M-Kulinda: Using a Sensor-Based Technology Probe to Explore Domestic Security in Rural Kenya

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ABSTRACT
In rural Kenyan households, property theft is a persistent problem. To explore how Information and Communication Technologies (ICTs) may be used to address this problem we designed and deployed "M-Kulinda"—a sensor-based technology probe. We used interview, observation, diary, and data logging methods to understand 20 households' experiences using the system. Our findings suggest that a probe's approach is useful in this context, more specifically we found that participants used our system in different ways to address their specific needs (e.g., monitoring poultry, electronics, and their family members). We also observed changes in our participants' understanding of sensors; M-Kulinda prompted them to reflect on other areas where sensors could be used in their households. We present design implications based on these findings, and offer new perspectives on the role of technology in deterring crime.

Author Keywords
Technology Probes; Kenya; Rural; Home Protection; HCI4D; ICTD

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Over 50% of crimes in the developing world involves loss of personal property in the domestic space through theft [22]. In 2014, there were 2259 reported cases of burglary in Kenya [55]. While crime rates are declining in industrialized countries, [19] they are increasing in developing countries; [22] within the developing world, rural Africa is the most affected by crime. This is a persistent problem that results in significant loss of personal property. In this paper, we focus on domestic security. We define this as the state of being protected against theft of personal property, and against domestic intruders.

We explore the role ICTs can play in domestic security – specifically, the potential of sensor-based technologies for deterring theft in rural Kenyan households. Sensors have been used to address different concerns (see [5,27,33,70]); however, their impact on home protection in rural Africa has not been researched. This raises questions for researchers: for instance, how can rural Kenyan households use sensors for home security? What other ways can sensors be used for in rural Kenyan households?

To answer these questions, we designed and deployed "M-Kulinda" (*kulinda* is Swahili for "protection") a technology probe that uses sensors to monitor households and that, when activated, sends users an SMS alert to their mobile phone. The study consisted of two phases. We first interviewed 20 householders about their security practices and gave them the probe to interact with for a month. We then conducted follow-up interviews with these householders and asked questions about the impact of our system. Participants' diary entries also informed our analysis, as did data collected from data logging.

Technology probes should be flexible and adaptable technologies introduced to families [28]. We found that our participants used M-Kulinda in this way to provide security in their homes: for example, participants used our system to monitor their poultry, their electronics devices, and their lives. Our findings also suggest that M-Kulinda could foster neighborhood cohesion in rural Kenya. As well, we learned that providing participants with a sensor-based security system was useful for gleaning insights into how sensor-based technologies can be used in rural Kenyan households in ways other than supporting domestic security.

Using technology probes to study security in rural Kenyan households draws attention to how rural households in rural Africa use sensor-based security systems to suit their needs. The study also extends prior work on home security [17], by suggesting that, unlike in industrialized countries, crime-detection systems strengthen neighborhood cohesion and play a role in dissuading thieves from invading a home. This study also demonstrates how a technology probe's approach can be useful in rural Kenya, a context where they

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have not been used. Lastly, this research draws attention to future opportunities in HCI for studying sensor-based technologies in rural Africa.

RELATED WORK

Domestic Spaces

The home remains a central focus of research interest within HCI and its allied disciplines (i.e., Ubicomp). We do not review this vast literature here (see [16] for an overview); instead, we situate our investigation in prior studies that are most relevant to ours: specifically, research that encourages technologists to broaden their knowledge of home environments to include those outside of the "Western European world" [2.16], and studies that investigate domestic security and use technology probes in homes.

The breadth of family types, geographic regions, and cultures examined in prior research demonstrates that "homes are not the same everywhere" [2]; neither are the varied ways that ICTs have—and will—become integrated into people's domestic lives. However, significant gaps in the literature remain, and as Desjardins *et al.* found in their comprehensive review of these studies, this research overwhelmingly takes place in American and European contexts. They write that this narrow focus "creates a western view of the home," adding that this is a limitation of research in the field [16].

At the same time, interest in ICT use in Africa and similar contexts (generally described as "developing" countries) is growing, as evidenced by a number of studies conducted in Kenya [47,48,53,65,66] and elsewhere on the continent [1,3,26,38]. This broad area of study, which is sometimes referred to as Information Communication Technology and Development (ICTD), and/or Human-Computer Interaction for Development (HCI4D), is concerned with the "distinctive needs of users in developing regions" [24]. Research in these fields generally examines mobile phone use and/or mobile applications designed to address socioeconomic problems on the continent by providing peoples with "useful information" (on, e.g., education, health, governance, and livelihoods [63]), frequently via text messages (see [14,60,67] for overviews). There are exceptions [3,36], but little is known about domestic spaces in these regions, especially in rural areas. Further, even less is known about how ICTs can address other significant problems that are not strictly related to socioeconomic development, such as domestic security.

Domestic Security

Although domestic security has been understudied in HCI4D/ICTD research, it is a topic that scholars in criminology recognize as significant. Domestic security is a persistent problem in rural Africa; the most common issues include: burglars breaking into households; poultry theft; cattle rustling; and theft from grocery stores [7]. Although there are few examples of these studies in rural Africa, findings from Bunei *et al*., suggest that crime in the home is one [8]. Prior research suggests that rural areas are targeted by "thieves" more than are urban ones, because rural areas do not have close supervision [8]; that is, rural areas often lack social services like police stations [46]. One way people have worked to solve this problem is through "community policing," which has been introduced in places where neighboring households are close together. These collections of households have their own authorities to whom members report crimes and conflicts. This security measure is called 'Manyumba Kumi' ("ten houses") in rural Kenya and it has proven to help in reducing crime [34]; however, the integration of this initiative with technology has not been explored.

Within HCI, Oduor *et al*. studied the role of using smartphone-based applications to report crime, and claimed that participants preferred using online platforms to report crime [46]. However, in a country like Kenya where over 85% of mobile phone users use feature phones [43], the outcome of using smartphones in research may not be representative of the rural population. Prior research has called for providing people in rural areas with technology to secure their homes. For example, Tilley *et al*. studied the economically disadvantaged population living in rural areas of the U.K [58], and concluded that providing people with more technology to secure their homes may decrease burglary, especially in poorer neighborhoods.

