The studies conducted in Kenya also received approval from Kenya's National Commission for Science, Technology, and Innovation[2] (NACOSTI), and the study conducted in Malawi was approved by the Malawi National Commission of Science and Technology[3] (NCST).

Each study took place in two phases. In these phases, I used a mixed methods approach that included semi-structured interviews, observations, data logging, and diary studies. I used these methods because they provide a deep understanding of user experience and behaviours with technology (Olson & Kellogg, 2014). These methods also provide a way for HCI researchers to explore unexpected ways people use technology. Semi-structured interviews, observations and diary studies are qualitative methods which are "rooted in a phenomenological paradigm which holds that reality is socially constructed through individual and collective definitions of the situation" (Firestone, 1987, p. 1). These methods are generally based on an inductive approach to research (Shoemaker et al., 2004). This means that research begins with data. It is marked by "a rich complexity of abundance" (Tracy, 2010). Researchers utilizing this approach, can go to the field and collect data without necessarily having a research hypothesis. This is aligned with RtD's generative nature because data collected from the field is analyzed to determine common patterns that are used to generate knowledge.

In Phase I, I conducted semi-structured interviews with participants to understand how they secured their homes, monitored power blacks and poultry farming activities. I complemented these interviews with observations of various tools they use in their households. In Phase II, I conducted an evaluation of the probes. I independently developed M-Kulinda, and I collaborated with local technicians in Kenya and Malawi to develop GridAlert and

[2] NACOSTI is an organization that review research proposals and grant permits to scholars conducting research in Kenya.
[3] NCST is an organization that review research proposals and grant permits to scholars conducting research in Malawi.

NkhukuProbe. Because the design process of each probe was different, I provide detailed descriptions of how the probes were developed in Chapters Four, Five and Six.

I used the same protocol in each study; that is, before deploying the probes, I demonstrated how they worked and asked participants to use them for one month. First, I connected the technology probe to a power source. I used solar battery to power M-Kulinda and NkhukuProbe, and grid electricity to power GridAlert. Following this, I asked for participants' phone number and linked it with the probe that was given to them. Depending on the type of probe being deployed, I asked participants to perform some tasks. For M-Kulinda, I asked them to walk in front of the probe to see if they get an SMS alert. For GridAlert, I asked participants to switch off their household's main switch then check if they got a power blackout notification. For NkhukuProbe, I asked participants to use USSD codes to access temperature, humidity, and light conditions of their chicken coop.

Table 1: Data collection timeline

Duration	Topic	Technology Probe	Location	# of participants	Length of Deployment
June – July 2017	Exploring the role of sensor-based technologies for domestic security in Kenyan homes.	M-Kulinda	Bungoma, Kenya	20	28 days
June – July 2019	Exploring the role of sensor-based technologies to support power blackout monitoring in Kenyan homes.	GridAlert	Kisumu, Kenya	18	28 days
August – December 2020	Exploring the role of sensor-based technologies to support poultry farming activities in Malawi.	NkhukuProbe	Nsaru, Malawi	15	28 days

Given that the technology probes were left with participants for one month—without researchers' presence—it was important to continuously monitor them. This helped me to remotely identify technical problems and troubleshoot them during the deployment. I used the diary method by asking participants to be recording their experiences on daily basis. I also used data logging to collect data about the probes' everyday usage by participants. The probes logged data every time participants interacted with them. For example, every time a participant switched on/off the probe, data about that interaction was logged in a MySQL database table. At the end of this phase, I conducted follow-up interviews and observations to understand participants' experiences using the probes. Table 1 shows a timeline of events during data collection.

3.2.1 Interviews

I used semi-structured interviews in each study. Semi-structured interviews consist of questions that are planned ahead of time but with the flexibility to include additional probing questions during interview sessions (Blandford et al., 2016). This was a suitable method to answer my research questions because prior research suggests that interviews are appropriate for understanding peoples' experiences with technology (Blandford et al., 2016). I used semi-structured interviews during both phases of each study.

3.2.1.1 Phase I and Phase II Interviews

During Phase I of each study, I conducted preliminary interviews with participants. The interviews took place in participants' homes—most of them in the sitting room. Each interview lasted approximately 45 minutes. Some of the questions I asked during the interviews included: "What measures do people use to provide security of your property?", "Tell me what happens when you have a power blackout in your home", "What are some of the tools you use for poultry farming?", and "What do you know about sensor-based technologies?" (See Appendices A2, B2, C2).

For each study, follow-up interviews took place approximately four weeks after preliminary interviews. For the studies in Bungoma and Kisumu, Kenya, I returned to participants' homes to conduct these interviews. For the study that took place in Nsaru, Malawi, my local research assistants conducted the follow-up interviews. The goal of the follow-up interviews was to understand participants' experiences using the probes and their reflections about how they can be useful in their homes. The follow-up interview protocol included these questions “Tell me three things you appreciated about the system”, “Tell me three things you did not appreciate about the system”, “Tell me about receiving messages”, “When did you receive them and what was your reaction?”, “What should be changed about the system?”, and “How do you see your future life with the use of sensors?”. All interviews lasted about 45 minutes. In each study, I digitally recorded the interviews and later transcribed them for analysis. I hired interview transcribers who were fluent in Swahili, Luo, and Chichewa to transcribe the audio recordings. At the end of each of the interviews, I compensated participants for their time. These compensations varied depending on which study they participated in (see ‘participants’ sections of Chapters Four, Five and Six).

3.2.2 Participant Observation

Participant observation is a way of collecting data in naturalistic setting by researchers who observe and/or take part in participants’ common and uncommon activities (Musante & DeWalt, 2010). In this dissertation, I used participant observation to observe the tools participants used in their homes. This was done to gain an understanding of participants’ way of life, resources they used in their homes and the context where the studies took place.

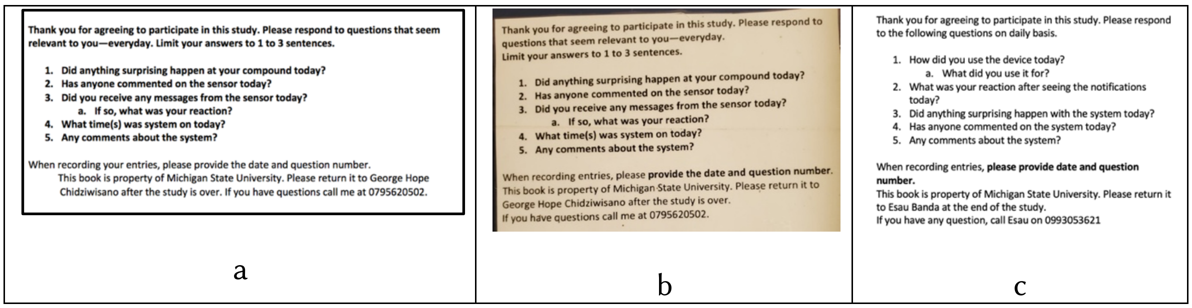
The observations took place after interview sessions. For the studies conducted in Kenya, I requested permission from participants to observe their homes. For the study conducted in Malawi, my research assistants requested permission from participants to observe their homes. Most participants were comfortable showing around their living rooms, kitchen, livestock kraals, and outside space. During these observations, I documented my observations by taking field notes and pictures given participants’ permission. I wrote memos based on my fieldnotes and observations daily. I also attached pictures to my memos to provide a visual aid of what I observed in the field.

During each studies' evaluation phase, I also conducted participant observations; however, for the study conducted in Malawi, my research assistants conducted these observations. During this time, I was interested in seeing where participants used the probes. Participants showed me around different places where they had placed their probes in and around their homes. These included tops of cabinets, near the windows, in chicken coops, and next to electronic appliances. I documented these observations using by writing fieldnotes and taking pictures. Participant observation was necessary because it gave me an understanding of the context in which my studies took place. This enhanced the quality of data I collected throughout my fieldwork.

3.2.3 Diary Method

The diary method is useful for collecting data from participants across time, sampling their thoughts, feelings, or behaviors at key moments throughout a day, week, or month (Hanington & Martin, 2012). A diary is a "document of life par excellence, chronicling as it does the immediately contemporaneous flow of public and private events that are significant to the diarist" (Plummer, 1983, p. 17). The diary method utilizes diaries to document experiences as they happen. This documentation occurs on daily basis in a relatively unobtrusive manner to capture phenomena over time (Cassell & Symon, 2004).

I used this method to document participants' experiences using the probes throughout a four-week period of each probe's deployment. My participants used diaries that were six inches by nine inches with 80 pages. Each diary was given a code that corresponded with participants' pseudonyms. I attached a pen to each diary using a string so that all research materials would be kept in the same place. This was important because it prevented participants from losing their pen before the study ended. I developed a set of questions that should be answered when recording information in the diaries. I did this to encourage participants to record relevant information in the diaries. The questions were printed on a piece of paper, as shown in Figure 2, that was attached to the front cover of the diaries. Some of the prompts that were included in the guidelines are: "Has anyone commented on the sensor today?"; "Did you receive any messages from the sensor today and if so, what was your reaction?"; and "Any comments about the system?".


Thank you for agreeing to participate in this study. Please respond to questions that seem relevant to you—everyday. Limit your answers to 1 to 3 sentences.

1. **Did anything surprising happen at your compound today?**
2. **Has anyone commented on the sensor today?**
3. **Did you receive any messages from the sensor today?**
   a. **If so, what was your reaction?**
4. **What time(s) was system on today?**
5. **Any comments about the system?**

When recording your entries, please provide the date and question number.
This book is property of Michigan State University. Please return it to George Hope Chidziwisano after the study is over. If you have questions call me at 0795620502.

a

Thank you for agreeing to participate in this study. Please respond to questions that seem relevant to you—everyday.
Limit your answers to 1 to 3 sentences.

1. **Did anything surprising happen at your compound today?**
2. **Has anyone commented on the sensor today?**
3. **Did you receive any messages from the sensor today?**
   a. **If so, what was your reaction?**
4. **What time(s) was system on today?**
5. **Any comments about the system?**

When recording entries, please **provide the date and question number.**
This book is property of Michigan State University. Please return it to George Hope Chidziwisano after the study is over.
If you have questions call me at 0795620502.

b

Thank you for agreeing to participate in this study. Please respond to the following questions on daily basis.

1. How did you use the device today?
   a. What did you use it for?
2. What was your reaction after seeing the notifications today?
3. Did anything surprising happen with the system today?
4. Has anyone commented on the system today?
5. Any comments about the system?

When recording entries, **please provide date and question number.**
This book is property of Michigan State University. Please return it to Esau Banda at the end of the study.
If you have any question, call Esau on 0993053621

c

Figure 2: Diary method guidelines for a) M-Kulinda, b) GridAlert and c) NkhukuProbe studies.

Prior to giving participants diaries, I demonstrated how to record experiences and reflections. During demonstrations I encouraged participants to record as much information as possible. During the deployment period, I stayed within the fieldsite (for the studies in Kenya), however I visited participants again after four weeks. I was staying in the fieldsite to assist participants in case they faced any technical problems with the probes. I used different strategies to encourage participants to continue recording information in the diaries. I did this in order to address the limitation that has been acknowledged by prior research; that is, when participants are not motivated, they stop recording data (Carter et al., 2005). Every week, I followed up with participants through text messages and phone calls. A follow-up message consisted of simple words encouraging participants to continue recording information. For example, I sent the following message to a participant:

"Hello Jonathan [4], I hope you are all well with your family. Did you have any new experiences with the system? Remember to record your experiences in your diary because they are very important for this research. Let me know if you experience any problems or you have any concerns while I am away."

To supplement the messages and phone calls, I also sent incentives to participants on weekly basis. These incentives consisted of 100 KES in Kenya or 800 MWK in Malawi ($1) worth of mobile phone credit that was also part of their compensation. It was necessary to send the incentives on weekly basis to encourage participants to continue recording their experiences in the diaries.

3.2.4 Data Logging

In addition to the qualitative data I collected, I used data logging to collect quantitative data from participants. Data logging methods involve "the use of electronic devices to sense, measure and record physical parameters in an experimental setting" (Newton, 2000, p. 1). Within HCI, researchers use data logging to trace events in user interfaces for later analysis (Guzdial et al., 1994). Data logging has been used by various researchers to support usability evaluations and to trace usage patterns (Liu et al., 2010). Data logging is cost-effective because data logs are collected automatically. Further, data can be collected while users are engaged in their everyday tasks thereby providing a greater validity (Guzdial et al., 1994).

I designed the technology probes to log data about how participants used them. This data included how often they used the probes, what time of the day they used them, and what features they used at each moment of interaction. I logged this data in a MySQL database and converted them to CSV files that were used for analysis.

[4] To preserve their anonymity, I replaced participants' names with pseudonyms

3.3 Data Analysis

Here, I describe the methods I used to analyze data. The data I collected included interviews recordings, pictures, fieldnotes, diary entries, and data logs. I used affinity diagramming technique to guide qualitative data analysis. This technique is compatible with my various data collection methods because it is used to externalize and make sense of seemingly dissimilar qualitative data (Lucero, 2015). In addition to analyzing qualitative data, I used Python to analyze the quantitative data that was collected through data logging. This was aligned with the studies I conducted because data logs enhance researcher's understanding of how participants interact with research artifacts deployed in field studies (Dumais et al., 2014).

Affinity diagramming has been used to "generate hierarchical categories to organize large amounts of unstructured, far-ranging, and seemingly dissimilar qualitative data about almost anything" (Hartson & Pyla, 2012, p. 159). This approach is in line with the methods I used to collect data because it provides tools for researchers to make sense of large sets of unstructured data early in the design process (Beyer & Holtzblatt, 1999; Lucero, 2015). Affinity diagramming is inductive; that is, category labels are generated from the data that is being analyzed (Hartson & Pyla, 2012).

This bottom-up approach consists of four basic steps: label making, label grouping, chart making, and explanation (Lucero, 2015). In label making, main patterns emerging from data are captured on separate pieces of paper (mostly sticky notes). Next, these separate pieces of paper are shuffled and spread on a table (Lucero, 2015). Then, individual notes are put on a blank wall, one at a time, forming clusters of labels that are iteratively arranged (Lucero, 2015). During this phase, notes that do not fit in any category are left out for future use. After iterations, clusters are given titles. These clusters are grouped into more abstract groups informing overarching themes. In chart making, emerging themes are arranged on a large sheet of paper where symbols are used to annotate them. Finally, in explanation stage, these themes are described in writing (Lucero, 2015).

Data analysis began while I was conducting Phase I of each study. I wrote fieldnotes to document my observations. I also encouraged my research assistants, including the ones I worked with remotely in Malawi, to write fieldnotes. Each day, I held face to face meetings with my research assistants to discuss our observations. For the study conducted in Malawi, I held these meetings over Zoom. These meetings allowed me to constantly think about my research and make changes on the research questions or methods whenever necessary (Olson & Kellogg, 2014). After these meetings, I wrote memos consisting of expanded fieldnotes paired with photographs.

All recorded interviews were transcribed, and I used open coding to determine patterns in the transcripts (Strauss, 1987). Data analysis of the diaries started with counting the number of diary entries recorded for each diary. An entry is a section of the diary that has been entered at one time consisting of participants' opinions, thoughts, or feelings with a length of at least five words. I read through all entries from the diaries. During this process, I coded frequently mentioned entries to determine patterns in the diaries. I then used affinity diagramming to group these patterns into categories, overarching themes, and then write detailed descriptions of the themes.

To ensure data validity, I triangulated the data I collected through fieldnotes, photographs, and categories generated from interview transcripts and diary entries to identify common themes. Data triangulation is performed by taking data from multiple sources and comparing them (Blandford et al., 2016). This encourages a more reflexive analysis and ensures data validity to give greater confidence in the findings. Further, I used Python's Matplotlib[5] library to plot graphs that illustrated how often participants interacted with the probes over time. These graphs enhanced data validity by showing that participants were using the probes throughout the deployment period.

3.4 Summary

My dissertation is guided by RtD methodology which encourages pursuing design research for the purposes of generating new knowledge through the involvement of users and researchers in the process of technology development. I used a technology probes method to design and deploy three probes and deployed them in Kenya and Malawi for a period of one month. This approach was appropriate for exploring how people use new forms of technologies based on their existing needs. I understand my own background and experiences influenced this work. As someone who grew up in Malawi, I have experienced power blackouts, domestic insecurity, and poultry farming challenges. These experiences informed the design of the probes. I primarily used qualitative methods to collect data from participants. These methods included semi-structured interviews, observations and diary studies. I also logged participants' interactions with the probes in a MySQL database. I used affinity diagramming technique to analyze data.

[5] https://matplotlib.org/

CHAPTER FOUR: M-KULINDA, USING A SENSOR-BASED TECHNOLOGY TO MONITOR DOMESTIC SECURITY IN KENYA

While prior research suggests that crime-detection technology does not dissuade burglars in industrialized countries (Erete, 2013), little is known about how technology can protect the domestic space in SSA. Despite this, domestic security (the state of being protected against theft of domestic property) is a major challenge facing homes in SSA, with over 50% of crime cases occurring in the domestic space (Grote & Neubacher, 2016).

Here, I focus on understanding how Kenyan homes can use sensors to support domestic security. In doing so, I also answer this dissertation's research questions: What is the role of sensor-based technologies in supporting domestic activities in Kenya?; and What are the reflections of people in Kenya about using sensor-based technologies to support domestic activities?

To do so, I designed and deployed M-Kulinda in 20 Kenyan homes for a period of one month. M-Kulinda is a technology probe that uses a motion sensor to monitor homes by sending an SMS alert when activated. I used interviews, diaries, observations, and data logging to understand participants' experiences with the probe. Findings from this study suggest that participants used M-Kulinda to reinforce domestic security. Participants used M-Kulinda for different activities including monitoring their poultry, livestock, and even their own lives. M-Kulinda supported existing security measures in homes such as neighborhood cohesion. Further, the deployment of M-Kulinda in participants' homes unveiled other unexpected uses of sensors. Participants, especially men, repurposed M-Kulinda to monitor their wives and children. M-Kulinda seemed to exacerbate existing patriarchal norms in this context. Participants also repurposed M-Kulinda for activities based on their needs like monitoring their employees.

The rest of this chapter is structured as follows: first, I present M-Kulinda's system overview, followed by the study context and participants. Then, I present the findings of this study. I focus on how M-Kulinda reinforced participants' domestic security measures, how they used it based on their needs, and how it unveiled other unexpected uses of sensors. I end this chapter with a summary of key findings.

4.1 M-Kulinda Design

M-Kulinda is a sensor-based technology probe that detects motion and sends an SMS notification to a mobile phone. M-Kulinda uses SMS notifications because a majority of the Kenyan population own a mobile phone equipped with SMS reception. This is a technology probe because of its three qualities: simplicity, flexibility, and adaptability for different activities. This complies with Hutchinson et al.'s (2003) description of a technology probe: it should maintain simplicity by having a single main purpose, and it should be flexibile and adaptable by being open-ended for different activities. M-Kulinda's main purpose is to detect motion and alert users; this makes it open-ended because users have flexibility to detect whatever they want to monitor. The open-ended design of M-Kulinda is aligned with RtD's nature of using technology to motivate users to explore problems and find ways of using technology to solve them (Zimmerman & Forlizzi, 2014).

M-Kulinda's main components consist of an Arduino UNO microcontroller, a SIM900 GSM shield, a light emitting diode (LED), and a Pyroelectric Infrared (PIR) motion sensor. These components are housed in a control box shown in Figure 3. An Arduino microcontroller was used because its application programming interface (API) software is open source and affordable (Pearce, 2012). The GSM shield was used to host a SIM card that connects to GSM network. This is necessary for the control box to send an SMS alert to participants' mobile phones. The probe was powered by a solar battery that could last up to 30 hours when fully charged. The decision to use a solar battery was made because most homes in rural areas of SSA are not connected to grid electricity. Further, this was affordable for participants because they did not need to pay to charge the battery.

Figure 3: M-Kulinda control box, solar battery, and a feature phone

To develop M-Kulinda's functionality, I considered various sensors that are used to detect crime. One of these sensors was a reed switch. This is a fixed electric switch operated by an applied magnetic field. Reed switches are attached to movable points of entry like doors and windows to detect motion when an intruder attempts to enter a building (Suh & Ko, 2008). This would make the probe immovable, so that participants could not choose where to place it. As such, I decided to use a PIR sensor which can detect motion made by humans and animals without fixing it to any place. Based on the amount of infrared available, PIR sensors detect a differential from their threshold and trigger a signal (Zappi et al., 2010).

The fabrication of M-Kulinda's form factor took place at Michigan State University College of Engineering's Maker Space. I worked in the Maker's Space for a period of two weeks to develop 20 M-Kulinda products. During this period, day to day activities included soldering M-Kulinda's components to a circuit board, fixing the board into M-Kulinda's box, making holes on the boxing, and testing ready-to-go probes.

The total cost of all components of the probe was $70. This amount included $20 for Arduino micro-controller, $25 for the GSM shield, $20 for the solar battery, $8 for the housing, and $2 for the PIR sensor. This amount is significantly lower compared to the average cost of existing off the shelf products that range from $199 to $399 (C. Perry & Allen, 2021). This suggest that the cost of M-Kulinda is affordable compared to existing products on the market. As the probe was designed for research, there are also different ways of reducing its cost when increasing the scale of production. For example, Arduino Nano Every, which costs $12, could be used instead of using Arduino UNO microcontroller (Arduino, 2021; Kurniawan, 2019). This could reduce the cost by 20%. Similarly, other components such as GSM shield and solar power battery could be replaced with affordable components to increase production.

Figure 4: Top left: Testing the hardware before assembly, Top right: Making openings on the enclosing box, Bottom left: fixing PIR sensors to the box. Bottom right: Final research products.

4.2 Study Context: Bungoma, Kenya

This study was conducted in Bungoma County, Kenya. I conducted my first study in this site because I knew other HCI researchers who were working in the area. My PhD advisor was already working in Bungoma, Kenya. As this was my first study, she provided me with useful guidance about conducting HCI research in the field. She also introduced me to her colleagues in the area who helped me to recruit participants. Further, mobile phone adoption in Kenya has been increasing rapidly compared to other African countries (GSMA, 2021). This made it easy to find participants for the study because the deployed probes required participants to have at-least one mobile phone in their homes.

Bungoma is located on the western side of Kenya, an 8-hour bus drive from Nairobi, Kenya's capital. People in this part of Kenya are involved in different income generating activities such as running a small-scale business, farming, and working for the Government of Kenya; with 58% of them practicing small-scale farming (Wiesmann et al., 2014). Mobile phone usage in the region is widespread with more than 80% of the adult population owning a handset (Kshetri, 2017; Poushter, 2016), yet only 4.5% of homes in the area are connected to grid electricity (Ngugi, 2013).

Domestic security is a major challenge in Bungoma. The levels of crime are high in rural areas where police units are far away (Bunei et al., 2013; Bunei et al., 2016). As of 2018, Kenya's National Research Crime Center (2018) found that 48.2% of the homes in Bungoma were affected by burglary. This percentage is higher compared to Kenya's national average of 42% (Kenya National Crime Research Center, 2018). In addition, prior research suggests that 98% of residents witness crime within every three months (Musoi, 2014). Further, during my formative fieldwork (S. Wyche et al., 2018), participants complained about losing their poultry, livestock, electronic devices, and agricultural produce to thieves.

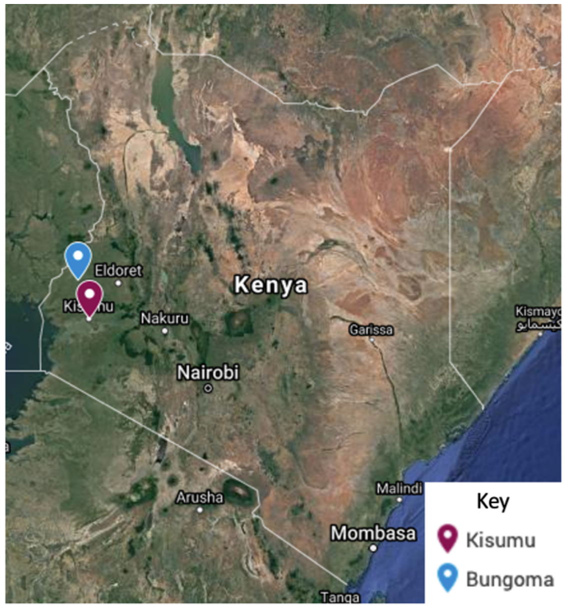


Figure 5: Map of Kenya showing Bungoma and Kisumu

4.3 Participants

I worked with two local research assistants to identify participants and gain access into their homes. In this work, a home is defined as a "person or group of people, related or unrelated to each other, who live together in the same dwelling unit and share a common source of food" (Musoi, 2014). I recruited 20 homes for the study using snowball sampling—a sampling technique that identifies study sample through referrals made among people who share or know of others who possess some characteristics that are of research interest (Biernacki & Waldorf, 1981). These included 12 men and 8 women. I used snowball sampling because I wanted participants who were well known and trustworthy, as prior research that involved deployment studies indicated that theft of probes was a possibility (Murugesan, 2013).

Participants were involved in different kinds of income-generating activities, which included agrarian and poultry farming (9 participants) like growing maize and millet and rearing chickens; full wage employment (2 participants); small-scale grocery stores (4 participants); shoe repairing (1 participant); and mobile phone repairing (1 participant). Three participants were involved in volunteering in community-based organizations. Twelve participants' homes were not connected to the country's electricity grid.

Participants received a total of 400 KSH ($4) for their participation in the interviews. They also received another 400 KSH (provided as phone credit) for their participation during the deployment. At the end of the study, the participants also received the solar charger used to power the probe (valued at about $25).

Table 2: M-Kulinda Participants' Demographics

ID	Age	Gender	Home Size
1	23	Male	5
2	44	Female	7
3	37	Male	6
4	34	Female	4
5	28	Female	10
6	43	Female	8
7	55	Male	3
8	36	Male	2
9	47	Female	6
10	41	Male	5
11	49	Male	7
12	40	Female	9
13	30	Female	4
14	43	Male	8
15	48	Male	7
16	37	Female	6
17	35	Male	5
18	36	Male	4
19	42	Male	7
20	37	Male	6

4.4 Findings

Here, I present key findings from this study. Generally, findings from this study suggest that participants are interested in using sensor-based technologies in their homes, and they quickly appropriate them to fit in with their needs. Here, I focus on the following themes: M-Kulinda's usage, neighborhood cohesion, and participants' reflections on using sensors.

4.4.1 M-Kulinda's Usage

Nineteen participants used the probe throughout the four-week evaluation period. One participant was not able to use the probe due to technical problems. Evidence from data logs suggests that M-Kulinda sent a total of 1176 alerts to participants. The ways participants used M-Kulinda in their homes varied depending on their needs. I will now present some of the ways participants used M-Kulinda.