Security in HCI

ICT's potential role in preventing domestic insecurity has been considered in prior HCI research. Erete investigated burglars' behaviors and found that burglar-detecting technologies, such as alarms, are not effective in preventing them from stealing. Her findings suggest that, instead, high community cohesion (neighborhood cohesion) is the most effective deterrent of burglars [17]. Based on these findings, she suggests that technology should be designed to encourage neighborhood cohesion; that is, ICTs should be designed to encourage collective action among community members [17].

In a related study, Lewis and Lewis analyzed 865 posts from a community web forum to examine the use of technology in community policing [37]. They found that residents use the forum to strengthen social ties, to discuss ways to take collective action, to share information and advice, and to regulate social norms of the neighborhood and web forum. They proposed that technologies intended for crime prevention should be designed to support communication and problem-solving discussion amongst residents, as opposed to simply providing information to people in a particular community.

At the same time, research suggests that technology can play an integral role in promoting civil liberties for people with differing socioeconomic backgrounds around the world [17]. Inequalities that influence crime are perpetuated by local policies which have mostly been shaped by groups

with political power [17]. This notion is also evident in Kenya where, for the most part, the poor have no say in formulating policies [31]. This results in policies that only favor the rich, thereby inciting crime and violence from the poor. Erete proposed that HCI researchers consider the broader ecological infrastructure that affect social issues. These opportunities should also be extended to developing regions. This presents an opportunity for HCI researchers to investigate the role technology can play in crime prevention.

The outcomes of this research might be different from how technology works to provide security in other regions across the globe, due to differing social and cultural parameters of an area, as well as the needs of the people living in that area. Few studies in the developing world have considered the domestic space a defensible area that should be protected from unwanted physical intrusion [7]. Little is known about how technology protects the domestic space, or what impact it has on potential intruders [17]. We begin to fill these gaps in the HCI literature by using a technology probe to investigate domestic security in rural Kenyan households.

Technology Probes

Hutchinson *et al.* described technology probes as "a particular type of probe that combines the social science goal of collecting information about the use and the users of the 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 to support their needs and desires" [28]. Technology probes do not necessarily turn families into designers, but allow participants to be active partners in the design process. They are typically used in the early stages of the design process, and are not focused on a specific purpose or expected manner of use; instead, they are to determine possible future technologies [28].

This approach has been widely used within HCI for exploring how to design technologies for domestic settings [6,29,35,45,51]. However, most studies that have used technology probes have taken place in industrialized countries. Prior research has shown that geographical, cultural and social settings of a region influence how people use technology [18,68]. Oyugi *et al*. discussed how cross-cultural differences affect evaluation methods [50]. They found that research approaches have different outcomes depending on location. For example, they deployed prototypes in the UK and in Kenya, and established that the DUCE method (see [32]) was successful in the UK, but not in Kenya.

Our study builds upon prior technology probes studies by balancing these multi-disciplinary influences: we used qualitative methods for data collection to learn about participants' behavior during the course of the study. We deployed a research product that worked in a real-world setting; and the research product inspired participants to reflect on their lives.

Sensors

Sensor-based technologies are providing new ways to augment human interactions with materials [34]. Findings from prior research suggest that new applications based on sensors have improved the way of life: networks to support agricultural production [27], sensing systems for real-world applications in health [9,20,21,23,62], embedded chips on appliances like kettles to support communication among family and friends in the UK [5], and sensor-based technologies for learning about outdoor environments [33].

There are exceptions: for example, using sensors to protect cattle from theft [33], or tracking goods in transit using GPS [13]; however, research investigating sensor-based technologies in developing regions are is rare, despite their potential for addressing problems. Within HCI there have been studies that have focused on sensor-based technologies [11,12,27,32,61]. For example, through the Aware Home Research Initiative, Kientz *et al.* evaluate users' experiences with sensor-based applications in order to develop applications that solve users' needs in the home [30]. Crabtree and Tolmie explored how non-digital materials in the home can be incorporated with digital materials. With sensors, almost everything can be connected to a network; thus, looking at things that have not been made digital is very important [12]. We build on these prior works that explore the process they have used to deploy sensor-based technologies in the domestic space.

SYSTEM OVERVIEW

Here, we describe the design and technical details of M-Kulinda, including the materials used to build it, and how it works. M-Kulinda is a sensor-based technology that is used to detect movement. Upon detecting motion, the system sends an SMS message to a mobile that hosts a SIM card of a number embedded in the system's program. We wanted participants to receive this notification through a device they owned; thus, we integrated the probe with a mobile phone.

The primary probe components are: a control box that includes an Arduino microcontroller, SIM900 GSM shield, light-emitting diode (LED), and a Pyroelectric Infrared (PIR) motion sensor. We used the Arduino microcontroller because it is open source [52] and affordable. Each GSM shield has a slot where we inserted a SIM card; we added 100 KES (about $1) of "credit" to each SIM card. This was necessary to send messages to participants' mobile phones. The system was powered by a solar battery, which lasted up to 30 hours with a full charge (Figure 1).

We used a PIR sensor, rather than a reed switch (a fixed electrical switch operated by an applied magnetic field), because we wanted the probe to be mobile; that is, we wanted participants to be able to choose where to place it during evaluation. The PIR sensors detect motion made by

humans and/or animals (up to 20ft and at a 120^0 detection angle) based on the amount of infrared radiated from the surrounding; when there is a change in the amount of infrared, the sensor detects the differential from its threshold, and triggers a signal [69].

Figure 1: Prototype: system unit, solar battery and user's mobile phone.

THE STUDY

Study Context

Our study took place in Bungoma County, Kenya, a rural area located in the western region of the country, about an eight-hour bus ride from Nairobi, Kenya's capital. Our participants lived in three of the county's constituencies: Kanduyi, Kabuchai, and Bumula. Similar to other rural settings in Africa, small-scale agriculture is the primary source of employment for 58% of households [63]; 4.5% of households in the region are connected to Kenya's national electrical grid [43], and mobile phone ownership is widespread with more than 80% of the population using mobile phones [33,54].

Domestic security is a major challenge in Bungoma. During our formative fieldwork, participants complained of losing their poultry, livestock, electronic devices, and agricultural produce to thieves. The levels of crime are high in rural areas where police units are far away [7]; prior research suggests that 98% of residents witnessed crime within the last three months [42].

Researcher Self-Disclosure

The primary author is originally from Malawi—a small landlocked country in southeastern Africa—and is currently pursuing a graduate degree in HCI at an American university. He has 20 years of experience living in his country's rural areas; these experiences—in particular, his encounters with burglary—influenced the project, inspired our intervention, and allowed him to empathize with participants in this study.

Participants

Two local research assistants helped us to identify participants, and to gain access to their households. We defined households 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" [42]; 20 participated in our study. Over the course of our deployment we primarily interacted with the heads of households (12 men; 8 women). We recruited them using snowball sampling: a sampling technique that yields a study sample through referrals made among people who share or know of others who possess some characteristics that are of research interest [4]. We used this technique because we wanted participants who are well known and trustworthy, as prior research that involved deployment studies indicated that theft of probes was a possibility [41].

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

Data Collection

This was a two-phase study; in both phases, we primarily used qualitative research methods to collect data. The first phase, or baseline study, involved interviews, M-Kulinda deployment, and home tours; the second phase, involved follow-up interviews and observations. We also used diaries [64], because we wanted participants to document their experiences when we were not there. Additional data collected included: time stamps when participants received alerts from the probe through messages that were logged into the SIM cards, and messages that participants sent to the primary author during the period of the study.

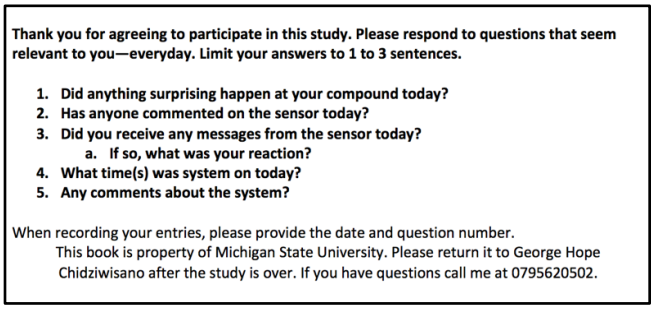
Phase I: Baseline Study and Prototype Deployment

English is widely spoken in Kenya, and this was the language used during interviews. The interviews took place in the "sitting room" in participants' homes. Some of the questions we asked were: "What measures do people use to provide security of their property?", "Tell us about recent examples where you witnessed insecurity in the area?", and "What do you know about sensor-based technologies?" At the conclusion of each interview we toured participants' compounds to observe what security measures they used, and then gave them the probe. All interviews (during the first and second phases) were digitally recorded, and with participants' permission we took pictures during sessions.

Following these tours, we introduced our technology probe to participants. We first explained how the probe worked, and then demonstrated it. Each participant provided us with their phone number so that we could embed it in the source code (set of instructions for controlling the probe). Then, we embedded the source code into the probe using a laptop. Finally, we unplugged M-Kulinda from the laptop. We powered it with the solar battery, we then asked participants to move around along the line of sight of the probe, and sent them a test SMS message. We also gave participants

instructions they could refer to over the course of the deployment (Figure 2). Lastly, we gave participants the primary researcher's mobile phone number, and encouraged them to call if they encountered problems.

During this phase, we also gave participants the diaries, and asked them to record their daily experiences with M-Kulinda over the four-week deployment period. Diaries included the following prompts: "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?". To motivate them to keep writing in the diary, we sent them 100 KES (about $1) worth of mobile phone credit every week.


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.

Figure 2: Diary study guidelines

Phase II: Follow-up Interview

Three to four weeks after the initial interview, we returned to participants' homes to conduct follow-up interviews. The goal of these interviews was to learn about participants' experiences with M-Kulinda—in particular, what (if any) impact if had on domestic security. Our 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". During this phase we also toured participants' compounds, asking them to show us where else they used the probe (for those who placed outside of their homes). As compensation for their participation, recipients received the solar charger, used to power the system (valued at about $25).

Analysis

Data analysis began in the field; each day, we wrote field notes documenting our observations. Interviews were transcribed, and we used open coding to identify themes [57]. We used an affinity diagraming process to organize these categories into groups based on their relationship at a higher level (presented here). The credibility and trustworthiness of these findings was enhanced through triangulation, which involved the analysis of our field notes, interview transcripts, digital photographs, diary entries, and messages sent from participants, as well as data collected from the logged-on SIM cards (documenting when SMS messages were sent).

FINDINGS

We begin by providing an overview of participants' compounds and the security measures they used in their homes. Next we present our findings about their experiences with M-Kulinda, including their general reactions to the system as well as their perceptions of sensors. Significantly, we found that M-Kulinda prompted different reactions from participants: it successfully worked as a technology probe. Despite its single functionality, participants used the probe for a variety of unexpected purposes.

Participants' Households and Security Measures

Most participants lived in compounds: that is, demarcated areas with more than three structures on them, including a main house. Structures in compounds typically included a house where parents sleep and where a household's most valuable property (e.g., TVs, radios, and food) were kept. They also included a boy's house, a girl's house, a pit latrine, a poultry house, and a kitchen. All structures were typically constructed out of brick, mud, and/or thatch, and had corrugated sheet metal roofs

Participants used different materials to define their properties' boundaries; these also served as an initial security measure. To limit entry to their compounds, these participants had a large iron gate with a sliding bolt lock (Figure 3). Those participants who were unable to afford such measures used banana trees, hedge, and/or sisal to fence their households. Participants mentioned other forms of security, such as using watchmen (*askari* in Swahili), and having multiple doors (layers on each other)—for example a grill door, followed by a steel door, and finally a wooden door. Iron doors that could be locked were preferred, but expensive.

We also observed this layering on windows: wire mesh, glass, and grill wire. The security measures mentioned above are used to provide a first line of defense. They deter thieves when they try to break into a compound: for example, a grill door provides participants with more security than a wooden door; however, when asked whether these forms of security are effective, participants' responses were mixed. For example "Davis"[1] said:

They are not 100% reliable (…). Because you need something which is okay, when you look back you have like something solid, which you are sure about that: my home is secured. You are sure about that but with the key and a wooden door anybody can break in, it's not really secure.

These and similar responses suggests that the current measures of security are not reliable. Participants use these measures only because they have no other options to complement these already existing measures of security in

[1] To preserve their anonymity, we replaced participants' names with pseudonyms

the home.