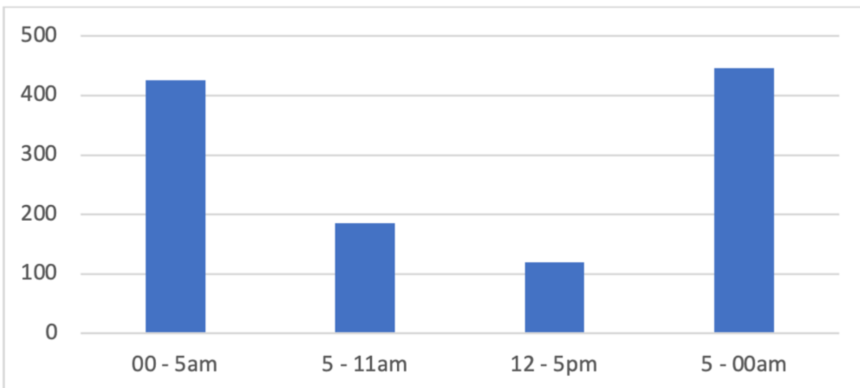


Figure 6: Frequency of messages received at different times of the day

The most frequent use of M-Kulinda was monitoring poultry. In Bungoma County, chickens are important for food and income. Mostly, chickens dwell in a coop that is constructed within participants' compound. Seven participants acknowledged losing their chickens due to theft and predators. Though no participant encountered burglary during the period of M-Kulinda's deployed, they thought of M-Kulinda as a surveillance tool for their chicken coops. "Francis"[6] used the probe to monitor his chickens that were dying mysteriously. He explained that:

> "There was a time before the sensor came, some chicks were missing, and I didn't know what was taking them, but I wanted to know. When I put the sensor on top of the chicken

[6] I changed participants' names to ensure anonymity.

house, it sent me a message. I rushed to see. I found big rats which caught the chicks. I was happy to know what is causing the problem."

Another example demonstrates how M-Kulinda was used by men to monitor movements of family members. Similar to other rural African settings, patriarchal attitudes remain the norm in Bungoma, and I encountered men who used the system to monitor their wives and daughters' movements. One participant who worked as a guard mentioned that he left M-Kulinda running when goes to work at night. He said this was done to monitor other family members rather than intruders. Likewise, "Joel" heard rumors from his neighbors that his daughters would sneak out at night and go to dances; he used the probe to find out whether this was true.

> "I placed the probe in the girls' house and went back to sleep. Immediately it reached at 2am, I heard a message that something has happened. I woke up slowly and then I went slowly at their house. I did not knock, I did not do anything, quietly I hide there I heard they were talking, talking and an incidence that has happened at the dances that night, I heard all the story and I confirmed that it is true the girls sneak."

Figure 7: M-Kulinda on top of a cabinet in participant's home

Data from diaries suggest that participants also used M-Kulinda in their shops. For example, "Phoebe" had a small business in town where she sold cold drinks and other groceries. She wrote that she used the system to monitor what time her employee arrived at work:

> "I placed the sensor in my shop, switched it on in the evening when I [knock off], in the morning, I receive alerts when my employee gets to work. At least I know whether she is late or not."

After using the probe, seven participants acknowledged using it to complement existing security measures of security they had been using before. These participants said that the probe alerted them whenever an intruder tried to tamper with pre-existing security measures. "Betty" explained that:

> "At night, I switch the sensor on. Before the sensor, I used to work up every time I hear dogs barking. Things completely changed the time I was using the sensor: when I hear dogs barking, I don't wake up right away, I wait until the system alerts me as well then, I know something serious is going on."

These uses of M-Kulinda demonstrate the multiple ways participants used the system in their daily routines, whether it be monitoring their poultry, their wives, their children, or their shops. M-Kulinda supported participants' way of doing things, as evidenced by the various ways participants used it. For example, some participants said that they used to wake up every night to check around their compound, but with M-Kulinda, they only woke up if they had received an alert from the probe. However, the ways men used M-Kulinda to monitor their wives and daughters poses privacy risks. Numerous researchers within HCI have studied privacy risks associated with the integration of sensor-based technologies in industrialized countries homes (Demiris et al., 2008; Reeder et al., 2016; Schulz et al., 2018). This study extends prior work by demonstrating that the introduction of sensor-based technologies in Kenyan homes can potentially amplify existing patriarchal norms and pose privacy risks on women.

4.4.1.2 Sensor-Based Technologies Support Neighborhood Cohesion

Findings suggest that participants used M-Kulinda to strengthen security initiatives in their neighborhoods. During baseline interviews participants consistently mentioned that when they were away from home, they relied on their neighbors to tell them what was happening. For example, neighbors would call when they saw people standing by their compound gate. "Mercy" described how mobile phones strengthen neighborhood cohesion:

> "If somebody tries to stand around, you will see my neighbor will call, there is somebody at the gate, so it has been helpful in that way because they can alert there is somebody hovering around you or somebody trying to open your gate."

After using M-Kulinda, participants showed the same trend of response whenever they received an alert while they are far from their home. They would call other household members who are nearby to check what is going on; if there was no one at home, they would call their neighbors to check their home. In one participant's words:

> "Sometimes I get alerts when I am not here, so I wonder what is happening. I call my neighbors to check the compound for me."

Further, participants suggested that rather than sending the messages to a single mobile phone, it would be more effective if other household members—as well as their neighbors—also received the alerts, a finding which suggests M-Kulinda could help to reinforce neighborhood cohesion. "Peter" explains:

> "I want something like alarm to complement the alert I receive. When I put alarm, many people can hear it and learn what's happening. Even if I am not at home neighbors can come. I think this system can also be linked to mobile phones of other

members because sometimes my phone might be off. So, they will be able to get alerts."

Similarly, data from the diaries (see Figure 8) suggest that participants wanted other family members to receive alerts as well. This detailed information provides a representative entry of how participants coordinated with their family members when they were at home. The story also justifies reasons why participants consistently mentioned that it would be good if alerts were sent to more than one family member.

In prior research, Erete (2013) suggests that neighborhood cohesion is a greater security measure than applications that are put in place to dissuade burglars. Collectively, findings suggest that sensor-based technologies can strengthen neighborhood cohesion as participants' consistent suggestions for inclusion of audio alarms reveal how they want to use sensor-based technologies to address their security concerns. These findings provide evidence on how sensor-based technologies can be used to support activities in Kenyan homes.

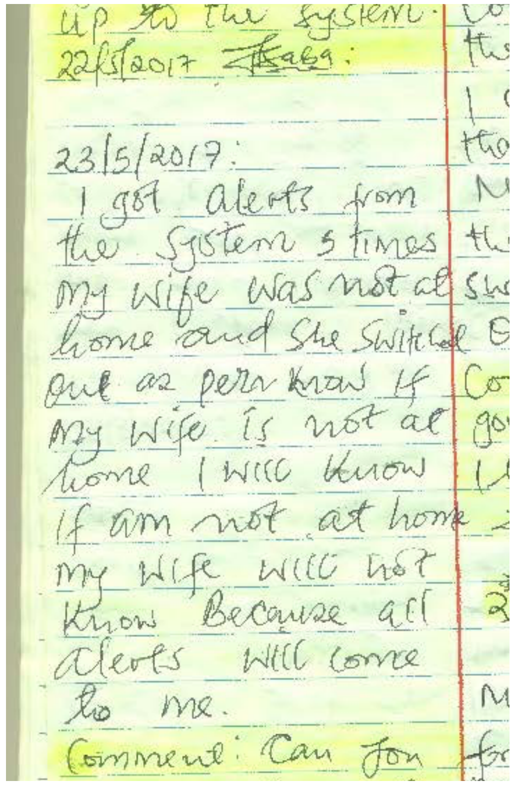


Figure 8: A diary entry suggesting sending alerts to other family members.

4.4.2 Participants' Reflections on Using Sensors

Though participants' understanding of sensors varied, there were shared ideas about how they could be used in their homes to support other activities. During the baseline interviews, participants only mentioned that sensors can be used to detect when something is wrong. "Neli" explained that sensors could be used for:

> "Notify[ing] you that there's something going on, like there are those cars which they put in a gadget so that whenever someone touches the car, the owner of the car might detect that there's somebody touching my car."

Participants used M-Kulinda as a point of reflection for other uses of sensors in their homes. M-Kulinda made participants think about other ways sensors can be helpful in their lives beyond home protection, and these reflections should be used for designing sensor-based systems that benefit rural African residents. "Betty" explained that:

> "It can detect when water is there or not by use of that sensor. You know a times water goes off for a long period. And when it comes you cannot detect with your naked eyes unless you go and open the tap and see."

M-Kulinda inspired participants to think beyond conventional ways to use sensors. Participants thought about the possibility of using sensors in relation to existing traditional practices. For example, they questioned whether it is possible to use sensors to detect witchcraft. As one participant said:

> "I hear noises at night in my house when we are all asleep and I think they witches that come to disturb me. Are there any sensors that can be used to detect witches? That would be useful because we believe witchcraft is real however no one has seen a witch or detect them."

Though it is not clear how technology can be used to support existing occult practices in Kenya, these are areas that have not been explored in HCI, and M-Kulinda allowed participants to think in this direction.

Participants' reflections of how sensors can be used in their everyday lives suggest that M-Kulinda deepened their understanding of how sensors work and what they can be used for. The single functionality in M-Kulinda enabled participants to think of other ways sensors can be useful in their lives. Sengers et al. (2005) observe that reflection on unconscious values embedded in computing and the practices that it supports can—and should—be a core principle of technology design.

4.5 Summary

Returning to the research questions, this study provides detailed evidence of how people in Bungoma, Kenya want to use sensors to support their daily activities. Participants' interactions with a sensor-based technology probe in their homes unveiled their reflections about using sensors. These findings provided answers to the research question seeking to explore participants' reflections about using sensor-based technologies in their homes. For example, participants suggested using sensors to monitor power blackouts (a common problem in SSA) and support poultry farming activities. These reflections are useful to understand areas participants want to apply sensor-based technologies in their homes.

As this study specifically focused on domestic security, it provided detailed evidence of how sensors could be used to deter crime in Kenyan homes. Prior research suggests that crime detection measures in industrialized countries do not dissuade burglars (Erete, 2013). However, this study has demonstrated that sensor-based technologies have the potential to deter burglary in Kenyan homes. Findings on neighborhood cohesion draws attention to the possibility of integrating sensor-based technologies with already existing crime prevention systems to support domestic security.

The open-ended nature of M-Kulinda allowed participants to use it for other activities outside the domain of domestic security. This generated answers to this dissertation's research question on understanding the role of sensor-based technologies in Kenya. For example, participants' interest in using sensors to monitor the time their employees arrive at work suggests that they are not only interested to use sensors in the domestic space, but also in their workplaces. Further, the ways men used M-Kulinda to monitor their wives and daughters could pose privacy risks. These findings suggest that the deployment of M-Kulinda in participants' homes potentially exacerbated patriarchal norms. These findings provide preliminary evidence about the unintended consequences of using sensor-based technologies in Kenyan homes.

Participants reflections on M-Kulinda suggest broad areas where sensors can be used. For instance, participants suggested using sensor-based technologies to support power blackout monitoring and poultry farming activities. Prior research suggests power blackout challenges and environmental conditions that negatively affect poultry farming in SSA (Nyoni et al., 2019; The World Bank, 2016). In Chapters Five and Six, I build upon these findings to specifically understand how sensor-based technologies can be used in these two domains.

CHAPTER FIVE: GRIDALERT, USING A SENSOR-BASED TECHNOLOGY TO MONITOR POWER BLACKOUTS IN KENYA

Participants in Chapter Four suggested using sensor-based technologies to monitor power blackouts. The World Bank estimates that an average home in SSA faces 700 hours of blackouts (approximately a month) every year. Most countries in this region, such as Malawi, Kenya, Tanzania, Nigeria and Uganda were given an electricity reliability score of 0 out 8 by The World Bank. A reliability score of 0 implies that an electricity supply system is completely unreliable while a score of 8 implies that an electricity supply system was extremely reliable (The World Bank, 2016). Power blackouts affect people's livelihoods in different ways; they damage electrical appliances, increase crime rates, constrain economic well-being, and reduce the benefits of using 'welfare-improving machines' like televisions and electric fans (Klugman et al., 2019; Matthewman & Byrd, 2014). Prior research suggests that sensors can be used to collect power blackout information and send it to electricity supply companies (Klugman et al., 2019; Klugman et al., 2014). However, their impact on providing feedback about power blackouts—to end users—has not been considered in HCI. Building on this work, this chapter focuses on exploring how sensor-based technologies can be used to support power blackout monitoring in Kenya.

I collaborated with local technicians in Kenya to design GridAlert's form factor using locally available resources, such as timber and labor. GridAlert is a technology probe that detects domestic power blackouts and sends a notification to users via a mobile app. GridAlert also allows users to control their appliances by turning an appliance on/off, scheduling appliance runtime, and visualizing appliance runtime. I conducted the study in two phases. I initially conducted 18 interviews with participants in their homes. I did this to understand how they monitor power blackouts. Next, I deployed the GridAlert in their homes for one month. During the deployment, I asked participants to record their experiences using a diary. I also logged power blackout and restoration data, as well as participants' interactions with the system. After a month, I conducted follow-up interviews with my participants and asked them about the impact of GridAlert in their homes.

My study's findings suggest that GridAlert protected participants' home appliances and allowed them to manage their time between power blackouts and restorations. GridAlert seemed to minimize participants' time lost due to blackouts as they were able to resume their activities as soon as they received a notification about power restoration. Further, it worked as a technology probe allowing participants to use it for different activities based on their needs. Participants also repurposed GridAlert for other activities in their homes. Participants, especially men, used GridAlert to monitor how other members of their homes were using electronic appliances. This suggests that GridAlert supported existing patriarchal norms practiced by the Luo people (Abonyo, 2005). Furthermore, GridAlert's form factor prompted mixed reactions among participants. Unlike other studies in HCI/ICTD that have focused on interface design, my study examines how the design of GridAlert's hardware (using locally available resources) influenced participants' experiences with the entire system.

The next sections in this chapter are structured as follows: I describe how GridAlert was designed. Then, I provide an account of the study's context and participants. Next, I present key findings from this study. At the end of this chapter, I summarize key findings that emerged from this study and how they motivated my next study.

5.1 GridAlert's Design

Here, I present GridAlert's design, as seen in Figure 9, and how it works. Before designing GridAlert, I considered commercially available products such as smart power strips. However, these required access to the Internet via Wi-Fi or cable network, and this is limited in Kenyan homes (KNBS, 2018). Consequently, I designed GridAlert to access the Internet via the Global System for Mobile Communications (GSM) network, which is widely available in Kenya.

Figure 9: GridAlert System

The system has two components: the power strip and an accompanying mobile phone application. The power strip supports a Particle Electron micro-controller with its battery and antennae, which controls two G-type sockets and also senses power blackouts and restorations. The GridAlert mobile app is an Android application that works as an interface for participants to access data provided by the power strip. It allows them to check power availability logged through the power-strip, switch electrical appliances on/off, and see reports about how long their electrical appliances are used each day. GridAlert automatically protects appliances connected to its sockets; however, it had only two sockets. Therefore, appliances not plugged on GridAlert required physical unplugging.

I developed the app using Apache Cordova that was linked to the physical device via a webserver. GridAlert syncs to the app using the GSM network that is widely available in Kenya. The system relays real-time data about power status to the server, which the app then reads and displays on its interface. Similarly, users' actions (e.g., switching on/off appliances) with the app are logged on the server to control appliances.

5.1.1 Electricity Blackout Detection Mechanism

GridAlert's micro-controller is powered by grid electricity and an embedded battery. The battery is charged by grid electricity. It provides backup power to run the micro-controller when there is no grid electricity. The micro-controller works as a sensor by detecting power blackouts when the charging system switches from grid electricity source to battery power source. It also detects power restorations when the charging system switches from battery power source back to grid electricity source.

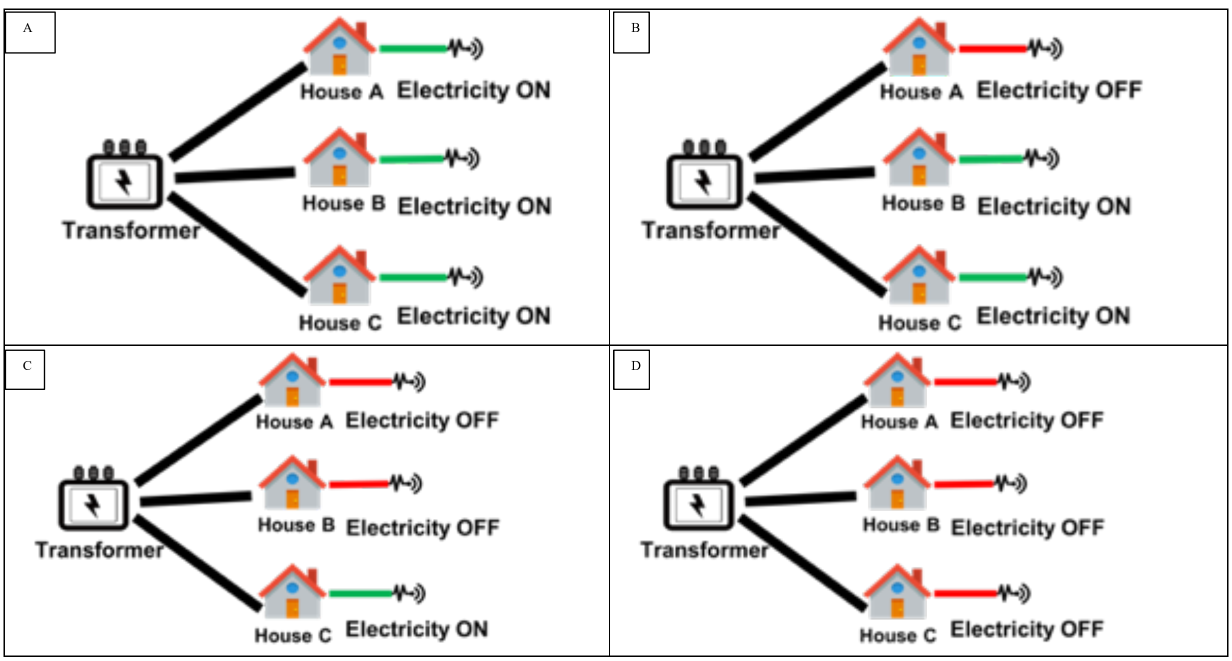


Figure 10: (a) No blackout detected (b) False blackout detected (c) True blackout detected (d) True blackout detected

One challenge with this system is that it detects 'false blackouts'; that is, reports of a blackout when grid electricity is still available. This happens when participants manually switch off electricity from their main switch. Prior research suggests that increasing the number of sensors deployed in a particular area can improve the robustness of power blackout detection

(Correa et al., 2018). To prevent false blackout detection, I designed the system to work with other GridAlert devices within the same transformer (Figure 10). A true blackout was reported if at least two different systems from the same transformer logged a blackout at the same time.

5.1.2 Designing GridAlert

I designed a preliminary version of GridAlert, and then worked with local technicians in Kisumu, to refine its design. Over the course of the project, I worked with two electricians, three carpenters, and one painter. They soldered electronic components together, designed GridAlert's housing, and assembled and tested the probes. Working with local technicians helped to design features that would support its operation in Kisumu. The technicians adapted the US-based 110V system to operate under the Kenyan 240V electricity supply. They procured step-down transformers (devices for converting high voltage to low voltage) for each unit. Step-down transformers controlled the input voltage, thereby preventing GridAlert from overheating. Together, we iterated upon the design, testing different transformers until we had a portable transformer (Figure 11).

Figure 11: Working with local collaborators in Kisumu, Kenya

Local technicians also helped me design GridAlert's housing. I worked with the technicians to make different sketches before coming up with the final model. I used plywood, because it is widely available in the area. Once the carpenters finished working on the boxes, they painted them brown. Carpenters chose the color brown, because they observed that most wooden items (e.g., furniture) in Kenyan homes are brown, and therefore the system would match with other home property. Finally, the electricians recommended making holes in the GridAlert housing, so that system electronics would not overheat as a result of poor ventilation. I paid each technician 5500 KES (about $53).

The total cost of developing GridAlert was $100. This included $25 for buying a relay, $60 for the particle electron micro-controller and, $15 of labor and housing materials. This amount is comparable to the cost of off-the-shelf products, such as "MySpool", which costs $99 and "Power Sensor", which costs $65 (AVTECH, 2021; MySpool, 2021). However, given that GridAlert was developed for research purposes, there are a number of ways of reducing the cost during large scale production. For example, the cost of a relay could be reduced by using a "HiLetgo" relay which costs $4 (HiLetgo, 2021). In addition, there can also be negotiations with local technicians and "Particle IO" to consider reducing the cost of their services and products, given they will have a contract with GridAlert developers. Further, other digital companies, such as M-Kopa, in Kenya have used a pay-as-you-go (PAYGO) model, that gives flexibility for customers to make payments as they are using the system (S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018). This model could also be used to allow customers make their payments as they are using GridAlert.

5.2 Study Context: Kisumu, Kenya

This study took place between May and July 2019 in Kisumu, Kenya, a port city on Lake Victoria. I conducted the study in Kisumu because my advisor was already familiar with the area. This made it easier for me to find experienced and trusted local research assistants who worked with me to identify participants and conduct interviews in Swahili and Luo (popular languages in Kisumu).

About 18% of homes in Kisumu are connected to grid electricity, which is 5% lower than the Kenya's national average of 23% (Kemibaro, 2016; Olang et al., 2018). Similar to other areas in Kenya, blackouts that range from four to eight hours are typical in Kisumu (Abdullah & Mariel, 2010). Prior research suggests that 68% of the population in Kisumu experiences at-least more than 3 episodes of power blackouts every month (Ojwang, 2012). Other sources of electricity that are used as alternatives to grid electricity are solar and kerosene; however, these sources of power have low capacity, and are only used for lighting, charging phones, and listening to the radio (Olang et al., 2018). Residents typically have multiple sources of income, such as fishing, owning small-scale businesses (e.g., selling soft drinks, printing and photocopying business), working for government agencies, and working in the private sector (Juma & Otieno, 2017).

5.3 Participants

I worked with a local research assistant to recruit 18 participants using purposive sampling (Biernacki & Waldorf, 1981). Specifically, I recruited participants who had grid electricity in their homes, and owned smartphones because GridAlert worked on Android phone. I primarily interviewed heads of households (ten men and eight women, ages 21-59). I grouped the sample into six clusters to prevent detection of false blackouts (see System's Overview Section). In this paper, a cluster is a set of three participants whose homes' grid electricity come from the same transformer. Table 3 summarizes demographic information of participants.

Participant #	Age	Gender	Home Size	# of Smartphones in Home	Occupation
1	53	Female	4	2	Farming
2	44	Female	3	1	Farming
3	42	Male	3	2	Small-scale business
4	31	Male	3	1	Fishing
5	36	Female	5	1	Small-scale business
6	28	Female	1	1	Works for solar company
7	37	Female	3	1	Farming
8	25	Male	2	1	Business
9	44	Male	6	2	Works for solar company
10	35	Male	2	2	Farming
11	39	Male	5	2	Small-scale business
12	32	Male	3	2	Small-scale business
13	21	Female	1	1	College student
14	59	Female	7	1	Farming
15	26	Male	2	1	Small-scale business
16	28	Female	3	1	Small-scale business
17	32	Male	2	2	Own innovation hub
18	42	Male	7	2	Small-scale business

Table 3: Participants' demographic information

Participants in the study received compensation in phases. At the beginning of the study, I gave each participant 200 KSH ($2). Each week during deployment, they received 100 KES in phone credit. This was done to encourage them to continue writing their experiences in the diaries. At the end of the study, I gave each participant a transformer adapter (valued at 1500 KES) and 200 KES as a compensation for their time. In total, participants received 2300 KES (about $22) for their participation in the study.

5.4 Findings

Here, I present key findings after the deployment of GridAlert because they provide answers to my research questions than findings before GridAlert deployment. For detailed findings before

GridAlert's deployment, see Chidziwisano et al. (2020). Findings after GridAlert's deployment provide detailed reflections on how participants want to use sensors to support different activities in their homes. These reflections provide answers to my research questions: What is the role of sensor-based technologies in supporting domestic activities in Kenya?; and What are the reflections of people in Kenya about using sensor-based technologies to support domestic activities? First, I provide a general descriptive account of how participants used GridAlert throughout the study.

Then, I present findings that consist of answers to my first research question. I describe how GridAlert seemed to help participants manage time when there is a blackout and how they used GridAlert to monitor their electrical appliances. Following this, I present findings suggesting how GridAlert worked as a technology probe allowing participants to repurpose it for different activities in their homes, which relates to my second research question.

5.4.1 Findings from GridAlert's Deployment

Participants said that during the deployment, several blackouts occurred. GridAlert's logged data suggests there were 46 blackouts from all clusters during the deployment period. This number is slightly lower than what participants reported. Eleven participants said that, on average, there were about three blackouts each week in their homes, two participants told us there were less than five blackouts during the whole period, and three participants said they could not exactly remember. Participants might not have given the exact number of blackouts encountered during deployment period. These blackouts ranged from 30 minutes to four hours, with an average of 2.5 hours.

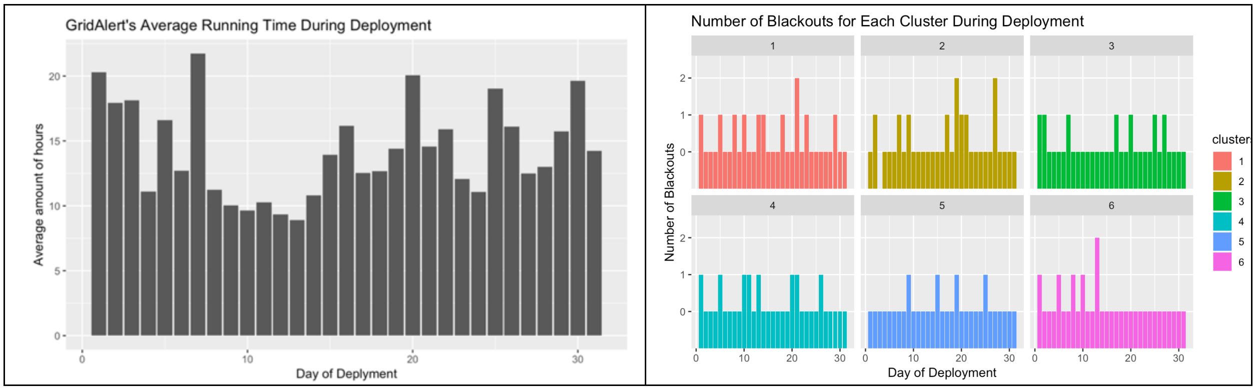


Figure 12: GridAlert's average runtime each day of the deployment; (b) Number of blackouts per cluster each day of the deployment

5.4.2 The Role of Sensor-Based Technologies in Supporting Domestic Activities

5.4.2.1 Protecting Electrical Appliances in Homes

Participants used GridAlert as a blackout awareness tool. They consistently said that GridAlert's detection feature was useful, because it protected their electrical appliances from damage. Eight participants said that whenever they saw a notification of a blackout, they immediately switched off all electrical appliances. I observed that participants mostly placed the GridAlert power strip near their music system stand (Figure 14c). These participants said that they did not switch off appliances that were connected to the GridAlert power strip, because the system would control the appliances when electricity was restored. In one typical quote, Jim explains:

> "I used GridAlert to protect my gadgets. Once I see a notification that there is no electricity, I switch off appliances that are not connected to GridAlert. I wish all appliances in my home were connected to GridAlert so that I shouldn't bother to switch them off: GridAlert protects things when electricity comes with more force."

Although six participants had a power surge protector, their diary entries suggested that they understood GridAlert as a different device. They wrote that GridAlert's app gave them more control for their appliances. Unlike surge protectors which only protected their appliances, they were also able to interact with their appliances even when they were outside or away from home. The following is a representative diary entry showing participants' comparison of GridAlert to a power surge protector:

> "The gadget controls damage of my appliances just like a 'fridge guard' (a common term used for power surge protector). But GridAlert has an app which I use to monitor my appliances are running. I am also able to schedule them. It also doesn't matter where I am, I can receive a notification on the app at any time electricity goes on/off."

Participants mentioned that it would also be useful if all their appliances were automatically protected, instead of needing to manually switch them off. Many seemed frustrated when they received power blackout notifications while they were away from home, because they were unable to return home to switch off their appliances. Participants wanted GridAlert power strip to be connected to all electrical appliances in their homes. Further, participants seemed frustrated that they could not control their devices when the phone is off, as described in a diary entry in Figure 13.