Figure 3: Top: Gate (main entrance into the compound). Bottom Left: Glass window with metal bars. Bottom Right: Sliding door.

Experiences using M-Kulinda

Nineteen participants used the probe throughout the four-week evaluation period; one participant encountered technical problems that limited his use of the probe. Participants told us that they mostly used M-Kulinda at night because during the day there was always someone at their home. This person was typically a woman who remained on compounds carrying out various domestic responsibilities (e.g., cleaning, food preparation, childcare). Evidence from the data collected from the SIM cards supported what participants told us: more than 850 alerts out of a total of 1176 alerts were sent at night. Participants added that they could hear the alerts at night because they kept their phones adjacent to their beds.

During Phase 1, study participants said that crime mostly takes place at night, which may explain this finding. Though data from a follow-up study indicated that there was no crime reported during the deployment period for all participants, we learned that chickens and agricultural produce were most likely to be stolen at night. M-Kulinda had no mechanism of detecting false alarms; however, data from diaries suggests that eight out of 20 participants found M-Kulinda useful for detecting intruders including unexpected visitors. Another reason our probe was mostly used as night, was because the batteries had to be charged during the daytime.

General Reactions to M-Kulinda

All participants were enthusiastic about M-Kulinda. They were appreciative that the technology probe helped them monitor their premises when no one was there. They especially appreciated receiving the SMS alerts. "Martha's" comments capture other participants' enthusiasm for the system:

The sensor was able to send me a message whenever it has detected something. I was happy there was something watching over my house. I could have a peaceful sleep.

Other evidence that suggested the probe was successful, included the SMS messages participants sent to the author, and their diary entries. During the study, 14 participants called and sent messages (at least three times) to the principal researcher on a weekly basis (Figure 4). This appreciation for the system extended beyond participants: it also included their neighbors, who expressed interest in participating in the study, and some of these messages were inquiries as to whether the neighbors could also participate in the study.

At the conclusion of the deployment, it seemed that participants generally had positive experience with the probe, as evidenced by their integration of the probe into their everyday activities, by how they used it, and by the concerns expressed at the end of the study about us taking the probe back, for example:

So you are taking the sensor? Why are you taking it away, I got used to it. Can I buy it?

Of course, this positive feedback may be biased and influenced by the researchers' affiliation with an American university [15]; however, the consistency and frequency of the positive reactions led us to generally conclude that M-Kulinda was useful for responding to our participants' concerns about domestic security.

M-Kulinda Usage

Technology probes should give participants flexibility so that they can be used in different ways [28]; here we describe instances of this in our study, they include home surveillance, neighborhood cohesion, and complementing non-digital forms of security in the home.

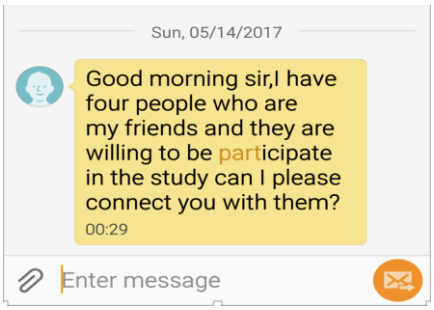


Figure 4: Representative SMS sent to author

Home surveillance

Although they installed M-Kulinda in specific locations in the households, 16 participants told us that they were also able to use the probe in different places. These participants expressed satisfaction in the portability of the system. How participants used the system varied depending on their personal needs. For example, the most frequent use was monitoring poultry in the home. In Bungoma County, chickens are important for food and income. "Francis" used the probe to monitor his chickens who had been dying mysteriously. He explains:

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 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 the M-Kulinda was used by men to monitor movements of family members. Similar to other rural African settings, patriarchal attitudes remain the norm, and we encountered men who wanted to use the system to monitor their wives and daughters' movements. For example "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.

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 said that she used the system to monitor what time her employee arrived at work:

I placed the sensor in my shop, switch 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 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" explains:

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 work 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 children, or their shops. M-Kulinda changed participants' way of doing things, as evidenced by different 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 wake up if they have received an alert from the probe.

Experiences Over Time

The trajectory of how participants experienced M-Kulinda changed over the course of our deployment. Chronologically, these experiences consisted of moments of excitement, frustration, acceptance, and appreciation. Diary entries at the beginning of the study (first week) indicate that participants had high expectations as they consistently mentioned that they are thankful that they have found a new way of protecting their homes. Participants also frequently showed the probe to their neighbors and commented on this in their diaries, writing that their neighbors wanted to acquire the probe. Also during installation of the probe, participants expressed excitement when they received an alert on their phones. They were curious on how the system was working. For example, here is "Mable's" reaction after testing the probe and seeing that it is working:

So is it you or the sensor that sent me an alert? How is it working? I am excited I will know what is going on even if I am not at home.

There were also some problems with the probe. After two weeks, nine participants called the principal researcher describing challenges they faced: these typically were related to keeping the solar battery charged—most often because it took too long to charge and they did not want to leave the battery outside (without monitoring) because someone may steal it. One participant explains:

The charging process takes long and I can't leave it outside by itself. It might be stolen. Sometimes I take the battery with me and charge it while I am at my garden.

Another frustration, identified in participants' diary entries, was the high number of alerts they received on their mobile phones: indeed, some received 90 alerts over the course of the study. In addition to the number of messages, participants were also frustrated that many SMS were unrelated to security, but were just alerting them that a family member had entered their household. However, by the end of the study, participants had found ways to ensure that they were not getting alerts unnecessarily. The impact of the probe in their lives outweighed the challenges they faced. "Betty's" quote from her diary reflected other participants' reactions:

Two weeks after using the sensor, I was frustrated that it was sending messages even if it sensed me. However, with time, I found my way around it. I was only switching it on when I am not at home or when I am sleeping. This helped in reducing unnecessary alerts. When the system alerted me when my boy entered the room where I keep money, I was

alerted too. The benefits of the sensor buried my frustrations and I got used to it.

This quote is representative of other participants' experiences with M-Kulinda: namely, that it improved with time, and they found many ways of making it useful in their home. Odom *et al*. found that new technologies are novel and 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 [45]. The fact that M-Kulinda's usage improved with time, and participants eventually appreciated how it worked, justifies the findings of prior research in different geographical, social, and cultural settings.

Neighborhood Cohesion

During baseline interviews participants consistently mentioned that when they were away at work or travelling they relied on their neighbors to tell them what was happening (e.g., neighbors would call when they see people standing by their compound gate). The increase in mobile phone penetration in Kenya has helped in improving economic and social standards though its use in some areas like home security is overlooked. "Mercy", for example, described how the mobile phone strengthens 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 receive an alert while they are far from 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 home so I wonder what is happening. I call my neighbors to check the compound for me.

Further, and related to sending SMS alerts, 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 they can see what's happening. Even if I am not at home neighbors can come.

In prior research, Erete suggests that neighborhood cohesion is a greater security measure than applications that are put in place to dissuade burglars [17]. Collectively, our findings suggest that neighborhood cohesion is crucial for home protection; participants' consistent suggestions for inclusion of audio alarms reveals how important this is in rural Kenya.

Participants' Perceptions of Sensors

An unexpected outcome of our deployment was learning that the probe was useful for understanding how technology could address their concerns about domestic security, and more generally about our participants' perceptions of 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, all participants only mentioned that sensors can be used to detect when something is wrong. "Neli" explains:

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 households. M-Kulinda made participants think about other ways sensors can help in their lives beyond home protection, and these reflections should be used for designing sensor-based systems that benefit rural African residents. "Betty" explains:

It can detect when the 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.

"Betty's" perception of how sensors can be used in her everyday life, as well as other participants' comments, 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 beyond regarding other ways sensors can help in their lives. A comparison of participants' views regarding sensors before M-Kulinda deployment, and after four weeks of use, suggests a change in how participants perceive sensors. This illustrates that the installation of M-Kulinda in participants' homes transitioned participants' knowledge on how sensors can be used in their homes. Sengers *et al.* 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 [56].

DISCUSSION

A contribution of our study is to show how people in rural Kenyan households use technology probes and thereby provide insight on how sensor-based technologies can be used in rural households. Participants' experiences of living with a technology probe in their houses consisted of a reflection of how sensor-based technologies can be helpful in their lives. Our findings on neighborhood cohesion draw attention to similarities between Western and non-Western contexts, and also reveal differences between these contexts including domestic security measures and infrastructural problems.

Design Implications

Our findings suggest some of the constraints that participants consistently mentioned in their diaries and during follow-up interviews. These constraints provide guidelines for

designing sensor-based security systems for rural Africa, and provide a starting point for designing products that meet these users' needs.

The first thing to consider when designing for rural Africa is the question of how the product will be integrated with existing infrastructure to deliver its functionality. This is important because for a product like M-Kulinda to work, it must rely on pre-existing systems, like communication networks and power supplies. Designers should carefully consider how the products they are developing will be powered in rural Africa. For example, it is important to include multiple ways of powering the product so that it will still works even if one form of power supply is not available.

Designing for Strengthening Neighborhood Cohesion

Erete found that crime detection system like alarms do not dissuade burglars; hence, she encouraged adopting crime prevention systems that strengthen neighborhood cohesion [17]. Based on findings, our view is that crime detection systems like alarms can also be used to foster neighborhood cohesion in rural Kenya. Crime detection systems can play a big role during different times—for example, when it is raining. During such times, the community members are mostly inside their households and no one can watch another person's house unless there are designated watchmen. Crime detection systems should be designed for such cases to alert other members in their households whenever there is crime.

It is important for designers of crime detection systems to carefully consider the constraints users will face. In addition to the obvious ones such as poor network infrastructure and power supply, it can be difficult for users to communicate with their crime detection systems during the rainy season because most houses do not have ceilings to reduce the noise from heavy rain. Standard alarm systems would thus not work effectively during rainy season; however, a system that uses a mobile phone as a platform for user communication could be more effective.

Crime Detection plays a role in neighborhood cohesion

With higher penetration rate of mobile phones in rural Kenya [33,54], technology should be easily integrated with pre-existing initiatives that aim at fostering community cohesion. For example, all members of the 'Manyumba Kumi' project would be linked to a single automated real-time system using sensors. The sensors should be used to detect security breaches, and instantly alert all members of that particular community of where in the breach has been detected. In this way, community members would be alerted, and could respond instantly to the situation.

Our findings suggest that participants recommended integrating M-Kulinda system with alarms. Participants also recommended that M-Kulinda should be connected to their neighbors who are members of the 'Manyumba Kumi' project. This means that crime-detection measures would be used to foster community cohesion – which, according to Erete, is an example of crime-prevention measures. Based on our findings, we argue that crime-detection technologies are important for home protection. Crime-detection technologies should therefore should be integrated with pre-existing neighborhood cohesion measures like the 'Manyumba Kumi' project to provide home security.

Open-Ended Design

One of the goals of our study was to establish how participants adopt and use the probe. Findings suggest that participants were able to use M-Kulinda for different purposes in their homes. We did not tell participants specifically what to do with M-Kulinda; rather, we simply told them that the probe can send an alert when it has detected motion. The choice of what specific things to detect was left up to the participants. In that way, participants reflected on how M-Kulinda fit in their lives.

Home security might mean different things based on the problems the subject is facing; as such, the open-ended nature of M-Kulinda helped participants to easily fit it in their lives. By 'open-ended design', we mean that participants should use the probe to solve whatever problem they are facing. For example, participants used our probe to monitor different things, ranging from live 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 was for monitoring anything that participants wanted to protect.

Our study contributes to HCI by providing findings that justify the notion of designing open-ended security-based systems. The findings suggest that people in rural Africa have security problems in their homes that are non-specific (unique). The design of our probe allowed participants to adopt and use it in their homes despite the non-specific security challenges each home faced.

M-Kulinda helped participants to think more about sensors

In our study, participants consistently mentioned that they have never used (or even seen) sensor-based technology, prior to receiving our probe. Our findings suggest that exposing participants to sensors allowed them to think about how sensor-based technologies like M-Kulinda can help in their lives.

These findings suggest that probes can be used to explore people's attitudes towards sensor-based technologies in rural areas and other design possibilities. For example, researchers can deploy sensor-based technologies that monitor power outages. As this is one of the problems that came out of participants' reflections from our study, studying it would extend the work we have started in the right direction. Neither we nor our participants had thought of monitoring power outages with sensors before the study. However, the power of technology probes allowed participants to think beyond, thereby generating ideas for further research. In the end, a better solution for monitoring power outages could be established.