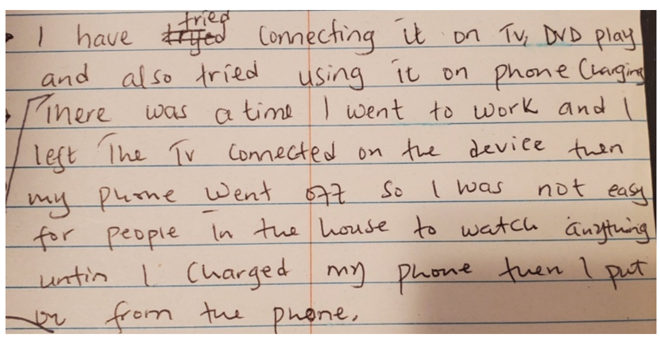

I have ~~tryed~~ tried connecting it on Tv, DVD play
and also tried using it on phone Charging
There was a time I went to work and I
left The Tv connected on the device then
my phone went off so I was not easy
for people in the house to watch anything
untin I charged my phone then I put
on from the phone.

Figure 13: Participants' diary entry suggesting how difficult it was to control appliances when her phone was off.

5.4.2.2 Time Management

Analysis of participants' diary entries suggest that they appreciated that GridAlert notified them when power was restored. Ten participants wrote that this awareness helped them to get back to work, and to other activities that required power. Elestina, a student, said that when she sees a notification that electricity is restored, she returns home from wherever she was, usually her neighbor's place, to continue writing assignments on her computer. Felix, a barber, said he goes back to open his shop.

> "When there is a blackout, I go home to rest. I wait for GridAlert to send me a notification that electricity is restored. Then I go back to open my barber shop."

These findings suggest participants used GridAlert to manage time during episodes of electricity blackout. Prior work suggest electricity blackouts negatively affect economic activities (Eberhard et al., 2008). My findings suggest participants found GridAlert useful because it helped them to save time, get back to business and make money.

5.4.2.3 Monitoring Electrical Appliances' Consumption

Participants appreciated GridAlert's analytics feature that displayed how many hours their appliances were used (see Figures 14a and 14b). These appliances included sub-woofers, televisions, phones, fans, and iron boxes. Nine participants said that after a day, GridAlert's home report graph showed the number of hours they spent using electricity each day. My analysis suggests that participants were surprised to see that the runtime for their electrical appliances could be hours longer than they expected. This made them realize that sometimes they leave their appliances running even when they are not being used. For example, Joseph said that his security light is only useful at night, and that he often forgets to switch it off in the morning. Through GridAlert's weekly reports, he realized that forgetting to switch off security light resulted in more hours of electricity use. He explained that:

> "Since I started using the system, I check the report to see how long my gadgets are running. At first, the report was showing that my gadgets are running for many hours. I have realized that this might be because of my security light. I mostly forget to switch it off in the morning when I am going to work. So, when I switch it on in the evening, I use GridAlert to schedule that it should go off at 6am."

Having the GridAlert app on Joseph's phone prompted him to switch off his security light every morning. Whenever he was switching on his security light using GridAlert, he also scheduled it to go off at 6am. Similar to Joseph, other participants mentioned that after two to three weeks, they noticed that their electricity units were lasting longer than before. They were not buying electricity units as frequently, and their digital meters—devices for buying and checking electricity credit—also showed that they had not used as much. However, participants recommended that GridAlert should also report the amount of money consumed by each appliance. Frank, who sold firewood in town, said that he mostly pays 250 KES ($2.50) for electricity credits every two weeks. He was surprised when, after two weeks with GridAlert, his landlord informed him that he only had to pay 160 KES (about $1.60). Frank shared one thing he will always remember about using GridAlert:

> "The fact that GridAlert has been able to reduce my bills from 250 KES to 160 KES will be the most memorable thing (...). I have always been paying more than 200 KES every two weeks; however, now things are different. Even my neighbors were asking me why my bill was less this time. I told them about GridAlert and they asked it to have it."

Data from logs suggest that the amount of time participants used electrical appliances each day decreased over the deployment period. For example, Joseph's weekly reports, shown in Figure 14, supported this observation. Data showed that the average amount of time she used her electrical appliances decreased with time. This suggests that using GridAlert prompted some participants to switch off their appliances when they were not in use. This reduced participants' electricity consumption.

Figure 14: Electrical appliance runtime weekly graphs on participant's phone c) GridAlert in one of participants' homes

Participants also said that the GridAlert app provided them with more control over their appliances. More specifically, GridAlert's scheduling function allowed them to switch their appliances on/off at the exact time they wanted. This reduced the amount of time they spent to physically switch their appliances on/off. Participants said this made their appliances 'ishi kulinanga na kila siku,' a commonly used term for 'fit in with everyday activities'. For instance, Chris, who loves listening to music, said:

> "When I go to bed I bring my music system to the bedroom. I play music throughout the night. In the morning, I feel bad that I left the music system to run all night. With GridAlert, I started timing that the music system should switch off after two hours for I know after that I will be asleep. Now, I always find my music system off every morning"

It seemed participants also used GridAlert to monitor their domestic activities while they were away from home. For example, Jim said that he had to charge a new shaving machine for nine hours. However, he was supposed to go to work, and he wouldn't be home to switch it off after the nine hours had elapsed. He used GridAlert's scheduling function to specify when the shaving machine should stop charging. He explained in the diary entry shown in Figure 15.

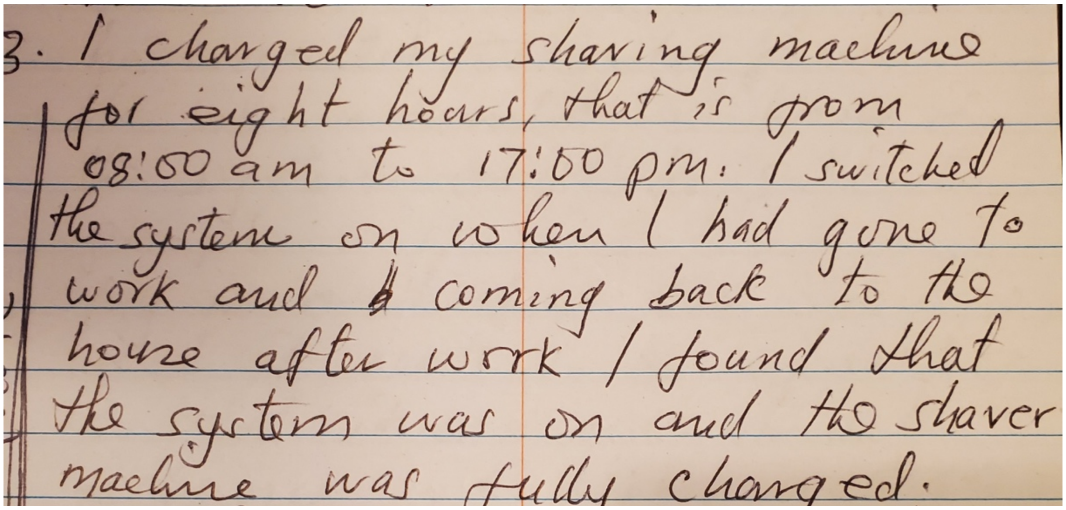


Figure 15: One of participants' diary entries explaining how he used GridAlert to charge his shaver.

These findings suggest participants' interaction with GridAlert allowed them to control their appliances without disrupting their daily activities. Participants' interaction with GridAlert also allowed them to learn more about how their appliances consume electricity, thereby minimizing costs and saving energy.

5.4.2.4 Controlling Household Members' Electrical Appliance Usage

GridAlert seemed to support men's intentions to control how members of their homes use electrical appliances. As earlier mentioned, in Kisumu, men are regarded as heads of households, and they have power over other family members. Five participants (all men) used it to control the amount of time their children spent watching television. They said their children spent more time watching television instead of doing homework or chores, (e.g., washing dishes, fetching water), especially when their parents were away from home. Participants said the GridAlert app also allowed them to control their television from anywhere. This allowed them to monitor whether their children were watching television or not. For instance, Charlie said:

"I am happy that I have this system to control my appliances. My children mostly spend their time on television especially when I am not around. With GridAlert, I am able to see whether they busy on the television. I can switch it off from anywhere to make sure that they are doing other things."

While men monitored their children's electrical appliances' usage with good intentions, these findings suggests that sensor-based technologies can potentially jeopardize other household members' privacy especially when they use electronic devices to access personal content.

Further, the deployment of GridAlert suggests that sensor-based technologies might influence who has access to electronic devices in patriarch headed homes. Male participants, who were heads of their households, seemed satisfied with GridAlert's capability to provide real-time information about electrical appliance's usage. Participants utilized this information to influence how other family members should use domestic appliances. For example, one participant said that he advised all inhabitants of his household to switch off lights in their rooms when they go to bed.

"After seeing how much energy we are using, I thought about different ways of reducing energy usage in my home. Mostly my children leave lights on when they go to bed. I told my them to remember to switch off lights in their rooms before going to bed. Later at night, I could check if they have really turned off lights in their bedrooms. If not, I could ask could just do it from the app"

While this was done to save energy consumption, prior research suggests that leaving lights on at night is a strategy for people who are afraid of darkness to go to bed (Alcañiz et al., 2007). It is unclear whether other family members were negatively affected by this recommendation from heads of their households. However, this can possibly bring frustration to other family members who prefer sleeping with lights on. Further, other family members' routines could be compromised when heads of their households monitor appliance usage especially when they remotely turn the appliance off while other inhabitants are using it. It seemed GridAlert provided more power to men who wanted to monitor how other family members utilize domestic appliances. In this way, GridAlert reinforced existing practices in this context by giving men more control over other inhabitants in their homes. These findings are similar to those in Chapter Four where M-Kulinda influenced men who had patriarchal attitudes to use it to monitor their family members (Chidziwisano & Wyche, 2018). These findings are also aligned with studies in HCI/ICTD that suggest that technology exacerbates people's existing intent (Toyama, 2011; S. Wyche et al., 2016). However, this study extends these studies by illuminating how sensor-based technologies can exacerbate patriarchal norms in Kenyan homes.

5.4.3 Participants' Reflections on Sensors

Data from Phase I interviews suggest that participants had little knowledge about how they could use sensors in their homes. Their interactions with GridAlert revealed ways that participants repurposed the probe to support their needs. Based on these interactions, participants reflected on how sensors can be used to support different activities in their homes. Here, I provide some of the examples of participants' reflections on sensors.

Participants used GridAlert for experimentation. For example, Joel's diary mentions that he wanted to verify whether GridAlert could be used to monitor a television. Though he didn't own a television, the presence of GridAlert in his house prompted him to borrow a 24-inch television from his neighbor (Figure 16).

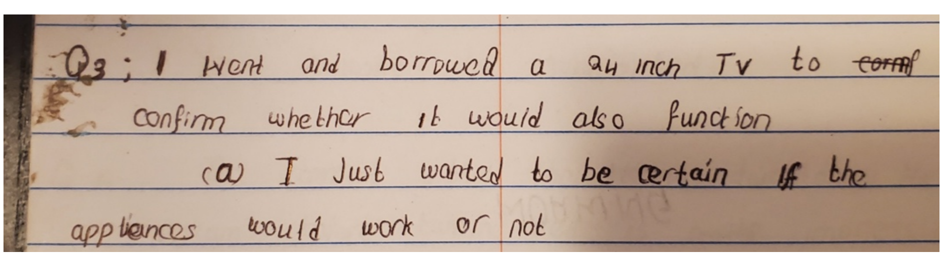


Figure 16: Participants' diary entry explaining how he tested GridAlert using a TV

Another participant was curious to see if GridAlert was compatible with other smartphones. She asked her neighbor (who was not participating in the study) to install the app on her phone. It seemed that these forms of experimentation helped participants to think more about how sensor-based systems can be used in their communities. Such experiments allowed participants to understand how GridAlert works thereby inspiring more ideas of how else it can be used. For example, participants suggested that it would be interesting if there were sensors for checking whether auto teller machines (ATM), before they go to withdraw or deposit money. Participants also suggested using sensors to improve power sharing strategies in their communities. These findings provide participants' reflections about using sensor-based technologies in their homes. Participants used their understanding of GridAlert to repurpose it for different activities in their homes. GridAlert provided a way for participants to experiment their thoughts about sensors and provided insights on how they could be used to support domestic activities in Kenya.

5.4.3.1 Reflections on GridAlert's Material Qualities

Here, I discuss participants' reflections on GridAlert's design, in particular its material qualities, i.e., the housing. Participants had mixed feelings about the housing. Some associated GridAlert with other things in their homes that were also made of wood. More than half said they initially thought GridAlert was a sub-woofer, a device for reproducing sound. During observations, I observed that participants' sound equipment was made of wood. These findings suggest that it was not a new thing to introduce an electrical appliance made of wood into participants' homes.

While those participants appreciated using an electrical appliance made of wood, seven thought the wooden box was not a "cool" way of casing GridAlert (as described in a diary entry in Figure 17). These participants described the wooden box as "old" and "traditional". They recommended using plastic casings when redesigning the probe, so that it would be more like other appliances manufactured in the U.S., and China. It seemed that participants felt socially superior in their communities when they had gadgets that were more obviously from abroad. I observed that such gadgets were typically placed in their sitting room so that visitors could easily see them. One participant's reactions to the system's design was typical:

> "It's not supposed to be a wooden box, it's not presentable that way to put it on the sitting room. I like all things on my sitting room to look modern. Though I use it to monitor my gadgets, I put it behind my TV then a teddy bear in front of it so that nobody sees it. I like what the system does but I don't want people to see I am using a wooden box because they will think of me as an old-fashioned lady."

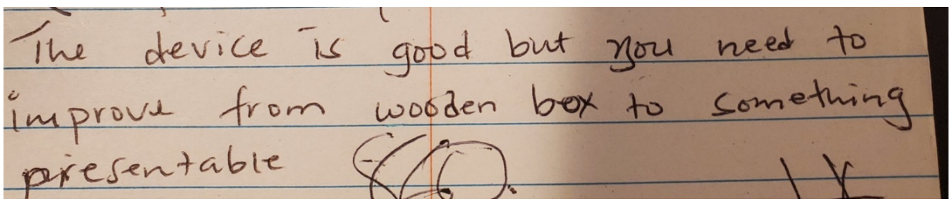


Figure 17: Participants' diary entry describing GridAlert's form factor.

Prior research emphasizes designing technological systems by utilizing locally available resources such as materials and labor (Klugman et al., 2019). However, my participants believed that imported products were appealing, modern, and long-lasting; they did not associate GridAlert with these words. Although participants had mixed perspectives about GridAlert's housing, they found the system's functions most important:

> "I thought the system would be made of plastic. I think the wooden box makes it look like an old technology. However, its ability to control things through my phone is the opposite of old technology. I enjoy controlling things from my phone and that's why I still use it."

These findings suggest participants' interest to use GridAlert despite their thoughts about its material qualities. Odom et al. (2009) underscored that the "presence of new technologies results in obsolescence of an object's function; however, a single-purpose functional object is more likely to continue to endure if it has some sense of engagement". GridAlert's function—monitoring electrical appliances and blackouts—provided a sense of relevance in participants' homes. Though participants had mixed feelings about GridAlert's housing, it offered them some level of familiarity, as it was similar to other electronic appliances they have used. Furthermore, its ability to control electrical appliances projects its sustainability.

5.6 Summary

Power blackouts are a part of Kenyans' everyday lives, making sensor-based technologies that monitor power usage and blackouts in homes useful. For example, GridAlert supported participants' efforts to manage their time between power blackouts and restorations, protect their appliances, and monitor power usage. These examples provide answers to my research question about how sensor-based technologies can be used to support domestic activities in Kenyan homes.

Further, participants' interactions with GridAlert prompted detailed reflections about living with intermittent power supply. These reflections contain recommendations based on their interest in sensor-based technologies, thereby contributing new design concepts in HCI. GridAlert also inspired users to consider novel ways sensors could be integrated into their homes. However, these findings also draw attention to how the integration of sensor-based technologies in participants' homes might influence patriarchal norms. One of the study's contributions is how these reflections draw attention to future opportunities in HCI to designing sensor-based technologies for Kenyan homes.

This study focused on power blackout monitoring and electricity management in the home, which was one of the areas that participants in Chapter Four thought sensor-based technologies could be used for. The participants in Chapter Four study also suggested using sensors to support poultry farming activities. To this point, it is still unclear how sensor-based technologies can be used to support poultry farming activities in SSA. I explore how sensor-based technologies can be used to support poultry farming activities by building on these two studies as described in the next chapter. My collaboration with local technicians to design GridAlert's form factor using locally available resources prompted participants to comment on the form factor; I use a similar approach as I explore the role of sensors in supporting poultry farming activities. Further, findings from this study suggest that participants wanted GridAlert to be controlled by all family members, not only heads of households. I use this finding to support NkhukuProbe's design so that other family members who have mobile phones can also access information from the probe.

CHAPTER SIX: NKHUHUPROBE, USING A SENSOR-BASED TECHNOLOGY TO SUPPORT POULTRY FARMING IN MALAWI

Findings from the previous two studies suggested that participants are also interested to use sensor-based technologies to support poultry farming activities. I also learned that involving local technicians in the design of the probes using locally available resources motivated participants to reflect on the probe's form factor. Further, participants in Chapters Four and Five suggested designing sensor-based technologies in such a way that other family members can have access to them. In this chapter, I build upon the work presented in the previous chapters to understand how sensors can be used to support poultry faming activities in Malawi. To do this, I conducted pilot interviews with domain experts to understand the challenges that poultry farmers encounter when managing their coops. I found that temperature, humidity, and light are three important environmental factors that poultry farmers want to monitor. Temperature is especially challenging in SSA, where summer temperatures can reach over 50°C, 22°C higher than the average temperature. These findings inspired the design of NkhukuProbe—a low-cost sensor-based technology probe that allows poultry farmers to monitor their coops' environmental conditions. Previously proposed sensor-based systems have automatically modified coops by opening windows and activating fans when poor environmental conditions arise (Phiri, 2018). However, each coop is different, so creating such a system often requires specially selected equipment for mechanical actuation. Instead, NkhukuProbe provides real-time data and alerts to poultry farmers through a USSD service so that they can take action to adjust the coop conditions themselves. I deployed NkhukuProbe in 15 Malawian homes for one month. I used a combination of observations, diaries, interviews, and data logging to learn about participants' experiences using the probe.

Findings suggest that NkhukuProbe can support participants in monitoring their chicken coop conditions, such as temperature, lighting, and humidity. This presents an opportunity for poultry farmers to save time and resources that are used in poultry farming. A reduction in the use of poultry farming resources like charcoal, also potentially reduce harmful environmental impacts associated with poultry farming. NkhukuProbe did not replace participants' existing poultry farming practices, but rather reinforced them by providing awareness benefits to participants.

The technology probe's open-ended design inspired participants to think about other ways of improving environmental conditions in their chicken coops, like inspecting their coops' roofing to identify leaks that might affect humidity. Further, NkhukuProbe allowed participants to experiment with it, demonstrate it to their neighbors, and use it beyond their chicken coops. These capabilities unveiled further opportunities for using sensor-based technologies in SSA homes (e.g., sensors as a platform for teaching poultry farmers). These findings directly relate to my research questions as they provide participants' reflections on using sensors and how they want to use sensor-based technologies in their homes.

Unlike in the two previous studies, participants in this study did not use NkhukuProbe to monitor other family members' activities. This distinction might be because Nsaru and all other parts of central Malawi is predominantly matrilineal; that is, women are more powerful than men (Phiri, 2009). As this was not this dissertation's goal but rather one of the unintended outcomes, future research should consider doing more research in patriarchal and matrilineal settings to understand how these existing socio-cultural norms influence the use of sensor-based technologies.

The rest of this chapter is structured as follows: I first describe participants in the pilot study followed by key findings that informed the design of NkhukuProbe. Next, I discuss how

NkhukuProbe was designed followed by a section on how the COVID-19 pandemic influenced the approach I used to deploy NkhukuProbe. Then, I describe the study context and participants' demographics. Following this, I present findings from NkhukuProbe's deployment. I end this chapter with a summary.

6.1 Formative Research

To understand the domain of poultry farming, I conducted pilot interviews with poultry farming researchers at Michigan State University. Specifically, this was done to understand the factors that influence poultry health, the tools that farmers use in Malawi to support poultry farming activities, and how sensors are currently being used in poultry farming. Since the COVID-19 pandemic made it challenging to conduct interviews with poultry farmers in SSA, I interviewed eight poultry farming researchers at Michigan State University who have conducted research in SSA, specifically in Malawi, Nigeria, and Tanzania. Three of these participants had PhDs, two were graduate students, and three had master's degrees. The interviews were held over Zoom and each one lasted approximately 45 minutes.

6.2 Formative Study Findings

Findings from the pilot interviews suggest that temperature, lighting, and humidity are the three conditions poultry farmers monitor. Participants said that rising temperature and humidity can lead to an increased prevalence of heat stress in chickens. Specifically, high temperature that is accompanied by high humidity increases heat stress in chickens more than high temperature with low humidity. Participants also frequently commented on the significance of proper lighting for inspecting their chickens and maintaining the chickens' daily cycle. Poultry farmers will typically keep their coops lit during the day (9:00 am–4:00 pm) so that their chickens can eat. After 4:00 pm, the lights in the coops are dimmed to encourage the chickens to rest. Chickens have different feeding requirements depending on their size, so it is important that the farmers regularly check the growth of their flock in order to adjust both their feeding and sleep schedule.

Poultry farmers in SSA have different strategies for controlling these conditions in their chicken coops. These strategies include opening their coops' windows to increase air circulation, putting wet blankets in the coop to absorb heat, planting trees around the coop, adding leaves under the coops' roof, reducing the number of chickens per coop, and taking chickens outside a coop to bask in the sun. These strategies are not generalized across all poultry farmers: each poultry farmer might use a strategy that is different from another farmer. These findings suggest that every coop is different; designing a fully automated system that controls chicken coop conditions might not work in some chicken coops. Participants also emphasized that electricity consumption should be taken into consideration when designing technology for poultry farms in SSA. Participants suggested making the system solar-powered to provide at least enough power to periodically activate sensors that monitor chicken coop conditions and provide feedback to farmers.

Despite the importance of temperature, humidity and lighting, participants said that poultry farmers in SSA do not have proper tools to help them anticipate when to apply control measures, particularly during adverse conditions. These challenges and opportunities provide design guidelines for the probe I developed and deployed to answer my research questions in the introduction. The different configurations in poultry farms informed my decision to design a sensor-based technology probe that captures temperature, humidity, and lighting conditions then provide feedback to farmers. This feedback would prompt poultry farmers to use their traditional mechanisms to control chicken coop conditions.

6.3 NkhukuProbe's Design

Existing sensor products often require Internet access and a smartphone app to retrieve data, making them inaccessible for rural Malawian farmers. Just 16.4% of the population has access to the Internet, and only 7% of the population own a smartphone (Malawi National Statistical Office, 2019; Marron et al., 2020). I used formative research findings to inform the design of NkhukuProbe as seen Figures 18 and 19. Below, I describe the probe's features and how the probe was designed in Malawi for rural poultry farmers.

Figure 18 NkhukuProbe hardware

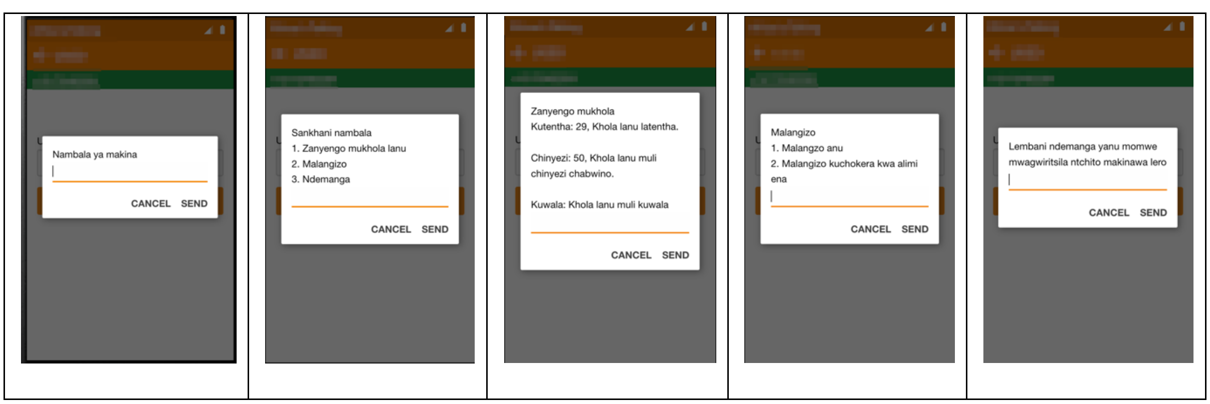


Figure 19 NkhukuProbe USSD user interface in Chichewa (Malawi's native language). A user enters a device ID then continuously selects a menu to view chicken coop conditions.

6.3.1 Constructing KhukuProbe

I remotely collaborated with local Malawians via Zoom to design a probe that met local aesthetic preferences and functional requirements. The local team included two local research assistants (a computer science student from the University of Malawi, an agriculture extension officer from The Farm[7]), and three local technicians (an electrician, a carpenter, and a painter). Each technician was paid 43,000 MWK ($55 USD). I worked together with the local research assistants to develop NkhukuProbe's software. The local technicians were responsible for procuring locally available materials to design and construct the probe's housing. The housing was made out of plywood since it was widely available in the area. The housing was painted brown to match the color of other furniture items in Malawian homes, which are typically made of wood. Holes were added to the housing to facilitate heat dissipation for the internal electronics. The local technicians soldered electronic components together, assembled the hardware, and tested the various components. Lastly, the research assistants and technicians tested NkhukuProbe using the local GSM and USSD network that would also be used by poultry farmers.

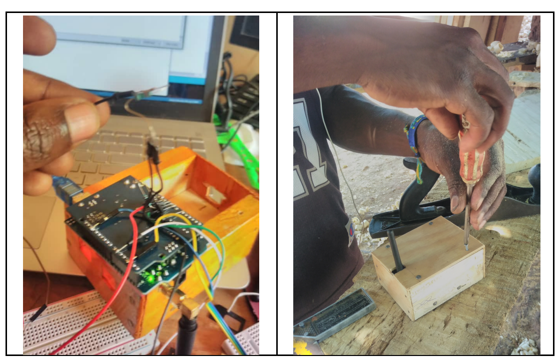


Figure 20: Working with local collaborators to design NkhukuProbe Housing

[7] The farm is an organization that partners with smallholder farmers by providing farmers with a livestock production bundle that comprises financing in the form of high-quality agricultural inputs, training on livestock production and farm management, veterinary services that ensure quality control and a guaranteed competitive price market for all the farm produce. The organization's goal is to provide farmers with a livestock bundle that includes agricultural inputs (e.g., day-old chicks), training on livestock production and management, veterinary services, and a competitive market for farmers to sell their produce. https://www.f6s.com/thefarmmw/about.

6.3.2 System Overview

NkhukuProbe had two primary components: a sensor hardware and an USSD mobile application. The main hub for the sensor hardware was an Arduino Uno micro-controller (5V operating voltage and 50mA direct current). The components connected to the micro-controller included a DHT11 temperature and humidity sensor, a photoresistor for measuring light, and a red light-emitting diode (LED) for communicating system status. The probe's control box was powered by a solar battery, lasting up to 30 hours with a full charge. Since 61% of the population owns a basic mobile phone, I designed NkhukuProbe to access the Internet via the widely available Global System for Mobile Communications (GSM) network (Marron et al., 2020). Therefore, the hardware also included a SIM900 GSM shield for transmitting data. The SIM card that accompanied each GSM shield was loaded with 4,000 MWK ($5 USD) worth of Internet data.