Automated Security Systems

In our findings, participants consistently said that when "thieves" see any sign of alert, they run away, thinking that they have been seen. Unlike in industrialized regions [17], crime-detection technologies like alarms and lights are broadly considered to be effective. For example, when thieves see a light switching on by itself, it is assumed that they would think that the owner is awake, and they would then run away. This suggests that home security can be strengthened by people's unfamiliarity with the technical details on how sensors operate.

Though these concepts have proven to be successful in rural Kenya, they may not work in other regions where populations have greater knowledge about technology. Thus, despite these crime-detection measures being less effective in industrialized nations [17], our findings suggest they are effective in rural Kenya.

LIMITATIONS AND FUTURE WORK

Our study contributes to HCI by demonstrating the potential uses that sensor-based technologies can have for improving domestic security in rural Kenya. However, this study was not without its limitations, and we acknowledge that in just four weeks we cannot fully learn about the implications of M-Kulinda. Answering questions about the unintended consequences of using the system—whether it actually supports neighborhood cohesion, and what are the long-term implications of the system on family members' personal privacy—require a longer deployment. Additionally, our findings are not generalizable as we used non-probabilistic sampling methods to get a sample of twenty participants. Furthermore, the infrastructural challenges our participants faced affected how they used M-Kulinda. These challenges were primarily power and network problems. As our participants used solar to charge the battery, they sometimes complained about how long it took to charge the battery, because this meant that they could not use M-Kulinda that day; similarly, on some days the sunlight was not intense enough to fully charge the battery. Some households complained that network problems meant they sometimes got an alert late. These infrastructural challenges might have influenced participants' experiences with M-Kulinda.

Our findings suggest that participants reflected on different ways on how sensor-based technologies can be used in developing countries. Participants reflected on these solutions based on needs like: how can sensors be used to improve poultry and agrarian farming; how can microcontrollers be used to allow transfer of mobile money from one mobile operator to another; can sensors be used to alert people whether there is a power and/or water outage; and how can cameras and alarms be incorporated in sensor-based technologies to provide security in the home. Participants also reflected on how M-Kulinda could be improved to be a better system by, for instance, adding features such as a camera and/or alarm. In the future, we will return to Kenya with another technology probe that accounts for participants' recommendations in its design.

CONCLUSION

M-Kulinda was successfully used to monitor participants' homes. The use of M-Kulinda in rural Kenya opened new opportunities for participants to realize how sensor-based technologies can be used in their households. These opportunities deepen the HCI community's understanding of the use of sensor-based technologies for home protection in developing countries. Our findings also suggest major differences from prior work [17]. We attribute this to geographical and cultural difference between rural Kenya and the U.S., and to differences in users' understanding of the technology. In developing countries like rural Kenya, crime detection systems can be used to strengthen neighborhood cohesion. Lastly, our findings provide direction for future research on sensor-based technologies in developing countries.

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REFERENCES

1. Seyram Avle and Silvia Lindtner. 2016. Design (ing)'Here'and'There': Tech Entrepreneurs, Global Markets, and Reflexivity in Design Processes. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2233–2245. https://doi.org/10.1145/2858036.2858509
2. Genevieve Bell, Mark Blythe, and Phoebe Sengers. 2005. Making by making strange: Defamiliarization and the design of domestic technologies. *ACM Transactions on Computer-Human Interaction (TOCHI)* 12, 2: 149–173. https://doi.org/10.1145/1067860.1067862
3. Nicola J Bidwell, Masbulele Siya, Gary Marsden, William D Tucker, M Tshemese, N Gaven, S Ntlangano, Simon Robinson, and Kristen A L I Eglinton. 2008. Walking and the Social Life of Solar Charging in Rural Africa. *ACM Trans. Comput.-Hum. Interact.* 20, 4: 22:1--22:33. https://doi.org/10.1145/2493524
4. Patrick Biernacki and Dan Waldorf. 1981. Snowball sampling: Problems and techniques of chain referral sampling. *Sociological methods & research* 10, 2: 141–163.
5. Margot Brereton, Alessandro Soro, Kate Vaisutis, and Paul Roe. 2015. The messaging kettle: Prototyping connection over a distance between adult children and older parents. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 713–716. https://doi.org/10.1145/2702123.2702462
6. Hilary Browne, Benjamin B Bederson, Catherine Plaisant, and Allison Druin. 2001. *Designing an interactive message board as a technology probe for family communication*.

7. Emmanuel K Bunei, Samwel Auya, and Joseph K Rono. 2016. Agricultural crime in Africa. *The Routledge International Handbook of Rural Criminology*: 117.
8. Emmanuel K Bunei, Gerard McElwee, and Robert Smith. 2016. From bush to butchery: cattle rustling as an entrepreneurial process in Kenya. *Society and Business Review* 11, 1: 46–61.
9. Ke-Yu Chen, Shwetak N Patel, and Sean Keller. 2016. Finexus: Tracking precise motions of multiple fingertips using magnetic sensing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 1504–1514. https://doi.org/10.1145/2858036.2858125
10. Eun Kyoung Choe, Sunny Consolvo, Jaeyeon Jung, Beverly Harrison, Shwetak N Patel, and Julie A Kientz. 2012. Investigating receptiveness to sensing and inference in the home using sensor proxies. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, 61–70. https://doi.org/10.1145/2370216.2370226
11. Eun Kyoung Choe, Bongshin Lee, Matthew Kay, Wanda Pratt, and Julie A Kientz. 2015. SleepTight: low-burden, self-monitoring technology for capturing and reflecting on sleep behaviors. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 121–132. https://doi.org/10.1145/2750858.2804266
12. Andy Crabtree and Peter Tolmie. 2016. A Day in the Life of Things in the Home. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, 1738–1750. https://doi.org/10.1145/2818048.2819954
13. Ben Crow, James Davies, Susan Paterson, and Julio Miles. 2013. Using GPS and recall to understand water collection in Kenyan informal settlements. *Water international* 38, 1: 43–60.
14. Nicola Dell and Neha Kumar. 2016. The ins and outs of HCI for development. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2220–2232. https://doi.org/10.1145/2858036.2858081
15. Nicola Dell, Vidya Vaidyanathan, Indrani Medhi, Edward Cutrell, and William Thies. 2012. Yours is better!: participant response bias in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1321–1330. https://doi.org/10.1145/2207676.2208589
16. Audrey Desjardins, Ron Wakkary, William Odom, and British Columbia. 2015. Investigating Genres and Perspectives in HCI Research on the Home. 3073–3082. https://doi.org/10.1145/2702123.2702540
17. Sheena Lewis Erete. 2013. Protecting the home: exploring the roles of technology and citizen activism from a burglar's perspective. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*: 2507–2516. https://doi.org/10.1145/2470654.2481347
18. Vannessa Evers. 2001. Cultural aspects of user interface understanding. *Doc. Diss. Open Univ, London*.
19. Graham Farrell, Nick Tilley, and Andromachi Tseloni. 2014. Why the crime drop? *Crime and Justice* 43, 1: 421–490.
20. Mayank Goel, Elliot Saba, Maia Stiber, Eric Whitmire, Josh Fromm, Eric C Larson, Gaetano Borriello, and Shwetak N Patel. 2016. Spirocall: Measuring lung function over a phone call. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 5675–5685. https://doi.org/10.1145/2858036.2858401
21. Mayank Goel, Chen Zhao, Ruth Vinisha, and Shwetak N Patel. 2015. Tongue-in-Cheek: Using Wireless Signals to Enable Non-Intrusive and Flexible Facial Gestures Detection. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 255–258. https://doi.org/10.1145/2702123.2702591
22. Ulrike Grote and Frank Neubacher. 2016. *Rural Crime in Developing Countries: Theoretical Framework, Empirical Findings, Research Needs*. Hannover , Germany.
23. Kyoung Nam Ha, Kyung Chang Lee, and Suk Lee. 2006. Development of PIR sensor based indoor location detection system for smart home. In *SICE-ICASE, 2006. International Joint Conference*, 2162–2167.
24. M R Ho, T N Smyth, M Kam, and A Dearden. 2009. Human-Computer Interaction for Development: The Past, Present, and Future. *Information Technology and International Development (ITID)* 5, 4.
25. Steven Houben, Connie Golsteijn, Sarah Gallacher, Rose Johnson, Saskia Bakker, Nicolai Marquardt, Licia Capra, and Yvonne Rogers. 2016. Physikit: Data engagement through physical ambient visualizations in the home. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 1608–1619. https://doi.org/10.1145/2858036.2858059
26. Lara Houston. 2013. Inventive infrastructures: an exploration of mobile phone'repair'cultures in Kampala, Uganda.
27. Steve Howard, Jesper Kjeldskov, and Mikael B Skov. 2007. Pervasive computing in the domestic space. *Personal and Ubiquitous Computing* 11, 5: 329–333. https://doi.org/10.1007/s00779-006-0081-8
28. Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, and Heiko Hansen. 2003. Technology probes: inspiring design for and with families. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 17–24. https://doi.org/10.1145/642611.642616

29. Hilary Hutchinson, Catherine Plaisant, and Allison Druin. 2002. Case study: a message board as a technology probe for family communication and coordination. In *Proceedings of the 2002 Conference on Human Factors in Computing Systems (CHI Workshop on Technologies for Families), Minneapolis: ACM Press*.
30. Julie A Kientz, Shwetak N Patel, Brian Jones, E D Price, Elizabeth D Mynatt, and Gregory D Abowd. 2008. The georgia tech aware home. In *CHI'08 extended abstracts on Human factors in computing systems*, 3675–3680. https://doi.org/10.1145/1358628.1358911
31. Paul Kieti Kimalu. 2002. *A situational analysis of poverty in Kenya*. Kenya Institute for Public Policy Research and Analysis.
32. Eric Mutisya Kioko. 2017. Conflict Resolution and Crime Surveillance in Kenya: Local Peace Committees and Nyumba Kumi. *Africa Spectrum* 52, 1: 3–32.
33. Nir Kshetri. 2017. The economics of the Internet of Things in the Global South. *Third World Quarterly* 38, 2: 311–339. https://doi.org/10.1080/01436597.2016.1191942
34. Stacey Kuznetsov, William Odom, James Pierce, and Eric Paulos. 2011. Nurturing natural sensors. In *Proceedings of the 13th international conference on Ubiquitous computing*, 227–236. https://doi.org/10.1145/2030112.2030144
35. Geoff Langdale, Judy Kay, and Bob Kummerfeld. 2006. Using an intergenerational communications system as a'light-weight'technology probe. In *CHI'06 Extended Abstracts on Human Factors in Computing Systems*, 1001–1006. https://doi.org/10.1145/1125451.1125643
36. Kenneth Lee, Edward Miguel, and Catherine Wolfram. 2016. Appliance Ownership and Aspirations among Electric Grid and Home Solar Households in Rural Kenya. *The American Economic Review* 106, 5: 89–94.
37. Sheena Lewis and Dan A. Lewis. 2012. Examining technology that supports community policing. *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*: 1371. https://doi.org/10.1145/2207676.2208595
38. Arunesh Mathur, Brent Schlotfeldt, and Marshini Chetty. 2015. A mixed-methods study of mobile users' data usage practices in South Africa. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 1209–1220. https://doi.org/10.1145/2750858.2804292
39. Izumi Matsuda, Hiroshi Nittono, and Tokihiro Ogawa. 2011. Event-related potentials increase the discrimination performance of the autonomic-based concealed information test. *Psychophysiology* 48, 12: 1701–1710.
40. Francis M Munene. 2003. Household Population and Housing Characteristics. *Kenya Demographic and Health Survey. KCB o. Statistics. Nairobi, Kenya Central Bureau of Statistics*.
41. San Murugesan. 2013. Mobile apps in Africa. *IT Professional* 15, 5: 8–11.
42. Kyalo Musoi. 2014. *A study of crime in urban slums in Kenya: the case of Kibra, Bondeni, Manyatta and Mishomoroni slums*. Nairobi, Kenya.
43. Eston Ngugi. 2013. *Bungoma county*. Nairobi, Kenya.
44. Rebecca Njuki, Jerry Okal, Charlotte E Warren, Francis Obare, Timothy Abuya, Lucy Kanya, Chi-Chi Undie, Ben Bellows, and Ian Askew. 2012. Exploring the effectiveness of the output-based aid voucher program to increase uptake of gender-based violence recovery services in Kenya: a qualitative evaluation. *BMC Public Health* 12, 1: 426. https://doi.org/10.1186/1471-2458-12-426
45. William T Odom, Abigail J Sellen, Richard Banks, David S Kirk, Tim Regan, Mark Selby, Jodi L Forlizzi, and John Zimmerman. 2014. Designing for slowness, anticipation and re-visitation: a long term field study of the photobox. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1961–1970. https://doi.org/10.1145/2556288.2557178
46. Collins Oduor, Freddie Acosta, and Everlyne Makhanu. 2014. The adoption of mobile technology as a tool for situational crime prevention in Kenya. In *IST-Africa Conference Proceedings, 2014*, 1–7. https://doi.org/10.1109/ISTAFRICA.2014.6880669
47. Erick Oduor, Carman Neustaedter, and Kate Hennessy. 2016. The design and evaluation of a photograph-sharing application for rural and urban Kenyan families. *Personal and Ubiquitous Computing*: 1–19.
48. Erick Oduor, Carman Neustaedter, Tejinder K Judge, Kate Hennessy, Carolyn Pang, and Serena Hillman. 2014. How technology supports family communication in rural, suburban, and urban kenya. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*, 2705–2714. https://doi.org/10.1145/2556288.2557277
49. Shigehiro Oishi, Edward F Diener, Richard E Lucas, and Eunkook M Suh. 1999. Cross-cultural variations in predictors of life satisfaction: Perspectives from needs and values. *Personality and social psychology bulletin* 25, 8: 980–990.
50. Cecilia Oyugi, Lynne Dunckley, and Andy Smith. 2008. Evaluation methods and cultural differences: studies across three continents. *NordiCHI '08: Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*: 318–325. https://doi.org/10.1145/1463160.1463195