NkhukuProbe leverages the GSM network's Unstructured Supplemental Service Data (USSD) for communication, since USSD is supported by feature phones. SMS notifications were also considered, but findings from prior research suggested that rural farmers would find SMS notifications annoying (Chidziwisano & Wyche, 2018). By using USSD, the mobile app served as an interface for farmers to monitor their coops' conditions in real time whenever they saw fit. The app was developed using the AfricaIsTalking API[8], which supports USSD app development using PHP to connect to a MySQL server that hosts sensor data from the hardware.

The cost of manufacturing each probe was $75. This included $20 for an Arduino micro-controller, $25 for a GSM shield, $20 for a solar power battery, $7 for housing, and $3 for a

[8] https://africastalking.com/ussd

DHT11 sensor. The total cost of NkhukuProbe is significantly lower compared to other off-the-shelf products, such as “LoRaWAN”, which costs $999 (IoTNVR, 2021). This makes NkhukuProbe affordable compared to existing sensor-based systems for monitoring chicken coop conditions. There are also possible ways to reduce the cost when developing NkhukuProbe for commercial purposes. These include using lower cost micro-controllers such as Arduino Nano Every, which costs $12 (Arduino, 2021; Kurniawan, 2019), as well as establishing contract agreements with third part service providers like local technicians.

6.4 NkhukuProbe Deployment

In this section, I describe the context in which I deployed NkhukuProbe and the data collection methods I used to understand the rural poultry farmers’ reflections on using sensor-based technologies. I deployed NkhukuProbe in 15 Malawian homes for one month during December 2020. The goal of the deployment was to field-test the probe, understand how participants could use sensors to control chicken coop conditions, inspire participants to think of other ways to use sensors, and to explore participants’ reflections on using sensors to support their poultry farming activities.

6.4.1 COVID-19 Pandemic Influence on this Research

This study was conducted during COVID-19 pandemic, specifically, from August to December 2020. The COVID-19 pandemic influenced the study design of this project because I was not able to travel to Malawi to conduct this study. Thus, I partnered with The Farm which provided agricultural extension officers and participants for my research. Agricultural extension officers were useful for the project because they already had a good rapport with participants in the study, and they also helped with conducting the interviews. I also collaborated with a computer science and physics undergraduate student from the University of Malawi who worked as a research assistant for the project. The research assistant worked hand in hand with agricultural extension officers in the field.

I worked with the research assistants remotely on weekly basis to provide guidance and track project progress. During the first week we conducted qualitative methods and research ethics training sessions. The training took place for two days via Zoom. On the first day, I introduced the project and focused on data collection using qualitative methods. More specifically, we discussed best practices when conducting qualitative research. The best practices included building a rapport with participants, taking field notes, understanding how researchers' roles might impact participants' feedback and more. Further, we discussed how to collect data using specific qualitative methods, like observations, diaries, and interviews. I emphasized the importance of documenting observations using field notes and pictures. Then, we practiced the interview protocols (see Appendix C2) that were developed as data collection tools from participants. During the practice sessions, I encouraged the research assistants to probe for more feedback, pause, and give more time for participants to provide in-depth answers.

On the second day of the training sessions, we focused on research ethics. First, I discussed with the research assistants how to obtain informed consent before involving anyone in the study. We used the study's consent form (see Appendix C1) to demonstrate the process of obtaining oral consent from participants. Following this, I presented important guidelines for the responsible conduct of research. These included the following principles: honesty, integrity, confidentiality, openness, and respect for colleagues.

The research assistants were also required to obtain a certificate from MSU IRB. To do this, I requested temporary MSU accounts for them to participate in the Human Research

Protection (HRP) training provided by MSU IRB. They successfully completed their training and provided their HRP certificates as a proof. Following this, the MSU IRB approved my study.

6.4.2 Study Context: Nsaru, Malawi

This study took place in Nsaru, Malawi (Figure 21). This location was chosen for three reasons. First, prior research suggests that Malawi is one of the countries in SSA that experiences low poultry production due to climate change (Beesabathuni et al., 2018; Maganga, 2013; Moshin et al., 2009). Second, it was easier to find research assistants in a country I have lived in for over twenty years. Lastly, according to Malawi's National Statistical Office (NSO), 84% of the population lives in rural areas (Malawi National Statistical Office, 2019).

People living in Nsaru practice a variety of income-generating activities including growing crops (e.g., maize, tobacco, and groundnuts), rearing animals (e.g., chickens, cattle, pigs, and goats), running small-scale businesses (e.g., selling groceries), and working in civil services (e.g., teachers and clinicians). Despite these income sources, poultry farming is considered an ordinary home activity.

Comparable to the general population in Malawi, 80% of the residents of Nsaru have access to the local cellular network (Marron et al., 2020). However, only 11.4% of the population are connected to the national electricity grid; the rest of the population uses solar (6.6%), battery (52%), paraffin (1.7%), candles (6.2%), firewood (4.4%), grass (2.1%), and other power sources (14.8%) (Malawi National Statistical Office, 2019).

Figure 21: Map of Malawi, depicting Lilongwe; a district where Nsaru is located.

6.4.3 Participants

I worked closely with two agricultural extension officers associated with The Farm and the two local research assistants to identify participants, schedule appointments, and assist with in-person enrollment. I recruited participants using purposive sampling (Blandford et al., 2016), selecting poultry farmers who had at least one mobile phone within their home. From The Farm's pool of 67 beneficiaries, I enrolled 15 homes. During the deployment, I primarily interacted with the heads of each household as shown in shown in Table 4.

Table 4: NkhukuProbe participants' demographics

ID	Age	Gender	Home Size	# of Chickens
1	22	Male	8	120
2	38	Female	8	45
3	40	Male	6	80
4	33	Female	3	63
5	27	Female	10	32
6	22	Female	5	109
7	31	Male	5	69
8	36	Male	5	24
9	52	Female	8	180
10	21	Male	3	166
11	25	Male	6	148
12	40	Female	12	79
13	33	Female	4	23
14	54	Female	8	150
15	37	Male	6	56

Participants lived in extended families that consisted of 3–12 members, and their coops held between 20–300 chickens. Those who had more than 150 chickens generally practiced poultry farming as a group by collaborating with their neighbors. These groups had one chicken coop at one of the member's home, then shared responsibility of who takes care of chickens each day. The poultry farmers were told that their participation was voluntary, and that all information would be anonymized. Participants were paid 2,000 MWK ($2.50 USD) for their time during the initial visit and they were paid an additional 2,000 MWK every week to encourage them to write their experiences in their diary. At the end of the study, I paid participants 2,000 MWK as compensation for completing the study, and they were also allowed to keep the solar charger (valued at $25) that was used to power the probe.

6.5 Findings

Here, I present findings from the deployment of NkhukuProbe. First, I provide descriptive statistics about participants' interactions with NkhukuProbe. These statistics include how often participants interacted with the probe on daily basis and over time. Then, I present findings that provide answers to my research questions about the role of sensor-based technologies in Malawian homes and participants' reflections on using them in their everyday activities.

Specifically, I focus on how NkhukuProbe affected participants' poultry farming practices and other ways they incorporated NkhukuProbe into their everyday routine. Findings suggest that participants found NkhukuProbe useful to monitor their chicken coop temperature, humidity, and lighting conditions, identify risk factors for poultry farming, and think about other ways of utilizing sensor-based technologies in their homes. Further, participants reflected on how NkhukuProbe can be used for other activities in their homes; for example, they experimented with NkhukuProbe in their bedrooms thereby practically thinking more about other ways of using sensors to support their domestic activities.

6.5.1 NkhukuProbe's Deployment Findings

Over the course of four weeks, participants used their mobile phones to access data from their NkhukuProbe a total of 1072 times, roughly an average of 34 server requests per day from all participants. This suggests that participants interacted with the probe on daily basis. Logged data also suggest the server collected 29101 data points (temperature, humidity, and lighting logs) throughout the deployment period. I found that the poultry farmers did not only use their NkhukuProbes to check on the environmental conditions of their chicken coops, but also for other uses in and around their homes. I now present detailed reflections of these interactions.

6.5.2 The Role of Sensors in Supporting Domestic Activities

6.5.2.1 Monitoring Temperature, Humidity, and Lighting Conditions

All participants said that they used NkhukuProbe to monitor the temperature, humidity, and lighting conditions in their chicken coops. Nine participants relied on the temperature information to determine when they needed to take action to lower the temperature of their coop, while seven participants said that they used the temperature information to decide whether they needed to light a charcoal oven or not:

> "The sensor helped me to know the temperature conditions of my coop. When I see that it is too high, I was aware that I need to open the windows. When it's the temperature was low, I was also aware that it's time to light my charcoal stove and put it inside the coop."

By knowing when it was unnecessary to use a charcoal oven, participants noted that they were able to save money through efficient use of their charcoal supply. Data from diaries (Figure 22) suggest that real-time chicken coop conditions encouraged them to clean their chicken coops often. They said that they used humidity as a signifier that their coop required cleaning. Six participants used the humidity information from NkhukuProbe to determine when the floor of their coop was too wet. In response to those situations, the poultry farmers would either clean their chicken coops or open windows to provide ventilation (unless heat needed to remain inside the coop), as told by one participant:

> "Sometimes the sensor was showing that there is high humidity in the coop. I have some basic knowledge and I know that humidity is associated with water vapor. I thought the floor of my chicken coop was wet too. So, that prompted me to clean my coop to keep it dry. That was helpful because after some time I could notice that the coop's humidity has reduced."

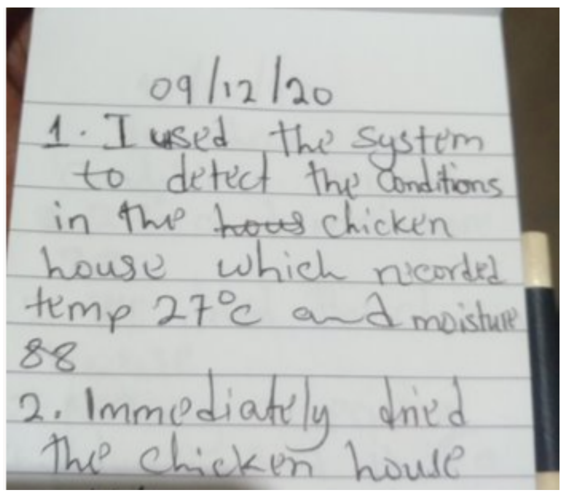


Figure 22: Participant diary entry describing how she used NkhukuProbe to keep her coop dry.

We also found that participants experimented with NkhukuProbe in their chicken coops. Even though research assistants verified that NkhukuProbe was functioning properly before leaving the poultry farmers' homes, participants still conducted their own experiments to convince themselves that it was working. These experiments were often based on the farmers' own observations or information that extension officers had shared with them. For example, one poultry farmer explained how they observed the arrangement of chickens in their coop to validate the temperature monitor:

"The extension officers conducted a training where they told us that when it's hot, chickens are scattered, and when it's cold they are close together. I was using these things I already know to see whether the probe is working properly. I noticed that when the temperature is too high, the chickens were scattered around the whole coop only to come together when the temperature goes down."

Participants infrequently used light measurements from NkhukuProbe. Four participants remarked that the light data helped them realize that their coops were not lit for a sufficient amount of time. This discovery was most common among poultry farmers whose chicken coops had small windows that could not be opened. Two of these participants, who had no electricity, said that the data from NkhukuProbe prompted them to let their chickens bask in the sun for a longer period of time. These findings suggest that providing information about chicken coop conditions is helpful, because it allows farmers to take necessary measures to maintain optimum conditions for their chickens.

6.5.2.2 Automating Non-Digital Poultry Farming Equipment

Though participants found the information from the probe useful, they also thought about how it could be improved to effectively support poultry farming activities. The probe allowed them to think beyond its capabilities. I designed NkhukuProbe to monitor, rather than adapt, the environmental conditions within chicken coops due to the poultry farmers' limited resources (e.g., electricity, hardware) and the diversity of their coop designs. Nevertheless, ten participants said that they wished that their NkhukuProbe could modify the configuration of the coop on their behalf. In fact, three participants mentioned that their neighbors asked them if NkhukuProbe had such functionality:

"My neighbors asked me what the system was. So, I explained that is used to monitor temperature, light and humidity in my khola [chicken coop]. They asked me whether the sensor is able to self-adjust conditions whenever there are changes in temperature. I felt that it would really be useful if it could control things by itself."

Requiring additional equipment, such as fans and servomotors, would introduce additional points of failure and impose long-term costs on poultry farmers due to maintenance requirements. Prior work has encouraged researchers to develop technology that supports existing practices within users' own contexts (Gulia et al., 2020); in the case of rural poultry farming, these existing practices involve non-digital equipment like charcoal stoves and windows. Building on this prior research, the discussion proposes ways of integrating non-digital equipment with sensors.

6.5.3 Participants' Reflections on Sensors

Before deploying NkhukuProbe, all participants said that they have not used sensors to support their domestic activities. Data from the diaries suggest that the deployment of NkhukuProbe provided a way to introduce participants to sensors and understand their reflections about how they could be used for their everyday activities. NkhukuProbe was not only used in chicken coops, but also within farmers' homes, as seen in Figure 23. Seven participants said that they used NkhukuProbe to monitor the temperature and humidity conditions in their bedrooms. For example, one participant noted:

> "I like exploring new things. Some days, I was just interested to use the sensor in my main house. I took it to my bedroom and check temperature conditions. It just gave me a sense of how hot the room is. That helped me open the windows when it's daytime but at night, I cannot open the windows. If I had electricity connection, I would have bought an electric fan to use at night…I think there is more a sensor could do. For example, I wish there was also a way to know whether there is fresh air in my bedroom."

Figure 23 NkhukuProbe in one of my participants' home

Another participant who used NkhukuProbe in their bedroom noticed that the humidity would rise in the morning. After investigating the structural integrity of the wall and roof, he noticed that there were small holes along the edges that were causing humid air to enter his home. Although NkhukuProbe did not help him to solve the problem, it was helpful to identify areas that required maintenance within his home.

NkhukuProbe's open-ended design allowed participants to perceive other ways sensors can be used to support domestic life, including air quality monitoring. These reflections led to an understanding of potential areas for using sensors in Malawian homes.

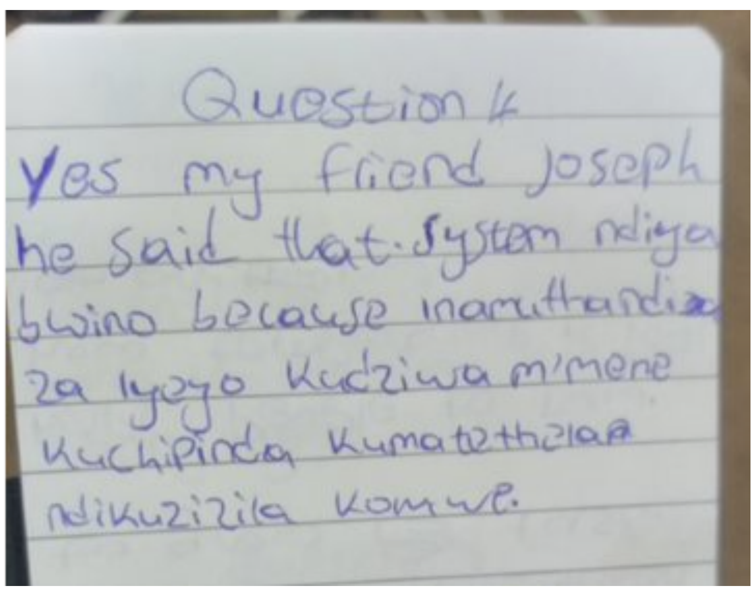


Figure 24: Participant diary entry describing how her friend used NkhukuProbe to know temperature condition in her room.

6.5.3.1 Probing Poultry Farming Risk Factors

Data from the follow-up interviews and diaries suggest that participants used NkhukuProbe to learn about how temperature, humidity, and lighting conditions affected their poultry's health and egg production. This was particularly true among the poultry farmers who had gone through more formal education[9]. For example, one participant used NkhukuProbe to diagnose a sudden catastrophe within his flock:

> "What had happed was that quail had just hatched over a hundred chicks and I left them in a brooder. Later in the morning, I found that most of the chicks had died. So, I wondered what had happened. Last time I checked they were all okay. So, I used the sensor to check what had happened, so I realized that temperature was the problem. The temperature was so low. The heater wasn't really heating, and it was cold inside. So, if it wasn't for the sensor, I wouldn't have known what had happened and I could have lost all of the chicks. I had put about 400 chicks in the brooder and about 270 died."

In cases when participants did not feel confident in interpreting the data for themselves, they turned to family members, friends, peers, and extension officers to help them interpret the data, as explained by another participant:

> "Previously they used to lay about 40 eggs per day but then there was a sudden drop in the numbers to about 18 eggs and other times about 12 so I was wondering why there was such a drop. My son, who is attending a business college, asked me to show him the diary where I was recording my experiences using the system. He checked temperature, humidity and lighting for each day and the number of eggs laid. He told

[9] At least secondary education, equivalent to grade 12 in the US education system

me that it looks like during days we had high temperature; chickens laid few eggs. We called the extension officer and he advised us to replace the small windows with bigger one. We did this, and since that time, chickens are laying more eggs."

These findings demonstrate the various ways participants used the information provided by NkhukuProbe. These ways were influenced by the specific problems they encountered in their chicken coops. Further, this information appeared to encourage conversations between poultry farmers and agricultural extension officers. This suggests an opportunity to use the data as teaching material for poultry farmers.

6.6 Summary

This study offers evidence that sensor-based technologies can support poultry farming activities in Malawi. While prior research suggest that sensors can automate digital equipment (Phiri, 2018; Phiri et al., 2018), it is not clear how they can support poultry farming practices. Participants' interactions with NkhukuProbe generated detailed findings on their day-to-day poultry farming activities. Further, these findings suggest the potential of using sensor-based technologies to save time, resources, and the environment.

My findings deepen HCI, ICTD and UbiComp communities' understanding of using sensor-based technologies to support poultry farming activities. Further, NkhukuProbe inspired participants to imagine novel ways to use sensor-based technologies in their homes. The use of NkhukuProbe in Malawi opened new opportunities for studying sensor-based technologies in Malawi.

Contrary to studies presented in Chapters Four and Five, participants in this study did not use NkhukuProbe to monitor other members in their homes. This difference is attributed to matrilineal norms which guide peoples' relationships in homes. Further, this difference might also be due to the nature of the probe that was deployed in Malawian homes. The discussion in

Chapter Seven focuses on implications for designing sensor-based technologies to support domestic activities in Kenya and Malawi.

CHAPTER SEVEN: DISCUSSION

In this chapter, I focus on broader implications of using sensor-based technologies to support activities in some Kenyan and Malawian homes. I use this chapter to discuss how these findings answer the research questions laid out in the introduction: What is the role of sensor-based technologies in supporting domestic activities in Kenya and Malawi?; and What are the reflections of people in Kenya and Malawi about using sensor-based technologies to support domestic activities? I found that using the technology probes method provide opportunities for participants to reflect on the role of sensors in their homes. Participants' reflections on the probes suggest different roles sensor-based technologies can play including monitoring utilities and poultry farming tools, saving participants' time and resources, and supporting collaborative practices and occult practices. These roles represent different functional relationships between participants and the probes; that is, the probes allowed participants to take different actions that supported these needs. These actions were not only interpreted through participants' minds, but also through a distributed hermeneutic process that included different elements, such as culture, resources and other members in their homes.

My findings suggest that there are opportunities for developing sensor-based technologies for domestic use in Kenya and Malawi. I discuss how my three studies extend prior work in HCI, ICTD, and UbiComp. A key contribution of this dissertation is how the empirical evidence in my findings draw attention to future opportunities in HCI for designing sensor-based technologies in these countries' domestic spaces. In all three studies, participants reflected on how sensor-based technologies could be useful in their everyday activities.

The rest of the chapter is structured as follows: I discuss the value of using technology probes in Kenyan and Malawian homes to demonstrate how the technology probes method allowed participants to think of different ways sensor-based technologies can be used in their homes. My findings suggest that participants used the probes based on their existing practices, so I also discuss the need to embrace perspectives from the Global South in HCI.

Then, I discuss my collaboration with local technicians, in which I used local resources to design sensor-based technologies. The collaboration provided a way to understand participants' reflections about designing sensor-based technologies with local resources. Following this, I discuss how HCI's design methods can be used to integrate sensor-based technologies with existing non-digital products in Kenya and Malawi. Based on my findings, the probes seemed to support participants' intent to save time and resources. So, I discuss how sensors can be designed to support these intentions in some Kenyan and Malawian homes, and how to integrate them for whole household access and control. My research findings also suggest that sensors can potentially support collaborative practices among neighboring homes, so I discuss the role of sensor-based technologies in supporting existing community practices.

Though sensor-based technologies can potentially support various activities in these homes, I found that they can also affect women's privacy especially in homes that are guided by patriarchal norms. Therefore, I conclude with a discussion on the need to design these technologies while being aware of privacy issues that might arise due the introduction of sensors in homes that are guided by patriarchal norms.

7.1 The Benefits of Technology Probes

One of my research questions is aimed at understanding the role of sensor-based technologies in Kenyan and Malawian homes. Before the deployment of the probes, participants said they had no knowledge of sensor-based technologies. Although a few mentioned incubators, heaters, and light bulbs as familiar technologies, nobody mentioned thermometers, home assistants, home security systems, or energy monitors. Despite their lack of awareness of sensor-based technologies, participants seemed excited by their potential and provided suggestions on how sensors could be used in their homes. Participants' thoughts about the probes' relative advantage encouraged them to frequently discuss sensors with their neighbors, and they consistently inquired whether there were extra probes to share. This is aligned with prior research that suggest that an innovation will experience an increased rate of diffusion if users perceive that the innovation provides benefits in their lives (Dearing, 2009; Surry, 1997). Participants' discussions with their neighbors supported distributed cognition theory which claims that cognition should be understood as a distributed phenomenon involving different entities outside the human brain (J. Hollan et al., 2000). These entities included participants, their family members, and neighbors whom they interact with on daily basis. The hermeneutic process of the probes motivated participants to reflect on their situation and actions thereby extending their understanding of the role of sensor-based technologies in their homes.

Findings from the three studies suggest that participants were able to use the probes for different purposes. Following Hutchinson et al.'s (2003) research, I did not specifically tell participants what to do with the probes; rather, I told them what the probes could do (e.g., M-Kulinda detects motion and sends an alert to user's mobile phone). The choice of how to use the probes was up to participants, who then provided their reflections about how the probes fit within their lives. Here, I discuss the benefits of using this method to conduct HCI/ICTD research in Kenya and Malawi. Specifically, I discuss how the technology probes method provided flexibility, encouraged learning, and inspired participants to think more about sensors.

7.1.1 The Technology Probes' Method Provided Flexibility

The probes' flexibility to adapt to different activities in the home allowed me to learn about participants' everyday lives, including the economic challenges they face. For example, participants adapted GridAlert to monitor power usage in their homes (e.g., scheduling GridAlert to switch off security lights in the morning). GridAlert worked as a technology probe—

unveiling other ways sensors could be used in Kenyan homes. It was beyond my expectations that participants would use GridAlert to monitor and control the amount of time their kids spent watching television. Wallace et al. (2013) described probes as tools for design and exploration centered on personal significance. Participants' interactions with GridAlert captured rich inspirational reflections for designers. This study therefore provides designers with novel ideas for future sensor-based technology applications that meet users' practical needs.

Similarly, in the M-Kulinda study, participants used the probe to solve whatever challenge they were facing. For example, participants used the probe to monitor different things, ranging from poultry to consumer electronics, to the behavior of their children. This was possible because the probe was not made to monitor a specific thing in the home; instead, it could monitor anything that participants wanted to protect.

The probes' flexibility allowed participants to experiment various ways of adapting sensors to support their everyday activities. Participants who used NkhukuProbe in their main house wanted to use sensors to monitor air quality. Participants also expressed interest in using sensors to diagnose diseases in their chickens, instead of relying on infrequent visits from agricultural extension officers (Zwane et al., 2017). Participants seemed to believe that sensor-based technologies could be used to detect abnormal sounds, like coughs, produced by their chickens. Knowing the type and frequency of chickens' sounds would be enough for a sensor to detect abnormalities, alert the farmer that there is an issue with their flock, and possibly forward this information to an extension officer so that they could prioritize visiting that farmer sooner. Though numerous researchers (Moore et al., 2018; Rai et al., 2017) have explored the application of sensors to solve these particular issues, these studies have mostly taken place in industrialized countries. While researchers have started exploring this area in SSA (Gulia et al., 2020), most solutions are proposed at a regional scale. These studies provide a foundation for future research at the household level where users have more control of their equipment.

7.1.2 Technology Probes' Method Encouraged Learning

Another benefit of using the probes was that they provided a way for participants to learn more about activities of their specific interest. Similar to Dema et al. (2019), my findings suggest that data provided by the probes triggered learning within households and small groups. These findings support prior works' finding that sensors foster engagement by encouraging users to discuss their local environment and how technology can support their activities (Dema et al., 2019; Moore et al., 2018; Segura et al., 2019). Poultry farmers who had little experience contacted other family members, neighbors, and extension officers to seek advice. NkhukuProbe's data encouraged poultry farmers to engage in conversations with agricultural extension officers to learn more about proper practices.

Prior research suggests that participants do not have sufficient access to extension officers (Beesabathuni et al., 2018; Maganga, 2013; Tebug et al., 2012). This is because most of poultry famers live in rural areas, which are resource constrained; that is, they tend to have poor road networks, low literacy levels, limited electricity connection, and insufficient social service, such as veterinary services for their domestic animals (The World Bank, 2016; Zwane et al., 2017). These factors make it difficult for extension officers to reach rural areas. My studies suggest the possibility of using real-time data from sensor-based technologies to increase interaction between poultry farmers and agricultural extension officers.

7.1.3 Technology Probed Allowed Participants to Think More About Sensors

My technology probes prompted participants to imagine different ways to use sensors. Unlike prior studies that deployed technology probes in industrialized countries (Brereton et al., 2015; Hutchinson et al., 2003; W. Odom et al., 2014), I deployed these probes in Kenya and Malawi.

By doing so, my findings provide novel ideas about how sensors can be used in Kenyan and Malawian homes. Emerging designs from studies that have used technology probes in industrialized countries centered around using technology to support family coordination (Brereton et al., 2015; Hutchinson et al., 2003), playful interaction (Segura et al., 2019), and slow technology (technology aimed for reflection during moments of mental rest) (Hallnäs & Redström, 2001; W. Odom et al., 2014, 2019).

On the other hand, emerging design ideas from my deployments provide design opportunities that are specific to Kenyan and Malawian homes, such as integrating sensors with non-digital materials in homes. These ideas were generated through participants' interactions with the probes within their contexts that constituted their cultural and social practices as well as the materials they use everyday. Indeed, it is important to deploy technological artifacts in participants' natural setting environment to facilitate distributed cognition processes that provide useful implications for designing technological solutions (J. Hollan et al., 2000; Zimmerman & Forlizzi, 2007). This approach to design research ensures a final technological solution is compatible with peoples' existing practices thereby increasing its adoption rate (Dearing, 2009).

7.2 Embracing Perspectives from the Global South in HCI

The studies presented in this dissertation suggest that participants' use of sensors in their homes was guided by their existing culture. This is aligned with other studies that have shown that culture influences how people adopt and use technology (Ahmed, Hoque, et al., 2017; Baker et al., 2007; Kusimba, 2018; Loch et al., 2003). HCI researchers have called for the design of new technologies that sustain existing local practices (Rodil et al., 2014; Winschiers-Theophilus & Bidwell, 2013). Doing so requires incorporating marginalized perspectives that are significant and influence people's practices in SSA.

The ways participants interacted with the probes prompted them to think about how sensors could be used to support their existing beliefs such as exploring whether sensors could detect witchcraft. These reflections are beyond the scope of research on the capabilities of sensors, and they have been under-appreciated in HCI. However, participants' curiosity about them presents new opportunities to expand existing research on sensors.

Beliefs about witchcraft in SSA have continued to thrive during the postcolonial era (Redding, 2019). Though it is novel to think of advancing the application of sensors in the direction of witchcraft, it is not uncommon. Researchers within HCI recognize the value of accommodating occult practices from the Global South as a platform for combating ideological hegemony in the field (Sultana & Ahmed, 2019). My research extends existing work in HCI by illuminating how participants in Kenya and Malawi would use sensors to support their occult practices. The studies in this dissertation practically demonstrate that participants in Kenya and Malawi are interested in using sensors to justify their beliefs that have for so long remained unproven.

Embracing occult practices in HCI would provide alternative ways for people in SSA to meet their needs. People in SSA rely on witch doctors—magicians credited with powers of healing, divination, and protection against others' magic—to achieve wealth, satisfaction, health, and happiness (Sultana & Ahmed, 2019). Other than mobile phones, witch doctors rarely use modern technology to support their practices (Sultana & Ahmed, 2019). The integration of sensor-based technologies with specific activities could lead to better outcomes for these initiatives. However, there is no current research regarding sensors' capabilities and uses in occult practices, so this work proposes a design-based exploration to understand how sensor-based technologies can be used to support them.

When embracing perspectives from the Global South in HCI, researchers should be encouraged to engage local technicians and designers including electricians, technology repairers, carpenters, and painters. HCI researchers have engaged local technicians in the Global South especially mobile phone repairers (Ahmed, Jackson, et al., 2015; Jackson et al., 2010; Jang et al., 2018; S. Wyche et al., 2015). My research contributes to these efforts by engaging with carpenters, painters, and electricians to develop the technology probes.

7.3 Designing Systems Using Local Resources

Prior research has emphasized the importance of collaborating with local technicians when developing technological solutions (Klugman et al., 2019). Drawing from these propositions, I collaborated with local technicians to design the probes in two of my studies. This collaboration proved useful for configuring the probes to work in Kenyan and Malawian homes, as local technicians have a better understanding of the existing infrastructure in their community, and they provide local support. The studies suggest the importance of collaborating with local technicians, but also raise questions as to whether participants prefer using products made within Kenya and Malawi.

My findings suggest that participants had mixed reactions about using locally available resources to design the probes. Various researchers in HCI/ICTD encourage the practice of empowering local technicians to design systems using local materials including reused and broken-down materials (Ahmed, Mim, et al., 2015; Jackson et al., 2012). However, my findings suggest that participants prefer using hardware materials made abroad (e.g., U.S. and China). They find these to be attractive and well-aligned with their needs. Similarly, findings from another study that was conducted in Kenya to explore *M-Kopa*, a solar home system, suggested that participants described it as durable, able to withstand dust, contact with water, and being dropped (S. Wyche, Chidziwisano, & Uwimbabazi, 2018). Unlike GridAlert and NkhukuProbe, M-Kopa systems are designed, developed, and assembled in the U.S. This supports my finding that participants seem to prefer imported products.

HCI/ICTD researchers should investigate this topic further in order to understand whether we should encourage technicians to make products using local materials. Various scholars have proposed designing technological systems for SSA and other contexts in the Global South using locally available resources (Ahmed et al., 2016; Ahmed, Mim, et al., 2015; Houston et al., 2016). Evidence from my three studies suggest that form factor design might affect participants' reflections about the product. In the GridAlert and NkhukuProbe studies, I engaged local technicians to design the probes before deploying them in participants' homes. This might have contributed to participants' reflections of these probes as "of low quality" compared to participants' reflections in the M-Kulinda study. These conflicting findings call for thorough engagement among researchers and target users to determine what materials should be used to design sensor-based technologies in Kenya and Malawi.

7.4 Methodical Assemblages

Though participants' preferences for locally made products are not well established, some products in SSA homes are non-digital products (e.g., furniture and textiles) that are made using locally available materials (Quartey & Abor, 2011). My findings suggest that participants are interested to integrate these materials with non-digital technologies. Here, I discuss how the integration of non-digital tools with sensor-based technologies can leverage HCI methods to meet participants' reflections.

Prior research in HCI proposes a shift from designing sensing technologies to designing ubiquitous systems that incorporate traditional tools along with digital devices (Kuznetsov et al., 2011). Similarly, I propose augmenting existing non-digital tools with sensor-based technologies. Participants' interaction with their non-digital tools—like door locks, windows, and charcoal stoves—follow a logical procedure. For example, when there is a blackout, at night, people switch on their alternative source of light (e.g., a torch or a candle). This follows a logical order where they start by using grid electricity then move to an alternative source of light when there is a blackout. Identifying and categorizing the order of events between power blackouts and restorations would help to automate a transition between different sources of light. HCI researchers refer to this technique as 'methodical assemblages', wherein technologies are designed by identifying categories and ordering them, where particular things routinely combine (Crabtree & Tolmie, 2016). In relation to distributed cognition, these categories should include of all important features that are necessary to complete a particular task (M. Perry, 2003). The categories are part of a distributed cognitive process, and they are organized in a particular manner to complete a specific task. In this case, the distributed cognitive process constitutes users, as actors, who follow specific steps, organized as categories, to complete a task.

Domestic life follows a local order of activities that constitutes a distributed cognitive process. For example, the M-Kulinda study demonstrated that participants rely on their neighbors to reinforce security in their homes. When people see a suspicious activity at their neighbor's home, they call household members immediately to alert them about what is going on. This commonly happens when household members are not at home. Therefore, sensors could be linked to a centralized platform where members of a neighborhood could easily receive alerts about security concerns, improving upon existing efforts and reinforcing neighborhood cohesion.

Similarly, through the NkhukuProbe study, I learned that poultry farmers first put their charcoal stove outside, add charcoal, light it, then wait until it is well lit to take it inside their chicken coop. Farmers regularly monitor their coops to see whether they should add more charcoal, taking it outside and waiting until it is well-lit each time. However, participants found this routine time consuming. Therefore, I suggest finding better ways of tracking charcoal stoves' status. For example, charcoal stoves could be augmented with sensors that track their status—whether they are well lit, whether the temperature is low, or whether they are producing carbon monoxide. This would then prompt poultry farmers to take charcoal stoves in and out of the coops while reducing the amount time they spend monitoring stoves.

From all the three studies, it is clear that most domestic activities in participants' homes happen in a specific order. By understanding the order of activities and interactions between different elements, researchers and designers can identify better ways of introducing new elements, such as sensor-based technologies, into an existing distributed cognitive process. This is important because new elements would be introduced to support domestic activities without eroding peoples' existing practices.

7.5 Saving Time and Resources

Participants' interactions with the probes allowed them to monitor different activities without being physically present. The probes appeared to save participants' time and allowed them to focus on other activities. This was possible because the deployed probes continuously monitored participants' homes against intruders, power blackouts, as well as chicken coop conditions and provided alerts to participants. This is aligned with two of this dissertation's motivations that sensor-based technologies afford real-time collection and real-time event detection (Dutta et al., 2005; H. Phiri, 2018). While sensor-based technologies have also been used to save time and resources in industrialized countries (Weiser, 1993; Yassein et al., 2016), the ways participants used them in my three studies seemed to improve their quality of life based on their specific needs. For example, a barber who used GridAlert to get notifications about power restorations reduced the amount of time lost during a period of blackouts. Similarly, participants who used

NkhukuProbe and M-Kulinda seemed to save time as well. For example, participants used NkhukuProbe to monitor their chicken coops without having to physically visit them. This allowed them to focus on other activities within their homes while having access to information about their coops' conditions. These findings suggest participants' interest to use sensor-based technologies as a time saving tool in their homes.

7.5.1 Using Sensors to Save Resources

Participants' experiences using the probes also suggest that sensor-based technologies have the potential to save resources (e.g., energy). The probes' information allowed participants to monitor and better allocate resources throughout their homes. For example, the probes allowed participants to know the proper time to switch on/off lights, use their electrical appliances, clean their coops as well as lit their charcoal burners. Thus, the probe's usefulness regarding environmental sustainability cannot be underestimated.

Prior research suggests that the use of charcoal has negative impacts on the environment (Chidumayo & Gumbo, 2013; Hobley et al., 2017). Thus, the utilization of sensor-based technologies can potentially minimize unnecessary use of resources that endanger the environment. These insights provide opportunities that draw attention to new ways to use sensors; that is, ways that have not been traditionally considered in HCI. Within HCI, sensors have been used to improve people's domestic activities in many ways including locating missing objects and utility monitoring (Kidd et al., 1999; Laput & Harrison, 2019; Park et al., 2020), but my findings extend this literature by demonstrating the potential of using sensors to reduce resource use in some some Kenyan and Malawian homes. In order to effectively save time and resource use, findings from the three studies suggest designing sensor-based technologies to monitor and control home activities at household level.

7.6 Designing for Whole Household Access and Control

As discussed in the previous section, findings from the three studies suggest that designers should consider how their systems will be integrated into existing infrastructure, so that they will be functional. It is well established in literature that not everyone in SSA has a smartphone or even a basic phone (S. Wyche et al., 2016). To account for this challenge, sensor-based systems should be accessible to household members through multiple channels. For example, the hardware should have an in-built interface for controlling the system. SMS platforms can also be utilized to provide notifications to household members who have basic phones.

7.6.1 Designing Sensors to Support Activities in Homes

Findings from these studies suggest that participants are interested in using sensor-based technologies to support multiple activities, including monitoring poultry, air quality, energy consumption as well as diagnosing the integrity of their roofing. It is costly to design independent sensor-based products that support each of these activities. Instead, I propose designing whole household sensor-based systems that can be used to serve multiple functions. For example, instead of only designing GridAlert to protect a few appliances, it should be designed to automatically protect all appliances when there is a blackout. Sensors can be integrated with a home's main switch, to protect all appliances and reduce, or even possibly eliminate, the need to switch off appliances when there is a blackout.

Whole-household power monitoring sensors have been used in industrialized countries (S. N. Patel et al., 2010). However, these systems require homes to have cable, Wi-Fi network, or computers. These resources are not available in most SSA homes (International Telecommunication Union, 2020). Clearly, because of this, the integration of sensor-based technologies in SSA homes cannot be the same as in industrialized countries. Rather, designers, engineers, and other experts should work with local technicians to explore different ways of integrating these systems.

7.6.2 Integrating Sensors with Existing Digital Tools

These studies also suggest that participants do not have enough control over existing digital and mechanical tools in their homes. In each study, I observed various digital tools participants used to support their activities like power surge protectors, incubators, digital meters, and security lights. Despite being useful, these tools did not provide any metrics on how they were working or the resources they were consuming. In the end, participants could not get enough information about these resources' energy consumption. Prior work suggests a "need for domestic devices that do not only stimulate consumption but instead offer alternatives and raise awareness" (Bell et al., 2005).

While these systems exist in industrialized countries (Dillahunt et al., 2009; Froehlich et al., 2009; S. N. Patel et al., 2010), existing digital infrastructure in SSA (e.g., M-Kopa home-based solar system see (S. Wyche, Chidziwisano, Uwimbabazi, et al., 2018)) stimulates consumption, because it doesn't provide information for inhabitants to control its consumption. I propose integrating existing digital tools with interfaces that provides users with this information. These interfaces would be used to display real-time data collected by sensors to sensitize users about how appliances in their homes consume energy. For example, providing incubator's energy consumption metrics would be useful to participants since they are interested to use these materials at a minimum operational cost.

7.7 Strengthening Neighborhood Cohesion

Other than supporting different activities within a home, my findings from the three studies also suggest that the introduction of sensor-based technologies to support domestic activities in Kenya and Malawi can potentially strengthen collaborative practices among neighboring homes. The design of these technologies should not only support whole-household access and control, but also existing community initiatives. Here, I discuss how to design sensor-based technologies in Kenya and Malawi to support neighborhood cohesion initiatives.

With a higher penetration rate of mobile phones in SSA (Kshetri, 2017; Poushter & Oates, 2015), sensor-based technologies can be easily integrated with pre-existing initiatives that aim at fostering neighborhood cohesion—trusting networks of relationships, values, and norms of residents in a neighborhood. While sensor-based technologies in homes of industrialized countries have not enhanced neighborhood cohesion (Erete, 2013), findings from my research suggest that they encourage engagement among neighbors in some Kenyan and Malawian communities. For example, participants used data from the probes to engage in discussions with their neighbors. Further, their ability to turn to their neighbors to get help in interpreting sensor data demonstrates that they can get support from their neighbors to improve their businesses (e.g., poultry farming) without the presence of extension officers who face challenges to visit rural areas.

Similarly, findings suggest that sensor-based technologies can be used to enhance existing neighborhood engagement infrastructure aimed at solving common problems. For example, participants in the M-Kulinda study suggested integrating sensors with an existing "nyumba kumi" project to enhance security measures in their neighborhood. Similarly, in the GridAlert study, participants suggested using sensors to improve power sharing measures in their communities that would reduce the frequency of power blackouts. These findings suggest that sensor applications in these homes may not only improve the quality of life in a single home, but potentially strengthen existing infrastructure for the whole community.

The ways participants used the probes to support neighborhood cohesion seemed to depend upon their interaction with other community members. Even community members who did not participate in the three studies, but had some ties with participants, influenced participants' reflections on sensors. This can be well explained using a distributed cognition notion that cognitive processes are distributed across a social group (J. D. Hollan & Hutchins, 2009). In this case, the social group consist of participants and other members of their communities. Since findings suggest that other members contributed to how participants reflected on the probes, these findings emerge from cognitive processes that were distributed within participants' social group.

7.8 Designing Sensors Applications for Privacy

While my research findings suggest potential applications of sensor-based technologies, the probes also raised some serious concerns. Prior research on sensors and privacy mainly focused on how sensor data can be used by external entities (non-family members who have access to sensor data, like companies) (Demiris et al., 2008; Reeder et al., 2020; Winkler & Rinner, 2014). However, my findings suggest that the introduction of sensor-based technologies in patriarchal homes can cause privacy issues among family members, especially women and girls.

Findings from these studies suggest that sensor-based technologies can cause privacy concerns in homes with dominant patriarchal norms. Unlike NkhukuProbe that was deployed in matriarchal homes, the deployment of M-Kulinda and GridAlert in patriarchal homes appeared to exacerbate existing patriarchal norms. These norms affect the privacy of other members in participants' homes, especially women and children. Prior work suggests that technology is an amplifier of underlying human and institutional intent and capacity (P. Agre, 1998; P. E. Agre, 2002; Toyama, 2011). Technology cannot substitute for missing institutional capacity and human intent: people will simply use it to achieve their needs (Toyama, 2011). Human intent is informed by existing culture which influences cognitive processes that are distributed among people, artifacts and the environment (J. Hollan et al., 2000). In this case, technology becomes part of a larger social system that is already defined by existing culture. While culture influences cognitive processes distributed among elements in a social system, culture itself is also a product of the interaction between people and artifacts (J. Hollan et al., 2000). In relation to this, the deployment of the probes appeared to exacerbate patriarchal attitudes. Fathers and husbands consistently used M-Kulinda and GridAlert to monitor their wives and daughters' movements without their knowledge.

These findings are aligned with other studies in HCI/ICTD. Scholars have explored the impact of mobile phone technology on women's privacy in relation to dominant patriarchal norms in developing countries (Ahmed, Hoque, et al., 2017; Freed et al., 2017; Karusala et al., 2019; Sultana et al., 2018; Vashistha et al., 2018). These studies suggest that women face challenges as they adopt mobile phone technologies, such as inadequately supporting women hoping to privately save capital for small-scale businesses (Mustafa et al., 2019). Sultana et al. (2018) proposed designing within the patriarchy; that is, empowering women within the structures of their society. However, these studies primarily focused on how mobile phone use jeopardizes women's privacy. This dissertation research extends upon these studies by understanding how sensors affect women's privacy in some Kenyan and Malawian homes.

Researchers who have studied the impact of sensors in the home found that their applications introduce new hierarchies that negatively affect other inhabitants' lives (Ehrenberg & Keinonen, 2021; Salovaara et al., 2021). The studies presented in this dissertation also support this finding; however, from a social perspective in SSA rather than industrialized countries where the other studies were conducted. Homes in SSA are predominantly patriarchal (Ali et al., 2017), so the deployment of sensor-based probes in participants' homes seemed to amplify men's power (especially head of households) to control other inhabitants in the home. For example, the probes were used to monitor other inhabitants' movements and the amount of time children spent watching television. Further, four participants, who owned grocery stores, also used the probes to monitor the time their employees arrived at work. Indeed, just like any other form of technology, sensor-based technologies have the potential to amplify existing practices (Toyama, 2011; S. Wyche et al., 2016).

7.8.1 Designing Domestic Sensors for All Household Members

It is beyond the scope of this study to understand how other household members and employees feel about being monitored using sensors. However, it is clear this is a risk that comes with the deployment of sensor-based technologies in Kenyan and Malawian homes. This suggests a need to think more about specific users when designing systems for Kenya and Malawi. For example, when designing these probes, the only user I considered was the head of household. Yet, homes are made of many family members (e.g., children), and the home as a unit of analysis has different identities that should be considered when designing sensor-based systems.

As such, feminist theories suggest that scholars should change their perspective towards the notion of 'the user' (Bardzell, 2010). Bardzell (2010) suggests that the notion of the user should be updated to reflect gender. She expressed concern over the fact that technology studies in the home have looked at the family as a unit of analysis. This is problematic as it overlooks how men and women play different roles in the home (Bardzell, 2010); the power relations between men, women, and children influence how technological systems affect households members. Failure to account for these different identities in homes (when designing systems) gives more power to the powerful (i.e., the heads of households and men). To address these issues, Bardzell (2010) proposes using pluralism—designing systems that resist a single point of view—over universalism. She gives an example of how the "World Washer" (a washing machine) designed based on universalism—to wash specific kinds of clothes—failed to work and brought frustration to south Indian women (Bardzell, 2010). When the World Washer was used in India it caused the destruction of personal property, such as women's garments, leading to user frustration (Bardzell, 2010).

Similarly, Schlesinger et al. (2017) proposed five recommendations for using intersectional HCI to better understand users' identities. These recommendations include: consistently reporting context and demographics, acknowledging limitations regarding identity, providing an author disclosure and embracing the complexity of identity (Schlesinger et al., 2017). These complexities of identity exist in my own research because different people within a home have different resources (e.g., different capabilities of mobile phones) to access the functionalities of the probes I deployed. When designing sensor-based systems for Kenya and Malawi, it is important to provide ways for all household members to access the sensors' services. Future research studies extending this topic should involve all members of households to establish how other household members perceive sensor-based applications in their homes.

CHAPTER EIGHT: LIMITATIONS AND FUTURE WORK

The work presented here has its limitations. In this chapter, I discuss these limitations and areas for future research. I discuss the methodological limitations; in particular, how the short deployment period was not enough to understand the long-term impact of sensor-based technologies. Next, I discuss miscellaneous limitations that affected sampling and deployment of the probes. I then describe future research directions to account for these limitations.

8.1 Methodological Limitations

The data collection methods I used have limitations. As I discussed in the methodology section, people's ability to self-report facts accurately through semi-structured interviews is limited (Blandford et al., 2016). My participants might not have provided all required details during the semi-structured interviews. To account for the limited information that was provided through interviews, I complemented the interviews with observations and diary studies. During the observations in Kenya, participants were aware that I was observing their homes. Similarly, in Malawi, my research assistants conducted the observations. This might have affected how they normally use/place existing technologies in their homes at that specific time. Further, these observations only took place twice: during the deployment and after follow-up interviews.

To continue documenting participants' experiences during the deployment, I used the diary study method. Prior research has also found some weaknesses in the diary method. One weakness is that in some cases participants fail to complete the diaries because they are not motivated to continue recording information until the end (Cassell & Symon, 2004). Participants may start recording data in diaries however the number of entries may decrease with time. For this reason, diaries are regarded as not good for long term studies (Richardson, 1994). Additionally, diaries can result in collecting irrelevant data especially in situations where researchers did not take enough time to design the diaries. This result in difficulties when analyzing data from diaries because they contain more data that is irrelevant (Bedwell et al., 2012). Furthermore, Bedwell et al. found that diary studies are difficult to use for collecting data in areas where literacy levels are low (Bedwell et al., 2012). These reasons might have affected the quality of data I collected using diaries.

Though my findings suggest that the deployment of the probes in participants' homes seemed to save time and resources, these preliminary results are inconclusive. This is because the methods I used cannot account for confounding variables (e.g., household income changes) that might have also influenced participants. My findings did not account for internal validity which focuses on how well an experiment is done to minimize bias (Gergle & Tan, 2014). Internal validity reduces the possibility of having more than one independent variable causing the same effect at the same time. To establish whether sensor-based technologies save time and resources in homes, specific experimental methods (e.g., randomized control trials) to determine cause and effect would be required (Angrist & Pischke, 2008). While this dissertation's goal was not to study the impact of probes on time and resources, it provides preliminary results that sensor-based technologies can potentially save time and resources in some Kenyan and Malawian homes.

Furthermore, the three studies were conducted with smaller sample sizes that were gathered using purposive and snowball sampling. Though these samples were from different study sites to account for external validity, a study without internal validity does not have external validity (Gergle & Tan, 2014). External validity the "predictive value of the study's findings in different context" (Angrist & Pischke, 2008, p. 127). While the smaller sample sizes gave me an opportunity to deeply engage with participants and generate detailed findings on their everyday interactions with the probes, their findings do not generalize to larger populations within SSA. Similar to the goal technology probes (Hutchinson et al., 2003) and other studies that have used a similar method (Brereton et al., 2015; Dema et al., 2019; W. Odom et al., 2014, 2019), I focused on smaller sample sizes to gain a deeper understanding of the study sites and issues that might require attention in future research studies.

During my field work, I primarily interacted with heads of households, most of whom were men. This made it difficult to understand other household members' reflections of using sensors. It is also not clear how these technologies impacted their daily lives. In SSA, patriarchal norms and values reinforce and sustain the low status of women in society (Ali et al., 2017). Men—especially heads of households—consider themselves superior to other household members. Findings from the three studies suggest that the deployment of sensors has the potential to exacerbate patriarchal norms. These norms guide men's attitudes, and these can violate women's privacy (Karusala et al., 2019). Yet, women's privacy needs are not well understood—especially when using domestic sensor-based technologies. This was beyond the scope of my research, so future research should focus on understanding women's perspectives and designing sensor-based technologies to better protect their privacy and meet their needs.

8.1.1 The Novelty Effect

All of my studies were conducted over a four-week period. This is a short period to fully understand the probes' long-term implications (Kjærup et al., 2021). To better understand the long-term implications of using sensor-based technologies, a longer-term study would be required. Further, the short deployment period made it difficult to understand participants' long-term experience using the probes.

Though participants in the three studies seemed excited to use the probes, it is unclear whether this experience could continue over time, because early excitement could be due to the novelty effect. Within HCI the novelty effect is defined as "first responses to using a technology, not the pattern of usage that will persist over time as the product ceases to be new" (Sung et al., 2009). As the novelty wears off, people's interest in using the technology might change based on whether or not it meets their expectations (e.g., a product not working according to user's expectations) (Kraut et al., 2000). Participants expressed interest to use the probes throughout the one-month period, however, because this could be due to the novelty effect, a long-term deployed is needed to understand their interest to continue using the probes over time.

8.2 Miscellaneous Limitations

Deploying technology probes that required participants to own at-least one mobile phone in their homes was also a limitation. During sampling, I approached eleven homes that were interested in participating but could not, because no one in their home had a smartphone. The probes also required participants to live in an area that had some GSM network coverage. Though some participants interacted with the probes on daily basis, six participants mentioned that sometimes they had network problems that made it difficult to use the probes. Furthermore, 18 participants who had no grid electricity in their homes (as in the studies presented in Chapter Four and Six) mentioned that the solar powered batteries sometimes took more than six hours to fully charge. This affected the amount of time participants interacted with the probes.

8.3 Future Work

Here, I present areas for future work that will build upon this dissertation work and address some of the limitations discussed in the previous section. More specifically, I describe how future work should consider engaging women to address privacy concerns when using sensor-based technologies in SSA households. I also describe a study design to address some of the methodological limitations of this dissertation, including the short deployment period, in order to understand participants' experiences over time. Further, participants reflections about sensor-based technologies provided numerous opportunities of HCI/ICTD research on designing domestic technology for Kenyan and Malawian homes. I also describe other potential areas for using sensor-based technology that future work should consider exploring.

8.3.1 Designing Privacy Aware Sensor-Based Technologies for SSA Homes

Findings from my research suggest that sensor-based technologies have the potential to solve some of the context-based challenges affecting these homes, such as electricity blackouts and domestic security. However, as discussed in Section 7.8, I also found that the deployment of sensors in these SSA homes can exacerbate patriarchal norms (Chidziwisano, Wyche, & Oduor, 2020; Chidziwisano & Wyche, 2018). In SSA, men—especially heads of households—consider themselves superior to other household members. The home is a primary site where patriarchal attitudes are enacted in everyday life (Bowlby et al., 1997). Patriarchal norms guide men's attitudes, and these can violate women's privacy (Karusala et al., 2019). The introduction of technology can perpetuate patriarchal attitudes and exacerbate the privacy challenges women experience (Ahmed, Haque, et al., 2017; Haque et al., 2020; E. Oduor et al., 2014). Women's privacy needs are not well understood—especially when using domestic sensor-based technologies. My future research will focus on understanding how to better design sensor-based technologies to maintain women's privacy in SSA homes.

8.3.2 Future Research Plan and Approach

To do this, I will use a mixed methods to conduct this study in two phases. In the first phase, I will conduct formative research, design a prototype, and pilot test it. I will conduct fieldwork using participatory and other qualitative methods, such as in-depth interviews, to learn about women's existing domestic activities in relation to how they experience patriarchal norms. I will conduct interviews and focus group discussions with women in rural Malawian homes (where patriarchal norms are dominant). Findings from this fieldwork will inform design guidelines for privacy-aware domestic sensor-based technologies. These interviews and discussions will not only consist of women from the households I visited, but also women and children from their neighboring homes. This will provide a different perspective that will enrich design recommendations for sensor-based technologies in these homes. Further, including neighboring family members will ensure that sensor-based technologies are designed in alignment with existing community practices, because my findings suggests that the probes were also used to support collaborative practices in these communities. I will then work with local technicians to develop a high-fidelity prototype based on these guidelines. Following this, I will pilot test the prototype in three Malawian homes for two weeks. Then, I will return to local technicians with findings from this study to iterate on prototype system design.

In Phase Two, I will conduct a one-year long-term deployment to evaluate the prototype. This would be enough time to address the short-term deployment limitation because prior studies that have used a similar timeframe to successfully understand long-term experiences of using new technologies (W. Odom et al., 2014, 2019). I will ask participants in these homes to interact with the prototype in their everyday domestic activities. The main goal of this evaluation will be to understand participants' intentions to continue using privacy-aware sensor-based applications in their households. During the evaluation, I will use a mixed methods approach (e.g., diary studies, data logging, surveys, and follow-up interviews) to collect data from participants.