51. Aggeliki Pantazi, Abu Sebastian, T A Antonakopoulos, Peter Bächtold, Anthony R Bonaccio, Jose Bonan, Giovanni Cherubini, Michel Despont, Richard A DiPietro, and Ute Drechsler. 2008. Probe-based ultrahigh-density storage technology. *IBM Journal of Research and Development* 52, 4.5: 493–511.
52. Joshua M Pearce. 2012. Building Research Equipment with Free, Open-Source Hardware. *Science* 337, 6100: 1303 LP-1304. Retrieved from http://science.sciencemag.org/content/337/6100/1303.abstract
53. Trevor Perrier, Nicola Dell, Brian DeRenzi, Richard Anderson, John Kinuthia, Jennifer Unger, and Grace John-Stewart. 2015. Engaging Pregnant Women in Kenya with a Hybrid Computer-Human SMS Communication System. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*, 1429–1438. https://doi.org/10.1145/2702123.2702124
54. Jacob Poushter and Russ Oates. 2015. Cell phones in Africa: communication lifeline. *Washingston DC: Pew Research Centre*.
55. RISC. 2016. *Kenya 2016 Crime and Safety Report*. Nairobi, Kenya.
56. Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph'Jofish' Kaye. 2005. Reflective design. In *Proceedings of the 4th decennial conference on Critical computing: between sense and sensibility*, 49–58.
57. Anselm L Strauss. 1987. *Qualitative analysis for social scientists*. Cambridge University Press.
58. Nick Tilley, Andromachi Tseloni, and Graham Farrell. 2011. Income disparities of burglary risk: Security availability during the crime drop. *The British Journal of Criminology* 51, 2: 296–313.
59. Peter Tolmie, Andy Crabtree, Tom Rodden, James Colley, and Ewa Luger. 2016. "This has to be the cats": Personal Data Legibility in Networked Sensing Systems. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing*, 491–502. https://doi.org/10.1145/2818048.2819992
60. K Toyama. 2010. Human–Computer Interaction and Global Development. *Foundations and Trends in Human-Computer Interaction* 4, 1: 1–79.
61. Richard Vokes. 2016. Before the Call: Mobile Phones, Exchange Relations, and Social Change in South-western Uganda. *Ethnos: Journal of Anthropology*: 1–16.
62. Eric Whitmire, Laura Trutoiu, Robert Cavin, David Perek, Brian Scally, James Phillips, and Shwetak Patel. 2016. EyeContact: scleral coil eye tracking for virtual reality. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*, 184–191. https://doi.org/10.1145/2971763.2971771
63. Urs Martin Wiesmann, Boniface Kiteme, and Zachary Mwangi. 2014. *Socio-economic atlas of Kenya: depicting the National Population Census by county and sub-location*. Kenya National Bureau of Statistics, Centre for Training and Integrated Research in ASAL Development, Centre for Development and Environment.
64. V Wiseman, L Conteh, and F Matovu. 2005. Using diaries to collect data in resource-poor settings: questions on design and implementation. *Health Policy and Planning* 20, 6: 394–404.
65. Susan Wyche, Tawanna R Dillahunt, Nightingale Simiyu, and Sharon Alaka. 2015. "If God gives me the chance I will design my own phone": Exploring Mobile Phone Repair and Postcolonial Approaches to Design in Rural Kenya. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 463–473. https://doi.org/10.1145/2750858.2804249
66. Susan P Wyche and Laura L Murphy. 2013. Powering the cellphone revolution: findings from mobile phone charging trials in off-grid Kenya. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1959–1968. https://doi.org/10.1145/2470654.2466260
67. Susan Wyche and Charles Steinfield. 2015. Why Don't Farmers Use Cell Phones to Access Market Prices? Technology Affordances and Barriers to Market Information Services Adoption in Rural Kenya. *Information Technology for Development* 1102, July 2015: 1–14. https://doi.org/10.1080/02681102.2015.1048184
68. Alvin Yeo. 1998. Cultural effects in usability assessment. In *CHI 98 Cconference Summary on Human Factors in Computing Systems*, 74–75. https://doi.org/10.1145/286498.286536
69. Piero Zappi, Elisabetta Farella, and Luca Benini. 2010. Tracking motion direction and distance with pyroelectric IR sensors. *IEEE Sensors Journal* 10, 9: 1486–1494. https://doi.org/10.1109/JSEN.2009.2039792