During this phase, I will also conduct a randomized controlled trial (Angrist & Pischke, 2008) to establish the impact of using sensor-based technologies in participants' homes. More specifically, I will randomly assign participants into a control or treatment groups. Participants in the treatment group will receive the prototype, and I will ask those in the control group to continue using the resources they use in their homes. This will help me to address one of the limitations of this dissertation; that is, whether the sensor-based technologies improve participants' initiatives to save time and resources. Further, I will conduct Phase II of study in multiple locations within SSA in order to establish whether findings can be generalized to larger populations.

At the end of the evaluation, I will be conduct a follow-up survey in alignment with the technology acceptance model (TAM), which suggest that perceived usefulness and perceived ease of use determine people's willingness to use a technology, which further influences usage behavior (Davis, 1989). Perceived usefulness is the "degree to which a person believes that using a particular system would enhance his/her job performance" (Davis, 1989, p. 3). Perceived ease of use is the "degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 3).

8.4 Summary

Although findings from the three studies provide empirical evidence about the role of sensor-based technologies in some Kenyan and Malawian home, they had some limitations. The studies were conducted for a short period of time making it difficult to tell the long-term impact of using sensor-based technologies in these homes. These studies also had smaller sample sizes and focused on participants' pluralistic aspects of using technology to meet their needs. Further, the studies did not account for confounding variables thereby affecting internal validity. Despite conducting these studies in different field sites, these findings cannot be generalized to larger contexts because a study with no internal validity lacks external validity. These factors affected generalizing the study's findings within the field sites and other populations. However, the goal of these studies was to generate knowledge about participants' individual reflections on the probes with the purpose of enhancing technology design process. These reflections are important in HCI's early design process.

This dissertation generated numerous questions that remain unanswered. What are women's reflections about their privacy when using sensor-based technologies to support domestic activities? How can sensor-based technologies leverage machine learning algorithms to optimize electricity reliability in SSA? Do SSA inhabitants prefer sensor hardware to be designed with locally made materials or imported materials from industrialized countries? How can sensor-based technologies be integrated with existing occult practices in SSA to improve people's livelihood? These questions open-up numerous opportunities for future research. Prior research in HCI/ICTD suggest that scholars are increasingly interested in HCI research in SSA (Dell & Kumar, 2016); the emerging research ideas from this dissertation offers potential areas for them to explore. HCI/ICTD researchers should build upon this research to answer these questions and illuminate the needs and stories of people in sub-Saharan Africa.

CHAPTER NINE: CONCLUSION

Sensors are continuously revolutionizing domestic technology design. While these technologies have transformed the livelihoods of people living in industrialized countries, they have not been fully developed to meet the needs of people living in SSA homes. Further, current sensor-based products for the domestic space require infrastructure that is not widely available in most SSA homes. My dissertation was guided by distributed cognition theory and research through design methodology to investigate different ways of using sensor-based in some Kenyan and Malawian homes. This combination allowed participants to reconsider and reflect on using sensors in their everyday activities. Distributed cognition theory provided a framework for understanding participants' hermeneutic processes while using sensor-based technologies in their homes.

RtD's knowledge generating nature provided a way for me to use different design methods to collect relevant data for understanding the role of sensor-based technologies and participants' reflections about using them in some Kenyan and Malawian homes. Further, RtD's aspect of deploying technology artifacts guided the design and deployment of technology probes that were appropriate for understanding participants' experiences using sensor-based technologies in their homes. Findings from this research suggest numerous applications for sensors-based technologies in some Kenyan and Malawian homes. These applications are specific to addressing the challenges facing these homes. The implementation of these applications requires integrating existing technological infrastructure with sensors. Since most of the materials used in Kenyan and Malawian domestic spaces are non-digital, I propose using methodical assemblages when designing sensor-based technologies for these homes. This approach will encourage introducing sensor-based technologies without eroding existing practices.

In SSA homes, where social, cultural, and technological aspects of life are becoming intertwined, distributed cognition theory provides a lens for understanding participants' reflection on the role of technology in their context. This is because participants' reflections are not just informed by cognitive processes in their heads, but through a distributed cognitive process that also include their family members, neighbors, and the resources they have. This dissertation research, therefore, encourages researchers who conduct HCI/ICTD research in SSA homes to think of all members of households as participants rather than heads of households. This is important because outcomes of these kind of research projects are not just informed by participants, but they are also informed by their way of life and the resources they have in their homes.

Returning to my research questions, I make the following conclusion in answering them. What is the role of sensor-based technologies in supporting domestic activities in Kenya and Malawi? Sensor-based technologies have the potential to reduce existing challenges—including domestic insecurity, power blackout, and rising temperature conditions that affect poultry farming—facing some homes in SSA. These technologies can potentially reduce these challenges by supporting users' interest to monitor utilities and resources, save time and resources, and support collaborative practices. The deployed probes successfully supported these tasks because they afford real-time data collection and real-time event detection, they encourage engagement among users, and they are available at low cost. What are the reflections of people in Kenya and Malawi about using sensor-based technologies to support domestic activities? The technology probes method allowed participants to interact with sensors and reflect on other ways of using them in their homes. Participants' reflections on sensors suggest numerous opportunities for using sensor-based technologies beyond the domestic security, power blackouts, and poultry farming. Among others, these opportunities include using sensors to support occult practices, improve air quality monitoring as well as improve power sharing strategies within a neighborhood

This dissertation makes three contributions to the fields of HCI, ICTD and UbiComp. First, it provides empirical evidence about the potential of using sensor-based technologies in some Kenyan and Malawian homes. My findings suggest that participants are interested to use sensor-based technologies to support domestic activities, and they find different ways of repurposing them to fit in with their needs. The ways participants repurposed the probes provide opportunities and recommendations for designing domestic sensor-based technologies in Kenya and Malawi. My findings extend domestic technology research to homes that have been given less attention in HCI. Further, these findings extend ICTD research by focusing on other domains beyond traditions domains of development which are mostly studied in this field.

Second, this dissertation makes methodological contributions to HCI/ICTD by using the technology probes method in HCI's non-traditional context. While researchers in these fields have encouraged using alternative design methods in non-traditional context, few scholars have used them in SSA. My collaboration with local technicians to design the probes provides an alternative approach to designing technology probes thereby extending how technology probes have been traditionally developed. Further, the deployment of technology probes provided flexibility for participants to use them based on their unique needs. Among others, these included monitoring utilities, saving time and resources, as well as neighborhood cohesion. Future HCI, ICTD, and UbiComp researchers should further explore these opportunities and uses for probes in SSA. Finally, my dissertation contributes to UbiComp by development of three sensor-based prototypes for supporting domestic security, power blackout monitoring, and poultry farming activities. The prototypes directly contribute to UbiComp by using real-time data collection and event detection to continuously support peoples' everyday activities in some Kenyan and Malawi homes—a context that has been given little attention in UbiComp.

This dissertation also draws attention to the unintended consequences of using sensor-based technologies, especially in patriarch-headed homes. For the two studies that were conducted in dominant patriarchal contexts (Kisumu and Bungoma, Kenya), the probes seemed to exacerbate men's pre-existing practices like monitoring their wives and daughters. My findings provide preliminary evidence about the consequences of using sensor-based technologies in some SSA homes.

APPENDICES

Appendix A: Study Materials for M-Kulinda Study

Appendix A1: Informed Consent

Michigan State University, East Lansing, Michigan, U.S.
Project Title: Security System Project
Investigator: George Chidziwisano

1) CONSENT FORM

Introduction:
I am a student at Michigan State University in the United States. You have been asked to participate in this research. The purpose of the interview is to study IT based security systems in rural Kenyan households. To be clear, I do not work for technology companies. I am not here to advertise products; instead I am here to learn.

Procedures:
The name of the study is IT Based Security System for rural Kenya. If you agree to participate, you will be asked to take part in a 1 hour interview where I will ask security related questions. After the interview, I will install the security system in your house at a location you prefer. Then I will give you a diary where you will be writing your experiences with the security system. If you agree, I would also like to take photographs and make an audio recording of my interview, so that I can have an accurate record of the information you provide. I will transcribe these recordings and will keep the transcripts, as well as the photos, confidentially and securely in my possession.

Risks:
Your participation in this study does not involve any physical or emotional risk to you beyond that of everyday life.

Benefits:
Taking part in this study may help us better understand how security systems for successful use in rural Kenya should be developed.

Financial Information:
Participation in this study will involve no cost to you and you will be compensated with mobile telephone credit of 100KES as a token of appreciation for your time. You will receive it at the beginning of the discussion and keep it whether or not you choose to complete the process.

Confidentiality:
I will follow these procedures to keep your personal information confidential:

- I will keep collected data confidential to the extent allowed by law.
- I will keep your records under a code number rather than by name. In other words, your real name will not appear on the files associated with this project.
- The data collected for this research study will be protected on a password protected computer or in a locked file cabinet on the campus of Michigan State University for a minimum of three years after the close of the project. Only the appointed researcher's

and the Human Research Protection Program (HRPP) will have access to the research data.

When results of this study are published your name and other facts that might point to you will not appear. The results of the research study may be published, but your name will not be used.

Subjects Rights:
Your participation in this research study is completely voluntary. If you decide not to participate, there will be no penalty or loss of benefits to which you are otherwise entitled. You can, of course, decline to discuss any issue, as well as stop participating at any time, without any penalty or loss of benefits to which you are otherwise entitled.

Whom to contact with questions:
If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact the researcher:

Name: George Chidziwisano
Address: 404 Wilson Rd. Room 249
Communication Arts & Sciences
Michigan State University
East Lansing, MI 48824
Email: chidziwi@msu.edu
Phone Number: 0795620502

If you sign below, it means that you have read (*or have had read to you*) the information given in this consent form, and you would like to be a volunteer in this study.
Subject Name:________________________________

Subject Signature Date

Signature of Person Obtaining Consent Date

Appendix A2: Interview Protocol

In-depth Interviews Protocol, Security System
Project Title: Security System Project
Investigator: George Chidziwisano
I am a student at Michigan State University in the United States. I am from Malawi. You have been asked to participate in this research. The purpose of the interview is to study IT based security systems in rural Kenyan households. To be clear, I do not work for technology companies. I am not here to advertise products; instead I am here to learn.
Informed Consent

- Read the informed consent and make sure participants have agreed and signed before proceeding
- Are you comfortable with us digitally recording?
- At the end of the interview you will receive 100KES and after the study you will be given the solar charger as compensation.

1) Introduction

- Tell me your name
- Tell me about yourself
    - What do you do for a living?
- Tell me how long you have stayed in this community
    - Why did you choose this location?
- How many people are staying in this house now?
    - How many children do you have?
- What valuable things do you keep outside your house?
    - How do you keep them secure?

2) Security Background

- Tell me what you know about the security of the homes in this area
    - In what ways are people in this area provide security?
    - Are there any experiences you have had that make you feel insecure living here?
        - If yes, tell me what happened
    - Which areas are used by a thief to enter houses in this community?

3) Security in the Home

- What security measures are in place around your home?
    - List them
- What are the things that are most important to keep secure?
    - List the things that are most important to you
        - How do you keep them secure?
    - Tell me about any actions you do to take care of your livestock and other materials that are outside
    - Are there other wild animals that threaten your livestock in this community?
        - If yes, tell me more about this
    - What measures have you put outside your house to secure your livestock?
        - How effective are these measures?

- Tell me what visitors at your home do when they did not find you at home
    - How do you feel when you someone important tells you he came to your home but did not find you?
        - If you leave keys with neighbors, how do you know your neighbor did not enter the house before your visitor?
    - Has the mobile phone changed how you feel about security around your home?
- What else should I know about security in this area that you have not already told us?

4) Technology Probe
Diaries
As part of exercise you will use this diary to record your experiences with the security system for 4 weeks. Use the diary as your daily activities book with this system. Every time you interact with the system record your experiences with the system. Also indicate how you would want the system to be modified to effectively suit your needs. You may include experiences relating but not limited to:

- General knowledge about security
- If a security incident occurs, record it in your diary
- How the system responds when you switch it on/off
- Your reactions when you expect the system to work but it didn't

5) Deploy the Prototype:

- Explain and demonstrate how the prototype works then ask participants where they would want the sensors to be placed in around the house as well as where the micro-controller should be placed. Finally test the prototype to make sure that it is working properly.
- Do you have any questions for me?

Thank you for your participation in my study.

Appendix A3: M-Kulinda Participant Guidelines

Security System and Solar Charger Instructions

1. Using the system
   a. **Make sure** the sensor is facing the direction you want to monitor. **Do not** face the sensor towards the wall!
   b. **Only activate the security system when you are away and when you are sleeping.**
   c. **Note that the security system will only work when it is connected to the solar charger.**
   d. **DO NOT UNSEAL AND USE THE PORT COVERED WITH BLACK TAPE ON THE SOLAR CHARGER!**
2. Charging:
   a. Disconnect the solar charger—but not the cable—from the security system.
   b. Place the solar charger in the sun for at least 6 hours, and then reconnect the solar charger to the security system.
   c. **REMEMBER** to charge your solar battery whenever it is drained (approximately every 3 days).
3. IMPORTANT:
   a. **DO NOT USE THE SOLAR CHARGER TO CHARGE MOBILE PHONES DURING THE STUDY!**
   b. Call **George Chidziwisano (on 0795620502)** if you have any questions or you experience any problems.

Appendix A4: Diary Study Guidelines

Thank you for agreeing to participate in this study. Please respond to questions that seem relevant to you—everyday. Limit your answers to 1 to 3 sentences.

1. **Did anything surprising happen at your compound today?**
2. **Has anyone commented on the sensor today?**
3. **Did you receive any messages from the sensor today?**
   a. **If so, what was your reaction?**
4. **What time(s) was system on today?**
5. **Any comments about the system?**

When recording your entries, please provide the date and question number.
This book is property of Michigan State University. Please return it to George Hope Chidziwisano after the study is over. If you have questions call me at 0795620502.

Appendix A5: Follow-Up Interviews

Follow-Up Protocol: Security System Study
I am conducting a short follow-up interview related to the study you are participating since 3 weeks ago. I want to know about your experiences with the sensor I gave you and other security related issues during the last 3 weeks.
There are no right or wrong answers. Please speak freely and tell me as much points as possible, I am here to learn from you. At the end of the interview, I will leave you with the solar charger and I will take the sensor with me for further improvements.
Before I start, do you have any questions for me?

Informed Consent

- Ask them if they are willing to participate in the study.
- Can I audio-record the interviews?

Start Recording

1. What things were you monitoring with the sensor in the last 3 weeks?
    a. Give me some examples
    b. What experiences have you had while monitoring those things?
2. Are there any other places where you have taken the sensor other than where I placed it at first?
    a. Tell me what you observed in those places?
3. How did you feel when you received a message on your phone that the sensor has been activated?
    a. What action did you take?
    b. What did that message mean to you?
    c. On average, how many massages were you receiving per day
4. Are there moments when you expected the system to work but it didn't?
    a. If yes, tell me more about that
    b. Is there anything you did for it to start working again?
5. What factors affected the operation of the sensor?
    a. List them
    b. Is there anything you did to overcome those factors?
6. Tell me what you feel should be changed about the system
    a. What other things would you want to be included on this device?
    b. What things do you think do not work well with the system?
7. How long does the battery last when you are using the system?
    a. How often were you charging the battery?
8. You told me about sensors before you used the system, now after using it, what is your impression of sensors?
    a. In what ways do you think sensors can be used in your household?
    b. Tell me what your neighbors say about the sensor
9. What is your impression of the materials which have been used to make the device?
10. If you were to design your own security system, how would it look like?
    a. Take a moment and imagine how it would be like?
    b. What things would you consider for your system?
11. What else do you want to tell me about your experience in the last three weeks?
12. Do you have any question for me? **Thank you!**

Appendix B: Study Materials for GridAlert Study

Appendix B1: Informed Consent

Study Title: GridAlert: Exploring the role of sensor-based technologies in monitoring power blackouts in Kenya
Researcher and Title: George Hope Chidziwisano
Department and Institution: Media and Information, Michigan State University
Contact Information: chidziwi@msu.edu
Sponsor: National Science Foundation

Research Participant Information and Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

You are being asked to participate in a research study of exploring how sensors can be used for power monitoring in Kenyan households. Your participation in this study will take about a month.

There are no potential risks associated with you participating the study beyond everyday life activities.

Your participation in this study will help you to understand electrical power consumption in your household which might help you to economically save power in your household. However, your participation in this study may contribute to the understanding of how sensors should be designed to monitor power blackouts. I hope that findings from this study will help in informing the design of different technologies that might be useful in a rural Kenyan context.

1. PURPOSE OF RESEARCH

The main goal of this project is to explore how sensor-based technologies can be designed to monitor power failure in Kenya. To do this, I will use GridAlert: a home-based grid electricity monitoring system I developed to alert you about the status of grid electricity in your home. More specifically, this research is conducted to answer the following questions:

1. How should sensor-based systems be designed to monitor power blackouts in Kenya?
2. What are participants' experiences with using GridAlert to monitor power blackouts in their households?

2. WHAT YOU WILL DO

The project will be based on an exploratory study design which utilizes qualitative research methods. I will use in-depth interviews, diary study, data logging, and observations to collect data in the project's two phases. Data logging will allow us to collect your interactions with GridAlert on daily basis. More specifically, I will be recording how you are using the system each day. During observations, I will take a tour in your household to see electrical appliances that use electricity. In both phases, participants will be free to skip any questions.

Phase I: In-depth Interviews and observations
I will use the in-depth interviews and observations to explore how you monitor power blackouts in your household. This phase of the study will take about one hour with you.

Phase II: GridAlert Deployment
Phase two of the study will take four weeks. During this phase, I will deploy GridAlert in your household to explore how you use it in a natural setting environment. I will give all you a diary to be recording everyday experiences with the system. I will also be using data logging to record your daily interactions with the system. At the end of the four-week period, I will conduct a follow up study with you to learn more about their experiences with the system. All interviews with participants will be audio recorded.

3. POTENTIAL BENEFITS
Taking part in this study may help us better understand how sensors should be designed to monitor power blackouts. I hope that findings from this study will help in informing the design of different technologies that might be useful in a rural Kenyan context.

4. POTENTIAL RISKS
Your participation in this study does not involve any physical or emotional risk to you beyond that of everyday life.

5. PRIVACY AND CONFIDENTIALITY
I will follow these procedures to keep your personal information confidential:

- I will keep collected data private to the extent allowed by law.
- All materials that will related with this research will be labeled with a pseudocode. I will have a separate key that will be kept separately from the data.
- I will keep your records under a code number rather than by name. In other words, your real name will not appear on the files associated with this project.
- I will keep your records (e.g., recorded interviews) on a password-protected computer in a locked office. Study staff and the MSU HRPP will only be allowed to look at the interviews. I will destroy the information at the end of the study.
- The files associated with this study will destroyed at the completion of this study.

When results of this study are published your name and other facts that might point to you will not appear. The results of the research study may be published, but your name will not be used.

6. Your rights to participate, say no, or withdraw
Your participation in this research study is completely voluntary. If you decide not to participate, there will be no penalty or loss of benefits to which you are otherwise entitled. You can, of course, decline to discuss any issue, as well as stop participating at any time, without any penalty or loss of benefits to which you are otherwise entitled.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY
Participation in this study will involve no cost to you and you will be compensated with 200KES per week as a token of appreciation for your time. You will be receiving this amount every Sunday throughput the course of this study.

9. Conflict of Interest
Not applicable

10. Contact Information
If you have any concerns or questions, about this study, such as scientific issues, how to do any part of it, or to report an injury (i.e. physical, psychological, social, financial, or otherwise), you should call Dr. Susan Wyche, who can be reached at 0795620502 or spwyche@msu.edu.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

11. Documentation of Informed consent.

You consent to the interview being audio recorded (circle one choice).

YES NO ______Initials

Your signature below means that you voluntarily agree to participate in this research study.

____ ____________________________

Signature Date

You will be given a copy of this form to keep.

Appendix B2: In-depth Interviews Protocol, GridAlert

Project Title: GridAlert System Project
Investigator: George Chidziwisano

I am a student at Michigan State University in the United States. You are been asked to participate in this research. The purpose of the interview is to study how IT based systems can be used to monitor power blackouts in Kenyan households. To be clear, I do not work for technology companies. I am not here to advertise products; instead I am here to learn.

First, I will ask you some questions on how you monitor electricity in your household. Then, I will take a tour of the electrical appliances you have in your household. Thereafter, I will demonstrate to you how my prototype (GridAlert) works and deploy it to be used in your household for at-least four weeks. I will provide a diary and a pen for you to use when recording your experiences with GridAlert.

Each week, I will be sending you 200 KES through M-Pesa as a compensation for your time. I will also be sending text messages of even call you to remind you to write in the diary. After four weeks, I will come back to learn more about your experiences with GridAlert. At the end of the study, I will get back the system. I will audio record your responses and I will also be taking pictures whenever necessary. There are no wrong or right answers in this exercise. This first session should last about one hour.

Informed Consent

- Read the informed consent and make sure participants have agreed and signed before proceeding

Do you have any questions before I begin?

1) Introduction

- Tell me about yourself
    - Tell me your name
    - How old are you?
    - What do you do for a living?

- How long you have stayed in this community
    - Why did you choose this location?

- How many people are staying in this house now?
    - How many children do you have?

2) Electricity Usage

- How long has your house been connected to grid electricity?

- What other sources of power do you use in your household
    - Among these, which one is the best for you? Why?
    - At what times do you use each of the sources of power you have mentioned?
    - What do you use each of them for?

- What electronic appliances do you have in your house?
    - List them all
    - Which one do you frequently use? Why?
    - What do you use them for?

- How much do you spend on electricity each month?
    - Which appliance costs you more money to use?
    - Do you sometimes stay without paying for electricity?
    - Describe a situation you stayed without electricity in your household

- How often do you have power blackouts in your household?
    - When was the last time you had a power blackout?
    - How do you know you have blackout?
    - How do you know when power is back again?
    - What do you do when there is blackout?
    - Describe the moment you last had a power blackout

- Do you have any tools you use to monitor power usage in your household?
    - Tell me more about the tools you use

- Tell me about power looping in this area

- What challenges people face while using electricity in this area?

- Do you have any questions for me?

3) Deploy GridAlert

I will now demonstrate to you how GridAlert works.

- Download GridAlert app and install it in participants' phone
- Ask participants to connect an appliance to GridAlert power strip
- Explain and demonstrate how GridAlert works
- Explain to participants that they can use GridAlert with any appliance of their choice. They should not be limited to the appliance that I have used for demonstration.

Diaries

As part of exercise you will use this diary to record your experiences with the system for at least a month. Use the diary as your daily activities book with this system. Every time you interact with the system record your experiences. Also indicate how you would want the system to be modified to effectively suit your needs. You may include experiences relating but not limited to:

- Your experiences/reactions when you use the system
- Your actions when you use the system
- What you feel should be changed about the system
- Your reactions when you expect the system to work but it didn't

Data Logging:
The system has also been automatically connected to a remote web server that will help us to track how you use the system. This has been done in order to record how long does the system stay on, when is it switched on/off and how many times in day are messages sent to the owner.

- Do you have any questions for me?

Thank you for your participation in my study.

Appendix B3: Follow-up Interviews Protocol, GridAlert

Project Title: GridAlert System Project
Investigator: George Chidziwisano

I am here to follow up on your experiences using GridAlert system for the past month. I will ask you some questions to learn more about your experiences with GridAlert. There is no wrong or right answer and feel free to speak as much as you can. At the end, I will get back the system so that I can make further modifications on it based on your recommendations.

Do you have any questions before I begin?

Follow-up Questions

1. Tell me three things you appreciated about the system
2. Tell me three things you did not appreciate about the system
3. In what ways have you been using the system for the past month?
4. What did your neighbors comment about the system?
5. What is one memorable thing you remember about using the system?
6. Walk me through an example of how you used the system?
7. On average, how many blackouts have you had since last time I came?
8. What kind of notification were you seeing from the system?
    a. On average, how many alerts were you getting each day?
9. What was your reaction when you see that there is a blackout?
    a. What action did you take after the notification?
10. What was your reaction when you see that power is back on?
    a. What action did you take after the notification?
11. Are there any moments you expected the system to work but it didn't work?
    a. Tell me about those moments
12. What things should be changed about the system?
13. In what other areas do you think a system like this can be useful in your community?
14. Do you have any questions for me?

Thank you for your participation in my study.

Appendix C: Study Materials for NkhukuProbe Study

Appendix C1: Informed Consent

Study Title: NkukuProbe: Exploring the Role of Sensor-based Technologies in Supporting Poultry farming in Malawi
Researcher and Title: George Hope Chidziwisano
Department and Institution: Media and Information, Michigan State University
Contact Information: chidziwi@msu.edu
Sponsor: MSU Graduate School, MSU Department of Media and Information

Research Participant Information and Consent Form

You are being asked to participate in a research study. Researchers are required to provide a consent form to inform you about the research study, to convey that participation is voluntary, to explain risks and benefits of participation, and to empower you to make an informed decision. You should feel free to ask the researchers any questions you may have.

You are being asked to participate in a research study of exploring how sensors can be used for poultry farming. Your participation in this study will take about a month.

There are no potential risks associated with you participating the study beyond everyday life activities.

Your participation in this study may contribute to the understanding of how sensors should be designed to support poultry farming activities. I hope that findings from this study will help in informing the design of different technologies that might be useful in Malawian households.

1. PURPOSE OF RESEARCH
The main goal of this project is to explore how sensor-based technologies can be designed to support poultry farming. To do this, I will use NkhukuProbe: a sensor-based technology probe that monitors chicken coop conditions and provide feedback to farmers. More specifically, this research is conducted to answer the following questions:

3. What role do sensor-based technologies play in supporting poultry farming activities in Malawi?
4. What are the perceptions of people in resource-constrained settings about using sensor-based technologies to support domestic activities?

2. WHAT YOU WILL DO
The project will be based on an exploratory study design which utilizes qualitative research methods. I will use in-depth interviews, diary study, data logging, and observations to collect data in the project's two phases. Data logging will allow us to collect your interactions with NkhukuProbe on daily basis. More specifically, I will be recording how you are using the system each day. During observations, I will take a tour in your household to see materials participants use to manage their poultry. In both phases, participants will be free to skip any questions.

Phase I: In-depth Interviews and observations
I will use the in-depth interviews and observations to explore how you manage your poultry faming activities. This phase of the study will take about one hour with you.

Phase II: NkhukuProbe Deployment and Follow Up Interviews

Phase two of the study will take four weeks. During this phase, I will deploy NkhukuProbe in your households to explore how you use it in a natural setting environment. I will give all you a diary to be recording everyday experiences with the system. I will also be using data logging to record your daily interactions with the system. At the end of the four-week period, I will conduct a follow up study with you to learn more about their experiences with the system. All interviews with participants will be audio recorded.

3. POTENTIAL BENEFITS

Taking part in this study may help us better understand how sensors should be designed to support poultry farming in Malawi. I hope that findings from this study will help in informing the design of different technologies that might be useful in a rural Malawian context.

4. POTENTIAL RISKS

Your participation in this study does not involve any physical or emotional risk to you beyond that of everyday life.

5. PRIVACY AND CONFIDENTIALITY

I will follow these procedures to keep your personal information confidential:

- I will keep collected data private to the extent allowed by law.
- All materials that will related with this research will be labeled with a pseudocode. I will have a separate key that will be kept separately from the data.
- Your identification information (e.g., name, contact, and location) collected as part of the research, even if information that identifies you is removed, will not be used or distributed for future research studies.
- I will keep your records under a code number rather than by name. In other words, your real name will not appear on the files associated with this project.
- I will keep your records (e.g., recorded interviews) on a password-protected computer in a locked office. Study staff and the MSU HRPP will only be allowed to look at the interviews. This information will be kept for at-least a period of three years to comply with HRPP policy.
- The files associated with this study will be kept for at-least a period of three years to comply with HRPP policy.

When results of this study are published your name and other facts that might point to you will not appear. The results of the research study may be published, but your name will not be used.

6. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW

Your participation in this research study is completely voluntary. If you decide not to participate, there will be no penalty or loss of benefits to which you are otherwise entitled. You can, of course, decline to discuss any issue, as well as stop participating at any time, without any penalty or loss of benefits to which you are otherwise entitled.

7. COSTS AND COMPENSATION FOR BEING IN THE STUDY

Participation in this study will involve no cost to you and you will be compensated with 2000 MWK after the first interview. Each week, you will also be getting 2000 MWK as a token of appreciation for your time. You will be receiving this amount every Sunday throughput the course of this study. At the end of the study you will receive the power bank.

9. CONFLICT OF INTEREST

NOT APPLICABLE

10. CONTACT INFORMATION

If you have any concerns or questions, about this study, such as scientific issues, how to do any part of it, or to report an injury (i.e. physical, psychological, social, financial, or otherwise), you should call George Hope Chidziwisano, who can be reached at chidziwi@msu.edu.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 4000 Collins Rd, Suite 136, Lansing, MI 48910.

11. DOCUMENTATION OF INFORMED CONSENT.

You consent to the interview being audio recorded (circle one choice).

YES NO ______Initials

You consent that the researchers can take an pictures while observing some of the materials you use for poultry in your households (circle one choice).

YES NO ______Initials

Your signature below means that you voluntarily agree to participate in this research study.

____ ______________________________

Signature Date

You will be given a copy of this form to keep.

Appendix C2: In-depth Interviews Protocol, NkhukuApp

Project Title: Exploring the Role of Sensor-based Technologies for Poultry Farming in Malawi
Investigator: George Chidziwisano

I am a student at Michigan State University in the United States. You are been asked to participate in this research. The purpose of the interview is to study how IT based systems can be used to support poultry farming in Malawi. To be clear, I do not work for technology companies. I am not here to advertise products; instead I am here to learn.

First, I will ask you some questions on how you manage your poultry farming activities. Then, I will take a tour of the electrical chicken coop and the materials you use. Thereafter, I will demonstrate to you how my probe (NkhukuApp) works and deploy it to be used in your household for at-least four weeks. I will provide a diary and a pen for you to use when recording your experiences with NkhukuApp.

At the end of this ..... Each week, I will be sending you 2000 MWK through MPAMBA/Airtel Money as a compensation for your time. I will also be sending text messages of even call you to remind you to write in the diary. After four weeks, I will come back to learn more about your experiences with NkhukuApp. At the end of the study, I will get back the system. I will audio record your responses and I will also be taking pictures whenever necessary. There are no wrong or right answers in this exercise. This first session should last about one hour.

Informed Consent

- Read the informed consent and make sure participants have agreed and signed before proceeding

Do you have any questions before I begin?

Start the recorder

1) Introduction

- Tell me about yourself
    - Tell me your name
    - How old are you?
    - What do you do for a living?

- How long you have stayed in this community
    - Why did you choose this location?

- How many people are staying in this house now?
    - How many children do you have?

2) Poultry Farming

- How long have been practicing poultry farming?
    - How many chickens are in your coop?
    - How many eggs do you get from your poultry per day?

- What are the benefits of raising poultry in your households?
    - What do you do with the products of your poultry farming?

- What tools do you use to support your poultry farming activities?
    - Tell me more about these tools and practices

- What poultry farming practices do you use to support your poultry farming activities?
    - Tell me more about these tools and practices

- Tell me about the day to day activities you do to take care of your poultry

- How often do you feed your poultry each day?

   - Walk me through the steps you follow to do this

- Do agricultural extension officers visit farmers in your field site?
   - If so, how often do they visit farmers
   - Tell me more about how this is done?
   - Are there any collaborative practices among farmers to provide advice to each other?

- Are you aware of any sensor systems that are currently being used in poultry?
   - Can you walk me through an example of how this is done?
   - Do you have any thoughts of how these sensor-based systems can be improved?

- Do you have any other suggestions of how sensor-based technologies can be used to support poultry farming?

- What challenges do you face with your poultry farming?

- Do you have any questions for me?

3) Deploy NkhukuApp Probe
I will now demonstrate to you how NkhukuApp works.
- Download NkhukuApp and install it in participants' phone
- Ask participants to connect an appliance to NkhukuApp hardware
- Explain and demonstrate how NkhukuApp works
- Explain to participants that they can use NkhukuApp in their households. They should not be limited to the appliance that I have used for demonstration.

Diaries
As part of exercise you will use this diary to record your experiences with the system for at least a month. Use the diary as your daily activities book with this system. Every time you interact with the system record your experiences. Also indicate how you would want the system to be modified to effectively suit your needs. You may include experiences relating but not limited to:

   - Your experiences/reactions when you use the system
   - Your actions when you use the system
   - What you feel should be changed about the system
   - Your reactions when you expect the system to work but it didn't

Data Logging:
The system has also been automatically connected to a remote web server that will help us to track how you use the system. This has been done in order to record how long does the system stay on, when is it switched on/off and how many times in day are messages sent to the owner.

- Do you have any questions for me?

Thank you for your participation in my study.

Appendix C3: Follow-up Interviews Protocol, NkhukuApp

Project Title: Exploring the Role of Sensor-based Technologies for Poultry Farming in Malawi
Investigator: George Hope Chidziwisano

I am here to follow up on your experiences using NkhukuApp for the past month. I will ask you some questions to learn more about your experiences with NkhukuApp. There is no wrong or right answer and feel free to speak as much as you can. At the end, I will get back the system so that I can make further modifications on it based on your recommendations.

Do you have any questions before I begin?

Follow-up Questions

15. Tell me three things you appreciated about the system
16. Tell me three things you did not appreciate about the system
17. In what ways have you been using the system for the past month?
    a. In what other areas do you think a sensor like this can be useful in your household?
    b. What are the other things you found the sensor useful for in your home
    c. Walk me through an example of how you used the system.
18. Tell me more about your expectations about how you thought the sensor should have been used.
19. What did your neighbors comment about the system?
20. What is one memorable thing you remember about using the system?
21. On average, how many eggs were your chickens laying each day?
22. What kind of notifications were you seeing from the system?
    a. On average, how many alerts were you getting each day?
23. Are there any moments you expected the system to work but it didn't work?
    a. Tell me about those moments
24. What things should be changed about the system?

25. Do you have any questions for me?

Thank you for your participation in my study.

Appendix D: IRB Applications

Appendix D1: GridAlert: Exploring the role of sensor-based technologies in monitoring power blackouts in Kenya

Name of Principal Investigator: George Chidziwisano

Sponsor (if applicable): National Science Foundation

Sponsor ID (if applicable):

Section I. IRB Protocol for All Studies

Section I is completed for all studies and includes questions to determine whether the study qualifies for exemption. Section II is <u>only</u> completed if the study does not qualify for exemption.

1. **Hypothesis / Objective / Goals / Aims**
   Briefly describe the study's hypothesis / objectives / goals / aims.
   The main goal of this project is to explore how sensor-based technologies can be designed to monitor power failure in Kenya. To do this, we will use GridAlert: a home-based grid electricity monitoring system we developed to alert users about the status of grid electricity in their homes. More specifically, this research will be conducted to answer the following questions: How should sensor-based systems be designed to monitor power blackouts in Kenya?; and What are participants' experiences with using GridAlert to monitor power blackouts in their households?.

2. **Procedures**
   Describe the research procedures that involve obtaining data about a living person through interaction or intervention and/or by obtaining their identifiable private data. If subjects will participate in or undergo an intervention, in addition to providing data, please fully describe the intervention. *CLICK™ IRB: Upload instruments (e.g. surveys, interview questions, questionnaires, etc.), measures, variables, etc. to the Supporting Documents SmartForm page.*
   The research project will consist of two consecutive phases: a baseline study and a field deployment study. We will use the baseline study to build some good rapport with participants and explore how they monitor power blackouts in their households. We will use in-depth interviews and observations to collect data from participants in this phase. This phase of the study will take one week.

   Phase two of the study will take four weeks. During this phase , we will deploy GridAlert in participants' households to explore how they use it in a natural setting environment. We will give all participants diaries to be recording everyday experiences with the system. We will also be using data logging to record participants' daily interactions with the system. Data logging will allow us to collect participants' daily interactions with GridAlert. More specifically, we will be recording how participants are using the system each day. At the end of the four week period, we will conduct a follow up study with each of the participants to learn more about their experiences with the system. During the study, we will also observe different electrical appliances participants use in their households. All interviews with participants will be audio recorded.

3. **Subject Population**

A. Describe the subject population.

The study will have a sample size of ten households from Kisumu, Kenya. We have previously conducted research studies in Kisumu so it will be easy to get participants there. We will use purposive sampling technique to select participants who have a smartphone and electricity in their households. We will also target participants who live in slums because it is where power blackouts mostly occur.

B. Select the age range of subjects (select one):

☒ Adults who are 18 or older

☐ Specific Age Range: ______ (Enter Minimum) to ______ (Enter Maximum)

C. Study purposefully includes the following subject population(s)(check all that apply):

☐ Cognitively impaired adults

☐ Minors (children) (view information about the definition of a child)

☐ Minors who are wards of the state

☐ Pregnant women

☐ Prisoners

☐ Students

D. Study involves:

☐ Incomplete disclosure or attempted deception of subjects

CLICK IRB: Upload the debriefing script, document, etc. to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

4. Estimated Study Duration

Provide the time estimated to complete all human subject research, including analysis of the subjects' identifiable private information.

6 Months

5. Risk

A. Minimal Risk or More than Minimal Risk

1. Select one of the following:

☒ Research presents minimal risk to subjects

☐ Research presents more than minimal risk to subjects

2. Explain the selection.

The study does not involve any form exercise that put subjects at any risk. Assitionally, the study does not seek to obtain any form of sensitive information from subjects.

B. Reasonably Foreseeable Risks

1. Select one of the following:

☒ There are no reasonably foreseeable risks to subjects

Explain the selection.

☐ There are reasonably foreseeable risks to subjects

i. Describe the risks, considering physical, psychological, social, legal and economic risks.

ii. Describe the procedures for protecting against or minimizing potential risks and provide an assessment of their likely effectiveness.

6. Conflict of Interest

Do any investigators or research staff have a financial interest related to the research that has not otherwise been disclosed elsewhere in this submission? ☒ No ☐ Yes

7. **Exemption Criteria. ☐ Not Applicable (***If the study does not qualify for the exemption criteria, proceed to Section II.)*

A. A study may qualify for exemption when the <u>only</u> involvement of human subjects will be in one or more of the following categories (please view full exemption categories here: https://hrpp.msu.edu/exempt-categories). If the <u>only</u> involvement of human subjects in this study will be in one or more of the categories, please select the category(ies) applicable to the study. *Note: Studies involving prisoners cannot be exempt.*

- ☐ Research conducted in established or commonly accepted educational settings, involving normal educational practices.
- ☒ Educational tests, survey procedures, interview procedures, observation of public behavior <u>unless</u> data is recorded in a manner such that subjects are identifiable and the responses could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation (research cannot involve children, except for educational tests or observation of public behavior where the investigator does not interact with the child).
- ☐ Educational tests, survey procedures, interview procedures, or observation of public behavior not otherwise exempt that involves public officials or federal statute.
- ☐ Collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens if publicly available or information is recorded by investigator in a manner that subjects cannot be identified.
  - ☐ Federal demonstration projects.
  - ☐ Taste and food quality evaluation and consumer acceptance studies.

☐ ONLY applicable to research NOT FUNDED by a federal department or agency: Research involving the study of previously collected identifiable data (please view additional exclusions before selecting this category).

By checking the boxes below, you are confirming that the study will not include any of the following for the study's duration:

☐ Federal funding or federal training grants

☐ FDA regulated

☐ Sponsor or other contractual restrictions
☐ Clinical interventions (including clinical behavioral interventions)
☐ Prisoners as subjects
☐ Receipt of an NIH issued certificate of confidentiality to protect identifiable research data
☐ Be a project for which MSU serves as the IRB of record

☐ ONLY applicable to research NOT FUNDED by a federal department or agency: Prospective data collection with adults through verbal or written responses involving a benign intervention (please view additional exclusions before selecting this category).

By checking the boxes below, you are confirming that the study will not include any of the following for the study's duration:

☐ Federal funding or federal training grants
☐ FDA regulated
☐ Sponsor or other contractual restrictions
☐ Clinical interventions (including clinical behavioral interventions)
☐ Prisoners as subjects
☐ Receipt of an NIH issued certificate of confidentiality to protect identifiable research data
☐ Be a project for which MSU serves as the IRB of record
☐ Children as research subjects

B. Confirm that the following are true and will remain true for the study's duration:

☒ Selection of subjects is equitable (considering the purposes of the research, setting in which research will be conducted, any vulnerable populations)

☒ If there is recording of identifiable information, there are adequate provisions to maintain the confidentiality of the data.

☒ There are adequate provisions to maintain the privacy interests of subjects.

☒ Safeguards are or will be put in place to protect against any coercion or undue influence if you or members of your study team are or may be associated with the subjects at any point in the study (e.g. students, employees, colleagues, patients).

C. Consent

1. There will be a consent process for the study's duration that will disclose information such as that the activity involves research, a description of the procedures, that participation is voluntary and withdrawal is without penalty, and the name and contact information for the researcher (select appropriate option below):

☒ For All Subjects
☐ For Some Subjects
☐ For None of the Subjects (consent will not be obtained)

CLICK IRB: Upload the consent document to the Consent Forms and Recruitment Materials SmartForm page.

2. Please explain your selection.

I will read a consent form to all participants and request for their consent to participate in the study. Additionally, I will also seek a permission from participants to audio record and take pictures during all sessions of the study.

Other Click IRB Documents to Upload As Appropriate (Applicable to All Studies)
• *Upload this completed protocol to the Basic Information SmartForm page, Question 10.* • *Upload any funding materials not accessible in Kuali Coeus in the Supporting Documents SmartForm page.* • *Upload the HRP-537 - Template - Use of Protected Health Information Application to the MSU Additional Study Information SmartForm page.* • *Upload the HRP-538 - Template - MSU Authorization to Use or Disclose Health Information for Researchers to the MSU Additional Study Information SmartForm page.*

IF THE STUDY MAY QUALIFY FOR AN EXEMPTION, STOP HERE AND DO NOT COMPLETE SECTION II. CONTINUE ONLY IF THE STUDY DOES NOT QUALIFY FOR AN EXEMPTION.

Section II. Additional IRB Protocol Questions for an Expedited or Full Board Study

Not all questions or sections are applicable to every study. If the question or section is not applicable, check the "Not Applicable" box. All other questions are required.

8. More than Minimal Risk Research (complete the following question if you selected that the research presents more than minimal risk to subjects in Question 5A1)

A. Describe the relevant prior experience and gaps in current knowledge, relevant preliminary data, if any, and the scholarly background for, and significance of, the research based on existing literature and how it will add to existing knowledge.

B. Sample Size

1. Total number of subjects who will be approached (including screen failures, controls and subject withdrawals) to reach enrollment numbers for the lifetime of the study at this investigator's sites

2. Total number of subjects who will be enrolled in the study at this investigator's site.

3. Describe the statistical justification or rationale for the proposed sample size. Considerations for sample size may include the acceptable level of significance, power of the study, expected effect size, underlying event rate in the population, standard deviation in the population, saturation of themes, and/or have a theoretical basis.

9. Minimal Risk Research (complete the following question if you selected that the research presents minimal risk to subjects in Question 5A1)

A. Briefly describe the background for conducting the research. (1-2 sentences)

The study builds on our prior studies in Kenya where we found that intermittent electrical power blackouts in households is one of the challenges. This study aims to explore how sensors can be used to monitor power blackouts in Kenyan households. Participants' will use our prototype to monitor and protect their eletrical appliances from damage during episodes of power blackouts. There are no major risks associated with participating in the study.

B. Sample Size

1. Provide an estimated sample size for the lifetime of the study at this investigator's sites.
   15

2. Describe the basis for that estimate.
   The study design is qualitative based, so with 15 participants we will be able to collect relevant data for answering our research questions.

10. Benefits

Describe any potential direct benefit(s) to subjects in this study, if any and the importance of the knowledge that may reasonably be expected to result. Within the description, do not include payment to subjects as a benefit.

Participants will be able to use the prototype in their households to protect their electrical appliances from damage. This study's findings will also contribute to the existing body of literature in Human Computer Interaction on how sensor-based technologies should be designed to monitor power blackouts in Kenyan households.

11. Inclusion and Exclusion Criteria

Describe the criteria for who will be included or excluded from the study, including how subjects will be screened for eligibility.

Participants will be included or excluded in the study based on two conditions. We will need participants to have a connection to grid electricity in their households and also to posses a smartphone. These are the two conditions required for participants to use our prototype.

12. Recruitment

A. Describe how subjects will be identified and recruited, including who will perform the recruitment.

Participants will be intentified using purposive sampling technique. Based on the two conditions mentioned above, we will approach participants from our previous studies who meet those conditions to participate in the study. If participants are willing, we will read them the informed consent so that they understand the benefits and risks of participation in the study. Once they agree to participate, then we will take them as part of the study. If they don't agree to participate, we will not coerce anyone to participate. We will only recruit participants who agree to take part.

B. Identify materials that will be used to recruit subjects. ☒ **None**

☐ Letter, email, flyer, postcards, CD, DVD

☐ Newspaper, television, or radio advertisements

☐ Use of websites or Apps (e.g. Facebook, ResearchMatch)

☐ Other,

CLICK IRB: Upload the recruitment materials to the Consent Forms and Recruitment Materials SmartForm page, Question 2.

13. Consent Process

A. If the study involves adults, consent will be obtained from (select appropriate option(s)):☐ **Not Applicable**

☒ All subjects

☐ Some subjects

☐ No subjects (consent will not be obtained)

CLICK IRB: Upload the consent document, script, etc. (including translations) to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

B. If the study involves children, parental permission will be obtained from (select appropriate option(s)): ☒ **Not Applicable**

☐ Both parents or guardians (unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the child)

☐ One parent or guardian

☐ Will not be obtained

CLICK IRB: Upload the parental permission forms to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

C. If the study involves children, child assent will be obtained from (select appropriate option): ☒ **Not Applicable**

☐ All children

☐ Some children

☐ Will not be obtained

CLICK IRB: Upload the child assent form to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

D. Describe the consent process, including an explanation of your selection(s) above. If the study involves screening activities, please describe whether consent will be obtained.

Before starting the study with each partipant, we will first read the consent form to them. This will explain all the benefits and risks of participating in the study as well as how their information will be kept confidential. Additionally, participants will also be told that they should feel free to stop participating at any point. Once participants agree to participate, we will ask them to sign the consent form. If they don't agree, we will not involve them in our study. We will move on to the next participant.

E. If your study involves use of a consent form, complete i and ii. ☐ **Not Applicable**

i.Select the appropriate option(s) below for the documentation of consent.

☒ Will use a written consent document signed by subjects

☐ Will use a short form written consent document signed by subjects

☐ Will not obtain a signed consent document for some subjects

☐ Will not obtain a signed consent document for all subjects

ii. Describe when and how the subject will receive a copy of the consent form.

Before they begin participating in the study. We will give participants a consent form to read and sign. For participants who do not know how to read, we will read it to them.

F. If the study involves cognitively impaired adults, explain the process to determine whether a subject is capable of consent, use of any legally authorized representative(s), and any assent process. ☒ **Not Applicable**

CLICK IRB: Upload any assessment tools to the Supporting Documents SmartForm page.

14. Coercion or Undue Influence

A. If some or all of the subjects are likely to be vulnerable to coercion or undue influence, such as children, prisoners, pregnant women, mentally disabled persons, or economically or educationally disadvantaged persons, describe additional safeguards that have been included in the study. ☒ **Not Applicable**

B. If you or your study team are associated with the subjects (e.g. your students, employees, colleagues, patients), explain the nature of any association and measures taken to protect subjects' rights, including safeguards against any coercion or undue influence (e.g. pressure a subject might feel to participate based on the association). ☒ **Not Applicable**

15. Privacy

How will subjects' privacy be protected? Consider the number of individuals interacting with the subject or subject's records, location of consent process and study, presence of individuals not associated with the study, sensitivity of the research.

All data collected will be kepy private. We will keep our data in a locked drawer at MSU College of Communication Arts and Sciences. This drawer will only be accessed by team members of this study. At the end of the study, all the data associated with participants will be discarded.

16. Withdrawal of Subjects ☒ Not Applicable

If there are any anticipated circumstances where the researcher will withdraw subjects from the study regardless of the subject's wishes, describe the circumstances and the procedures when subjects are withdrawn from the study.

17. Monitoring Plan to Assess Data to Ensure Safety of Subjects ☒ Not Applicable

A. If it is appropriate for the study to have a monitoring plan to periodically assess the data to ensure the safety of subjects or to ensure negative outcomes do not occur, describe the monitoring plan. *CLICK IRB: Upload any data safety monitoring plans to the Supporting Documents SmartForm pages.*

B. If there is a data safety monitoring committee or board, describe the composition and frequency of meetings. ☒ **Not Applicable**

18. Results and Data Sharing ☒ Not Applicable

A. Select all that apply:

☐ Study results will be shared directly with subjects

☐ Individual results or incidental findings will be shared with subjects or others

☐ Data will be submitted to a repository or database as part of data sharing agreement (e.g. genomic data sharing)

B. Explain your selection(s), including how the data or results will be shared and with who (e.g. subject's primary care physician, data repository).

19. Local Context and Multi-Site Study

A. Describe the locations of where the study team will obtain data through intervention or interaction with the subject or obtain the subjects' private identifiable information.

We will conduct the study in two field sites in Kisumu, Kenya: Nyalenda and Obunga. These are the slums where we have also conducted our prior studies and we have a good rapport with participants from these field sites. Additionally, Kisumu's slums are among the areas where people with low income – who mostly participate in chamas – are located in Kenya, therefore it will be easy to find participants from these fields sites. Prior studies have also shown that over 44% of people living in cities across Kenya have smartphones – a device required for participants in this study to possess. Among the 44%, 69.6% of them have access to strong internet connectivity.

B. If the study will engage employees or agents of non-MSU organizations (e.g. performance sites), explain how the employees or agents will be engaged (e.g. will they perform research procedures, will they obtain informed consent from subjects). ☒ **Not Applicable**

C. If the study involves multiple performance sites, describe the methods for communicating with engaged sites related to the protection of human subjects (e.g. any potential unanticipated problems that may involve risks to subjects others). ☒ **Not Applicable**

D. If there are any cultural or local contexts or requirements that may impact the protection of human subjects or present additional risks to subjects that have not otherwise been described, please describe. If research is conducted outside the state of Michigan, this could include additional state or international requirements or laws. ☒ **Not Applicable**

E. If translations to a language other than English will be provided to subjects, describe the translation process. *CLICK IRB: Upload translated documents to the appropriate SmartForm page(s).* ☒ **Not Applicable**

20. Resources and Financial Compensation and Costs

A. If someone will receive a payment for recruiting the subjects, explain the amount of payment, who pays it, who receives it, and why they are being paid. ☒ **Not Applicable**

B. If subjects will be compensated for participation in the study, provide details concerning payment, including the amount and schedule of payments including any terms and conditions. Payment should be proportionate to participation. ☐ **Not Applicable**

Participants will be given $5 in form of phone airtime as a compensation for their participation in the study.

C. If subjects will incur additional financial costs as a result of their participation in this study, explain the additional costs. ☒ **Not Applicable** ☐ **Unknown**

D. Describe any resources not otherwise described elsewhere in the submission (e.g. internal funding) for the protection of human subjects. *CLICK IRB: Upload any funding materials not accessible in Kuali Coeus in the Supporting Documents SmartForm page.*☒ **Not Applicable**

21. Data and/or Sample(s) Management and Confidentiality

A. Select the appropriate option:

☒ Identifying or coded information will not be stored with the data and/or sample(s)

☐ Identifying or coded information will be stored with the data and/or sample(s)

B. Please explain your selection. If you are storing identifying or coded information with the data and/or sample(s), explain why identifiable or coded data and/or sample(s) needs to be maintained and how long it will be necessary to maintain it.

Each participant will have a pseudonym that will be used to represent them in the study. These psuudonyms will be documented in an excel sheet. All data analysis process will be done using these pseeudonyms to maintain anonymity.

C. Describe the procedures and safeguards you will use to secure the data and/or sample(s), including during transport of data and/or samples.

At the field, data collected will be kept in an external hard drive that will be kept by the PI. This data will also be backed up a different external hard drive. Once we are back to MSU all the data will be kept in a locked drawer. Only to be accessed by the research team.

22. Drug and/or Device Storage, Handling, and Administration ☒ Not Applicable

Describe the procedure and plan for storage, handling, and administration of the drug and/or device so that they will be used only on enrolled subjects and be used only by authorized study personnel.

Other Click IRB Document Uploads As Appropriate (Applicable to Expedited or Full Board Studies)
• *Upload list of external study team members (non-MSU individuals) to the Study Team Members SmartForm page, Question 2.* • *Upload other institution(s) approval letter(s), if submitted to other IRB(s) or ethics committees, to the Supporting Documents SmartForm page.* • *Upload FDA communications, package inserts, FDA form 1572, or other information related to drugs or devices to the appropriate Drug or Device SmartForm pages.* • *Upload the HRP-540 - Template - ICH-GCP - For Investigator to the MSU Additional Study Information SmartForm page.* • *Upload HRP-541 - Template - Involvement of Prisoners in a Research Project to the MSU Additional Study Information SmartForm page.* • *Upload the investigator brochure to the Supporting Documents SmartForm page* • *Upload the MRI Screening Form – Women to the Supporting Documents SmartForm page.* • *Upload the translation of instrument(s) provided to non-English speaking subjects to the Supporting Documents SmartForm page.* • *Upload the curriculum vitae(s) when research is more than minimum risk to the Supporting Documents SmartForm page.* • *Upload case report forms to the Supporting Documents SmartForm page.* • *Upload the Non-MSU Employee Conflict of Interest Disclosure Form to the Supporting Documents SmartForm page.* • *Upload any other pertinent documents related to the proposed research study to the Supporting Documents SmartForm page*

Appendix D2: NkhukuApp: Exploring the Role of Sensor-based Technologies for Poultry Farming in Malawi

MICHIGAN STATE UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM

- Complete this template for new exempt, expedited, or full board studies.
  - Complete Section I for ALL studies (exempt, expedited, full board)
  - Complete Section II ONLY if your study does not qualify for exemption and requires an expedited or full board review. Contact the IRB office if you have any questions.
- CLICK™ IRB:
  - Include the template with a New Study Submission.
  - Upload the completed template to the Basic Information SmartForm page, Question 10.
  - When uploading documents to Click (e.g. consent documents, instrument), provide distinct file names.
- See the Click Quick Guides and the HRPP Manual for more information, available at hrpp.msu.edu

Study Title:	NkhukuApp: Exploring the Role of Sensor-based Technologies for Poultry Farming in Malawi
Click Study ID (if known):	STUDY00004806
Sponsor (if applicable):	National Science Foundation, MSU Graduate School, MSU Department of Media and Information
Sponsor ID (if applicable):	

Section I. IRB Protocol for All Studies

Section I is completed for ***all studies*** and includes questions to determine whether the study qualifies for exemption. Section II is only completed if the study does not qualify for exemption.

1. **Hypothesis / Objective / Goals / Aims.**

Briefly describe the study's hypothesis / objectives / goals / aims.

The goals of this research are: 1) to investigate the impact of sensor-based technologies in supporting poultry farming in Malawian households; and 2) to understand the perceptions of people living in resource-constrained settings about using sensor-based technologies to support domestic activities.

2. **Subject Population.**

2A. Study purposefully includes the following subject population(s) (select all that apply):

☐ Cognitively impaired adults
☐ Minors (children) (view information about the definition of a child)
☐ Minors who are wards of the state
☐ Pregnant women, fetuses, or neonates
☐ Prisoners
☐ Students

2B. Study involves (select all that apply):

Funding, support, or other requirement to comply with U.S. Department of Justice regulations
☐ Incomplete disclosure or attempted deception of subjects

CLICK IRB: Upload the debriefing script, document, etc. to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

3. Estimated Study Duration.

Provide the time estimated to complete all human subject research, including analysis of the subjects' identifiable private information.

One year

4. Reasonably Foreseeable Risks.

4A. There are (select one of the following):

☒ No reasonably foreseeable risks to subjects
☐ Reasonably foreseeable risks to subjects

4B. Explain the selection. *If you selected that there are reasonably foreseeable risks to subjects, describe the risks, considering physical, psychological, social, legal and economic risks.*

The study does not pose any foreseeable risks other than those encountered in participants' everyday activities.

4C. If you selected that there are reasonably foreseeable risks, describe the procedures for protecting against or minimizing potential risks and provide an assessment of their likely effectiveness.

5. Conflict of Interest.

Do any investigators or research staff have a financial interest related to the research that has not otherwise been disclosed elsewhere in this submission?

☒ No
☐ Yes

6. Exemption Criteria. ☐ Not Applicable

A study may qualify for exemption when the only involvement of human subjects will be in one or more of the following categories (please view full exemption category / description here: https://hrpp.msu.edu/help/required/exempt-categories.html). ***(If the study does not qualify for the exemption criteria, do not complete this question and proceed to Section II.)***

6A. Exemption Categories.

6A1. Select the category(ies) applicable to the study if the only involvement of human subjects in this study will be in one or more of the categories. Studies involving prisoners cannot be exempt UNLESS the research is aimed at involving a broader subject population that only incidentally includes prisoners *If your study is subject to U.S. Department of Justice requirements, do not complete this section; complete 6A2 below.*

☐ ***Exempt 1.*** Research conducted in established or commonly accepted educational settings, involving normal educational practices that are not likely

to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction.
IF YOU SELECTED THIS CATEGORY, EXPLAIN WHY THE RESEARCH WILL NOT LIKELY ADVERSELY IMPACT STUDENTS' OPPORTUNITY TO LEARN REQUIRED EDUCATIONAL CONTENT OR THE ASSESSEMENT OF EDUCATORS WHO PROVIDE INSTRUCTION.

☐ ***Exempt 2.*** Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior. IF YOU SELECTED THIS CATEGORY, SELECT THE APPROPRIATE OPTION(S) BELOW.

- ☐ (i) Information obtained is recorded by investigator in manner that identity of subjects cannot readily be ascertained, directly or through identifiers linked to subjects
- ☐ (ii) Any disclosure of subjects' responses outside research would not reasonably place subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, educational advancement, or reputation.
- ☐ (iii) **LIMITED IRB REVIEW REQUIRED**. Information obtained is recorded by investigator in manner that identity of subjects can readily be ascertained, directly or through identifiers linked to subjects, and responses could reasonable place subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; YOU MUST ALSO COMPLETE QUESTION 6E TO DESCRIBE PRIVACY AND CONFIDENTIALITY SAFEGUARDS.)

☐ ***Exempt 3.*** Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection. IF YOU SELECTED THIS CATEGORY, SELECT THE APPROPRIATE OPTION(S) BELOW.

- ☐ (i) Information obtained is recorded by investigator in manner that identity of subjects cannot readily be ascertained, directly or through identifiers linked to subjects.
- ☐ (ii) Any disclosure of subjects' responses outside research would not reasonably place subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, educational advancement, or reputation
- ☐ (iii) **LIMITED IRB REVIEW REQUIRED**. Information obtained is recorded by investigator in manner that identity of subjects can readily be ascertained, directly or through identifiers linked to subjects, and responses could reasonable place subjects at risk of criminal or civil liability or be damaging to subjects' financial standing, employability, educational advancement, or reputation (LIMITED IRB REVIEW IS REQUIRED; YOU MUST ALSO

COMPLETE QUESTIONS 6E TO DESCRIBE PRIVACY AND CONFIDENTIALITY SAFEGUARDS.)

☐ ***Exempt 4.*** Secondary research uses of identifiable private information or identifiable biospecimens.

IF YOU SELECTED THIS CATEGORY, SELECT THE APPROPRIATE OPTION(S) BELOW.

- ☐ Identifiable private information or identifiable biospecimens are publicly available.
- ☐ Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained directly or through identifiers linked to the subjects, the investigator does not contact the subjects, and the investigator will not re-identify subjects. ***IF YOU SELECT THIS CATEGORY, CONFIRM THE FOLLOWING:***
  - ☐ Investigator and research team will not contact the subjects
  - ☐ Investigator and research team will not re-identify the subjects
- ☐ The research involves only information collection and analysis involving the investigator's use of identifiable health information when that use is regulated under the Health Insurance Portability and Accountability Act (HIPAA) 45 CFR parts 160 and 164.
- ☐ The research is conducted by, or on behalf of, a Federal department or agency using government-generated or government-collected information obtained for nonresearch activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with specific federal privacy standards.

☐ ***Exempt 5.*** Federal demonstration projects.

☐ ***Exempt 6.*** Taste and food quality evaluation and consumer acceptance studies.

☐ ***Exempt 97***. ONLY applicable to research NOT FUNDED by a federal department or agency: Research involving the study of previously collected identifiable data (please view additional exclusions before selecting this category).

By checking the boxes below, you are confirming that the study will not include any of the following exclusions for the study's duration:

☐ Federal funding or federal training grants

☐ FDA regulated

☐ Sponsor or other contractual restrictions

☐ Clinical interventions (including clinical behavioral interventions)

☐ Receipt of an NIH issued certificate of confidentiality to protect identifiable research data

Multi-site collaborative research study where another institution plans to rely or is relying upon MSU's IRB review

☐ ***Exempt 98.*** ONLY applicable to research NOT FUNDED by a federal department or agency: Prospective data collection with adults through verbal or written responses involving a benign intervention (please view additional exclusions before selecting this category).

By checking the boxes below, you are confirming that the study will not include any of the following exclusions for the study's duration:

☐ Federal funding or federal training grants

☐ FDA regulated

☐ Sponsor or other contractual restrictions

☐ Clinical interventions (including clinical behavioral interventions)

☐ Receipt of an NIH issued certificate of confidentiality to protect identifiable research data

ulti-site collaborative research study where another institution plans to rely or is relying upon MSU's IRB review

☐ Children as research subjects

6A2. **DEPARTMENT OF JUSTICE Exemption Categories*.*** Complete this section ONLY if the research is subject to Department of Justice requirements.

6A2i. Select the category(ies) applicable to the study if the only involvement of human subjects in this study will be in one or more of the categories. Studies involving prisoners cannot be exempt.

☐ ***Exempt 1.*** Research conducted in established or commonly accepted educational settings, involving normal educational practices.

☐ ***Exempt 2.*** Educational tests, survey procedures, interview procedures, observation of public behavior unless data is recorded in a manner such that subjects are identifiable and the responses could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation (research cannot involve children, except for educational tests or observation of public behavior where the investigator does not interact with the child).

☐ ***Exempt 3.*** Educational tests, survey procedures, interview procedures, or observation of public behavior not otherwise exempt that involves public officials or federal statute.

☐ ***Exempt 4.*** Collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens if publicly available or information is recorded by investigator in a manner that subjects cannot be identified.

☐ ***Exempt 5.*** Federal demonstration projects.

☐ ***Exempt 6.*** Taste and food quality evaluation and consumer acceptance studies.

6A2ii. Explain why the study presents minimal risk to subjects.

The study does not involve any form exercise that put subjects at any risk. Assitionally, the study does not seek to obtain any form of sensitive information from subjects.

6B. By checking the boxes below, you are confirming that the following are true and will remain true for the study's duration:

Selection of subjects is equitable (considering the purposes of the research, setting in which research will be conducted, any vulnerable populations).

If there is recording of identifiable information, there are adequate provisions to maintain the confidentiality of the data.

☒ There are adequate provisions to maintain the privacy interests of subjects.

Safeguards are or will be put in place to protect against any coercion or undue influence if you or members of your study team are or may be associated with the subjects at any point in the study (e.g. students, employees, colleagues, patients).

6C. Consent

6Ci. There will be a consent process for the study's duration that will disclose information such as that the activity involves research, a description of the procedures, that participation is voluntary and withdrawal is without penalty, and the name and contact information for the researcher (select appropriate option below):

☒ For All Subjects

☐ For Some Subjects

☐ For None of the Subjects (consent will not be obtained)
CLICK IRB: Upload the consent document to the Consent Forms and Recruitment Materials SmartForm page.

6Cii. Please explain your selection.

I will read a consent form to all participants and request for their consent to participate in the study. Additionally, I will also seek a permission from participants to audio record and take pictures during all sessions of the study.

6D. Please acknowledge that you may not begin the research at non-MSU institutions (regardless of engagement), until you receive the appropriate approvals/permissions from the sites (e.g. IRB review/exempt determination from non-MSU sites, data use or research agreements, other regulatory approvals). An MSU exempt determination does not provide approval/permission for a non-MSU site, including sites with reliance agreements with MSU. Please note that non-MSU sites may have requirements that differ from MSU for exempt research. Note that this also applies to sites added after the MSU exempt determination.

☒ Acknowledged

6E. LIMITED IRB REVIEW. If the exemption(s) require limited IRB review (if you selected Exemption 2(iii) or 3(i)(C) in Question 6A), complete questions 1 and 2 to describe privacy and confidentiality.

6E1. Privacy of Subjects.

How will subjects' privacy be protected? Consider the number of individuals interacting with the subject or subject's records, location of consent process and study, presence of individuals not associated with the study, sensitivity of the research.

6E2. Confidentiality of Data.

6E2i. Select the appropriate option:

Identifying or coded information will not be stored with the information and/or biospecimen(s)

☐ Identifying or coded information will be stored with the information and/or biospecimen(s)

6E2ii. Please explain your selection. If you are storing identifying or coded information with the information and/or biospecimen(s), explain why identifiable or coded information and/or biospecimen(s) needs to be maintained and how long it will be necessary to maintain it.

6E2iii. Describe the procedures and safeguards you will use to secure the information and/or biospecimen(s), including during transport of information and/or biospecimen(s).

Other Click IRB Documents to Upload As Appropriate (Applicable to All Studies)
• *Upload this completed protocol to the Basic Information SmartForm page, Question 10.* • *Upload any funding materials not accessible in Kuali Coeus in the Supporting Documents SmartForm page.* • *Upload the HRP-537 - Template - Use of Protected Health Information Application to the MSU Additional Study Information SmartForm page.* • *Upload the HRP-538 - Template - MSU Authorization to Use or Disclose Health Information for Researchers to the MSU Additional Study Information SmartForm page.*

IF THE STUDY MAY QUALIFY FOR AN EXEMPTION (INCLUDING THOSE THAT MAY REQUIRE LIMITED IRB REVIEW), STOP HERE AND DO NOT COMPLETE SECTION II.

CONTINUE ONLY IF THE STUDY DOES NOT QUALIFY FOR AN EXEMPTION.

COMPLETE QUESTIONS 7-23 FOR AN EXPEDITED OR FULL BOARD STUDY.

Section II. Additional Questions for an Expedited or Full Board Study

Not all questions or sections are applicable to every study. If the question or section is not applicable, check the "Not Applicable" box. All other questions are required.

7. Expedited Categories.

7A. Please select the Expedited category(ies) and sub-categories as applicable to the study if the only involvement of human subjects in this study will be in one or more of the categories. If the study involves more than minimal risk or none apply, select "The study involves more than minimal risk OR none of the expedited category(ies) apply."

☐ ***The study involves more than minimal risk OR none of the expedited categories apply. IF THIS OPTION IS SELECTED, DO NOT SELECT ANY OF THE EXPEDITED CATEGORY(IES).***

☐ ***Expedited 1.*** Clinical studies of drugs and medical devices only when condition (a) or (b) is met. ***IF YOU SELECT THIS CATEGORY, SELECT THE APPROPRIATE OPTION(S) BELOW***.

☐ (a) Research on drugs for which an investigational new drug application (21 CFR Part 312) is not required. (Note: Research on marketed drugs that significantly increases the risks or decreases the acceptability of the risks associated with the use of the product is not eligible for expedited review.)

☐ (b) Research on medical devices for which (i) an investigational device exemption application (21 CFR Part 812) is not required; or (ii) the medical device is cleared/approved for marketing and the medical device is being used in accordance with its cleared/approved labeling.

☐ ***Expedited 2***. Collection of blood samples by finger stick, heel stick, ear stick, or venipuncture. ***IF YOU SELECT THIS CATEGORY, SELECT THE APPROPRIATE OPTION(S) BELOW***.

☐ (a) from healthy, nonpregnant adults who weigh at least 110 pounds. For these subjects, the amounts drawn may not exceed 550 ml in an 8 week period and collection may not occur more frequently than 2 times per week; or

☐ (b) from other adults and children [2], considering the age, weight, and health of the subjects, the collection procedure, the amount of blood to be collected, and the frequency with which it will be collected. For these subjects, the amount drawn may not exceed the lesser of 50 ml or 3 ml per kg in an 8 week period and collection may not occur more frequently than 2 times per week

☐ ***Expedited 3***. Prospective collection of biological specimens for research purposes by noninvasive means.

☐ ***Expedited 4***. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.)

☐ ***Expedited 5***. Research involving materials (data, documents, records, or specimens) that have been collected, or will be collected solely for nonresearch purposes (such as medical treatment or diagnosis).

☒ ***Expedited 6***. Collection of data from voice, video, digital, or image recordings made for research purposes.

☒ ***Expedited 7***. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

7B. **For Studies Regulated by the U.S. Food and Drug Administration or the U.S. Department of Justice**. If you selected an expedited category, explain why the study presents minimal risk to subjects.

8. More than Minimal Risk Research. *Complete the following question if you selected "The study involves more than minimal risk OR none of the expedited categories apply" in Question 7A (Expedited Categories).*

8A. Describe the relevant prior experience and gaps in current knowledge, relevant preliminary data, if any, and the scholarly background for, and significance of, the research based on existing literature and how it will add to existing knowledge.

8B. Sample Size.

8Bi. Total number of subjects who will be approached (including screen failures, controls and subject withdrawals) to reach enrollment numbers for the lifetime of the study at this investigator's sites.

8Bii. Total number of subjects who will be enrolled in the study at this investigator's site.

8Biii. Describe the statistical justification or rationale for the proposed sample size. Considerations for sample size may include the acceptable level of significance, power of the study, expected effect size, underlying event rate in the population, standard deviation in the population, saturation of themes, and/or have a theoretical basis.

9. Minimal Risk Research. *Complete the following question if you selected an expedited category in Question 7A.*

9A. Briefly describe the background for conducting the research. (1-2 sentences)

The proposed study builds on my prior research I conducted in Kenya. I deployed sensors for supporting domestic security and power blackouts and, findings suggest that participants are also interested in using sensors to support poultry farming.

9B. Sample Size.

9Bi. Provide an estimated sample size for the lifetime of the study at this investigator's sites.

15

9Bii. Describe the basis for that estimate.

Other studies that have explored the role of sensors have used this sample size. This will be sufficient sample size to collect enough data to answer my research questions.

10. Benefits.

Describe any potential direct benefit(s) to subjects in this study, if any and the importance of the knowledge that may reasonably be expected to result. Within the description, do not include payment to subjects as a benefit.

Participants will be getting notifications about various conditions (e.g., temperature) in their chicken coop. They can use these conditions to make decisions about how to improve their poultry farming business.

11. Screening, Recruitment, and Determining Eligibility.

11A. Describe how subjects will be identified and recruited, including who will perform the recruitment.

Subjects will be recruited through purposive sampling. Specifically, we will be looking for participants who have atleast 30 chickens in their coop and also have have a mobile phone.

CLICK IRB: Upload the recruitment materials to the Consent Forms and Recruitment Materials SmartForm page, Question 2.

11B. The study team will obtain for the purpose of screening, recruiting, or determining the eligibility of prospective subjects (please select the appropriate option(s)): ☒ Not Applicable

nformation through oral or written communication with the prospective subject or legally authorized representative. Before the information is obtained for the purpose of screening, recruiting, or determining eligibility, consent: ☐ will be obtained. ☐ will not be obtained. *Please describe screening consent procedures in Question 12.*

dentifiable private information or identifiable biospecimens by accessing records or stored identifiable biospecimens. Before the information is obtained for the purpose of screening, recruiting, or determining eligibility, consent: ☐ will be obtained. ☐ will not be obtained. *Please describe screening consent procedures in Question 12.*
e: The revised Common Rule permits an exception from informed consent for screening, recruiting, or determining eligibility when certain criteria are met; this exception does not apply to studies subject to the Pre-2018 Common Rule Requirements and/or studies regulated by the U.S. Food and Drug Administration (FDA).

11B1. ase explain your selection(s).

s is not applicable because our local collaborators in Malawi already have potential subjects who meet the requirements for the study. They will simply reach out to them and request their consent to participate in the study.

12. Consent Process.

12A. If the study involves adults, consent will be obtained from (select appropriate option(s)): ☐ Not Applicable

☒ All subjects

☐ Some subjects

☐ No subjects (consent will not be obtained)

CLICK IRB: Upload the consent document, script, etc. (including translations) to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

12B. If the study involves children, parental permission will be obtained from (select appropriate option(s)): ☒ Not Applicable

Both parents or guardians (unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the child)

☐ One parent or guardian

☐ Will not be obtained

CLICK IRB: Upload the parental permission forms to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

12C. If the study involves children, child assent will be obtained from (select appropriate option): ☒ Not Applicable

☐ All children

☐ Some children

☐ Will not be obtained

CLICK IRB: Upload the child assent form to the Consent Forms and Recruitment Materials SmartForm page, Question 1.

12D. Describe the consent process, including an explanation of your selection(s) above. If the study involves screening activities, please describe whether consent will be obtained and if consent will not be obtained, explain how the screening data will be used. If only some subjects will provide consent, explain who will or will not provide consent. If only some children will provide assent, explain which children will and will not provide assent.

Consent to participate will be read out to participant before they start participating in the study. Once they agree to participate, subjects will be asked to sign a consent form.

12E. If consent will not be obtained, explain why. Describe why the research could not be practicably carried out if consent was required. If the research involves identifiable private information or identifiable biospecimens, describe why the research could not practicably be carried out without using such information or biospecimens in an identifiable format. ☒ Not Applicable

12F. If your study involves use of a consent form, complete i, ii, and iii. ☐ Not Applicable

12Fi. Select the appropriate option(s) below for the documentation of consent.

☒ Will use a written consent document signed by subjects

☐ Will use a short form written consent document signed by subjects

☐ Will not obtain a signed consent document for some subjects

☐ Will not obtain a signed consent document for all subjects

12Fii. Describe when and how the subject will receive a copy of the consent form.

Subjects will receive a copy of the consent form before participating in the study.

12Fiii. If subjects will not be signing the consent document, please explain why. If some subjects will not sign the consent document, explain who will and will not sign the consent. ☒ Not Applicable

12G. If the study involves cognitively impaired adults, explain the process to determine whether a subject is capable of consent, use of any legally authorized representative(s), and any assent process.

☒ Not Applicable

CLICK IRB: Upload any assessment tools to the Supporting Documents SmartForm page.

13. Coercion or Undue Influence.

13A. If some or all of the subjects are likely to be vulnerable to coercion or undue influence, such as children, prisoners, pregnant women, mentally disabled persons, individuals with impaired decision-making capacity, or economically or educationally disadvantaged persons, describe additional safeguards that have been included in the study.

☒ Not Applicable

13B. If you or your study team are associated with the subjects (e.g. your students, employees, colleagues, patients), explain the nature of any association and measures taken to protect subjects' rights, including safeguards against any coercion or undue influence (e.g. pressure a subject might feel to participate based on the association).

☒ Not Applicable

14. Privacy.

How will subjects' privacy be protected? Consider the number of individuals interacting with the subject or subject's records, location of consent process and study, presence of individuals not associated with the study, sensitivity of the research.

All information in the study will be kept private in a hard drive that will be kept at MSU's Department of Media and Information. Only members of the research team analyzing data will have access to the hard drive.

15. Withdrawal of Subjects.

☒ Not Applicable

If there are any anticipated circumstances where the researcher will withdraw subjects from the study regardless of the subject's wishes, describe the circumstances and the procedures when subjects are withdrawn from the study.

16. Monitoring Plan to Assess Data to Ensure Safety of Subjects.

16A. Is there a monitoring plan to periodically assess the data to ensure the safety of subjects or to ensure negative outcomes do not occur?

☐ No
☒ Yes

Explain your answer. If you answered Yes, describe the monitoring plan.

Data will only be accessed by researchers during the time of analysis. Once all analysis is done, all data associated with the study will be discarded for privacy purposes.

CLICK IRB: Upload any data safety monitoring plans to the Supporting Documents SmartForm pages.

16B. If there is a data safety monitoring committee or board, describe the composition and frequency of meetings.

☒ Not Applicable

17. Results and Data Sharing.

17A. Could this research generate any results that could be clinically relevant, including individual research results, or general, or aggregate research findings?

☒ No
☐ Yes, clinically relevant individual research results
☐ Yes, clinically relevant general or aggregate research findings

17A1. If yes, explain what clinically relevant research results will be generated, whether they will be disclosed to subjects or others (e.g. subject's primary care physician), and if so, under what conditions. Address individual research results and/or general or aggregate research findings, as appropriate. *This also needs to be explained in the consent document.*

17B. For other research results, select all that apply:

☒ Not Applicable

☐ Overall study results will be shared directly with subjects
ndividual results or incidental findings of individual subjects will be shared with subjects or others
)ata will be submitted to a repository or database as part of data sharing agreement (e.g. genomic data sharing)

17B1. Explain your selection(s), including how the data or results will be shared and with who (e.g. subject's primary care physician, data repository).

The study's results will not be shared with participants and also, data will not be submitted to any repository for public use.

18. Local Context and Multi-Site Study.

18A. Describe the locations of where the study team will obtain information or biospecimens through intervention or interaction with the subject or obtain the subjects' private identifiable information.

The study will obtain information from Chikhwawa district in Malawi and MSU poultry farm. Specifically, information from MSU farm will be collected remotely through data logging. In addition to that information from Chikhwawa will obtained through diaries and interviews.

18B. If the study will engage employees or agents of non-MSU organizations (e.g. performance sites), explain how the employees or agents will be engaged (e.g. will they perform research procedures, will they obtain informed consent from subjects). ☐ Not Applicable

Subjects will be asked to use the proposed system on daily basis. We will encourage participants to interact with the system and comment about their experiences in a diary.

18C. If the study involves multiple performance sites, describe the methods for communicating with engaged sites related to the protection of human subjects (e.g. any potential unanticipated problems that may involve risks to subjects others). ☐ Not Applicable

The studies will be conducted sequentially thereby reducing risks of inardvently providing information of some subjects to other subjects.

18D. If there are any cultural or local contexts or requirements that may impact the protection of human subjects or present additional risks to subjects that have not otherwise been described, please describe. If research is conducted outside the state of Michigan, this could include additional state or international requirements or laws. ☒ Not Applicable

18E. If translations to a language other than English will be provided to subjects, describe the translation process. ☒ Not Applicable

CLICK IRB: Upload translated documents to the appropriate SmartForm page(s).

19. Resources and Financial Compensation and Costs.

19A. If someone will receive a payment for recruiting the subjects, explain the amount of payment, who pays it, who receives it, and why they are being paid. ☒ Not Applicable

19B. If subjects will incur additional financial costs as a result of their participation in this study, explain the additional costs.

☒ Not Applicable

19C. Describe any resources not otherwise described elsewhere in the submission (e.g. internal funding) for the protection of human subjects.

☒ Not Applicable

CLICK IRB: Upload any funding materials not accessible in Kuali Coeus in the Supporting Documents SmartForm page.

19D. If subject's biospecimens (even if identifiers are removed) may be used for commercial profit, describe whether the subject will or will not share in the commercial profit. *This also needs to be explained in the consent document.*

☒ Not Applicable

20. Information and/or Biospecimen(s) Management and Confidentiality.

20A. Select the appropriate option:

☒ Identifying or coded information will not be stored with the information and/or biospecimen(s)
☐ Identifying or coded information will be stored with the information and/or biospecimen(s)

20B. Please explain your selection. If you are storing identifying or coded information with the information and/or biospecimen(s), explain why identifiable or coded information and/or biospecimen(s) needs to be maintained and how long it will be necessary to maintain it.

Each participant in the study will be assigned a pseudonym that will be used throughout the study. This information will be kept separate to the hard drive that will contain all data.

20C. Describe the procedures and safeguards you will use to secure the information and/or biospecimen(s), including during transport of information and/or biospecimen(s).

All information in the study will be kept private in a hard drive that will be kept at MSU's Department of Media and Information. Only members of the research team analyzing data will have access to the hard drive.

21. Drug and/or Device Storage, Handling, and Administration.

☒ Not Applicable

Describe the procedure and plan for storage, handling, and administration of the drug and/or device so that they will be used only on enrolled subjects and be used only by authorized study personnel.

22. Future Research.

If the research involves the collection of identifiable private information or identifiable biospecimens, select the appropriate option: ☐ Not Applicable

The subject's information or biospecimens, even if identifiers are removed, could be used for future research studies or distributed to another investigator for future research studies

The subject's information or biospecimens, even if identifiers are removed, will NOT be used or distributed for future research studies

Please be sure to carefully consider the appropriate option, as this needs to be explained in the informed consent and can limit what is done or used for future research.

23. MSU Additional Information. ☒ Not Applicable

Identify if your study involves any of the following: (check all that apply)

☐ Use of human stem cells

Research with biospecimens will (if known) or might include whole genome sequencing (i.e., sequencing of a human germline or somatic specimen with the intent to generate the genome or exome sequence of that specimen). *If so, this needs to be explained in the consent document.*

Other Click IRB Document Uploads As Appropriate (Applicable to Expedited or Full Board Studies)
• *Upload list of external study team members (non-MSU individuals) to the Study Team Members SmartForm page, Question 2.* • *Upload other institution(s) approval letter(s), if submitted to other IRB(s) or ethics committees, to the Supporting Documents SmartForm page.* • *Upload FDA communications, package inserts, FDA form 1572, or other information related to drugs or devices to the appropriate Drug or Device SmartForm pages.* • *Upload the HRP-540 - Template - ICH-GCP - For Investigator to the MSU Additional Study Information SmartForm page.* • *Upload HRP-541 - Template - Involvement of Prisoners in a Research Project to the MSU Additional Study Information SmartForm page.* • *Upload the investigator brochure to the Supporting Documents SmartForm page* • *Upload the MRI Screening Form – Women to the Supporting Documents SmartForm page.* • *Upload the translation of instrument(s) provided to non-English speaking subjects to the Supporting Documents SmartForm page.* • *Upload the curriculum vitae(s) when research is more than minimum risk to the Supporting Documents SmartForm page.* • *Upload case report forms to the Supporting Documents SmartForm page.* • *Upload the Non-MSU Employee Conflict of Interest Disclosure Form to the Supporting Documents SmartForm page.* • *Upload any other pertinent documents related to the proposed research study to the Supporting Documents SmartForm page*

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