Reducing Maternal Mortality: An Ultrasound System for Village Midwives

Waylon Brunette[1], Matthew Hicks[2], Alexis Hope[3], Ginger Ruddy[4], Ruth E. Anderson[1], Beth Kolko[3]

[1]Dept. of Computer Science & Engineering
University of Washington
Seattle, WA USA
{wrb, rea}@cse.uw.edu

[2]The Information School
University of Washington
Seattle, WA USA
mattheau@uw.edu

[3]Dept. of Human Centered Design & Engineering
University of Washington
Seattle, WA USA
{alexishg, bkolko}@uw.edu

[4]School of Public Health
University of Washington
Seattle, WA USA
ginger.ruddy@gmail.com

***Abstract*—On average a woman dies in childbirth approximately every 90 seconds, and the majority of these deaths take place in Africa and Asia [1]. While ultrasound imaging is an effective tool for identifying maternal mortality risk factors, it is nearly absent in many rural healthcare facilities in developing regions due to the high costs of both equipment and required training. To leverage existing healthcare systems commonly found in these contexts, we have focused on increasing the diagnostic capabilities of village midwives—often central medical figures in rural and low-income communities. We have developed a low-cost, portable, easy-to-use ultrasound system designed specifically to enable local midwives to identify high-risk conditions for referral to a well-equipped health care facility. Our focus has been on designing an *appropriate* system for our context. Specifically, we had to: simplify our user interface, support a solitary work environment, balance cost and features, and create an integrated teaching help system. This paper describes technical, socio-technical, and socio-cultural factors, drawn from our collaboration with the University of Washington Department of Radiology and our field experiences with midwives in Uganda, that have influenced our design.**

Keywords-ultrasound, Uganda, ICTD, healthcare technologies, maternal health, design, appropriate technology

I. INTRODUCTION

Globally, a woman dies in childbirth on average every ~90 seconds; over ninety percent of women who die are in Africa and Asia [1]. In Uganda, for example, the maternal mortality rate is 430 per 100,000 live births. Countries that are more politically unstable, such as Chad and Somalia, have rates of 1,200 maternal deaths per 100,000 live births. On the other hand, rates of maternal mortality in the United States are 24/100,000 [1]. However, small changes, such as identifying high risk patients, can potentially reduce preventable deaths in developing countries. Most of these preventable deaths occur because of severe bleeding, infections, ecclampsia, obstructed labor and the consequences of unsafe abortions [2]. These conditions can often be prevented if a woman is diagnosed early enough to be treated in a well-equipped healthcare facility by trained medical personnel. Three of these five conditions, specifically causes of hemorrhage, risk of obstructed labor, and dangerous sequelae of abortion, can be predicted or diagnosed using ultrasound technology, as can three of the top five causes of neonatal mortality [3]: birth asphyxia, injuries, and defects. However, the effect of ultrasound on maternal health outcomes is still inconclusive as researchers have argued that longitudinal studies must be performed to assess the ability of ultrasound to lessen maternal deaths [4]. To create a viable longitudinal study to answer this question, we need to have a low-cost, portable ultrasound system that can be easily deployed in rural developing regions. Cost is traditionally seen as the major barrier for widespread deployment of medical technology, but the situation is more nuanced. Longitudinal studies must integrate an ultrasound system that is appropriate to the populations in which they are introduced. The problem space of maternal ultrasound and health outcomes, then, is twofold. While lower cost commercial systems are increasingly available, those systems lack some characteristics that would allow them to be fully integrated into maternal health practice outside of better-equipped hospitals as appropriate technology.

The suitability of ultrasound for low-resource settings has been addressed by researchers Harris and Marks, and drawing on UNESCO technology evaluation guidelines, they highlight the criteria of feasibility, appropriateness, and impact as key [4]. Harris and Marks discuss issues of appropriateness at length, and their considered analysis of how a technology can usefully be deployed—without replicating neocolonial patterns or disrupting valuable forms of local knowledge—is a welcome addition to technology and development considerations. Our own work considers a balance of these three criteria, and our efforts are focused on developing a low cost, easy-to-use ultrasound system that will respond specifically to the need for feasible and appropriate technologies within low-resource settings.

To help lessen maternal and neonatal mortality rates, we have developed a portable ultrasound platform targeted at health practitioners with limited training. Specifically, our project aims to create an ultrasound system for midwives in Uganda that will enable them to identify potential pregnancy complications. Once a condition is identified the midwife then refers the mother with high-risk conditions to a well-equipped medical facility for delivery. In our prior work [6], we discussed the feasibility of our system, demonstrating that the combination of older ultrasound technology and a netbook form factor provided adequate image quality to identify three of the major causes of maternal hemorrhage: placenta previa, breech, and multiple gestations.

Our research since then has focused on questions of appropriateness and potential for impact. We have conducted a year-long research study of technical, socio-technical and socio-cultural elements in order to refine our system design. We have considered elements such as image quality, infrastructure, power, technology durability, user serviceability, human-computer interaction, midwife work practice, institutional constraints, and cultural and community factors in an attempt to create a system that is appropriate for the usage context. Our goal is to use this system in a deployment that will address the last criteria: impact. However, ultrasound technology alone will not lessen high maternal mortality rates; maternal and neonatal deaths are multifactorial problems that require multifaceted solutions. Socioeconomic causes include poverty, malnutrition, and limited access to health care. Leading medical causes include bleeding, infection, and complications of unsafe abortion [2]. Aspects like messaging to mothers, counteracting cultural expectations to give birth at home, and overcoming challenges of how much it costs in money and time to travel to hospitals all need to be addressed to create a solution likely to have eventual impact.

II. Background

In the developing world, midwives are on the front lines of delivering safe, effective antenatal and perinatal care to women and neonates. Providing this care requires midwives to encourage women to visit clinics during the antenatal and perinatal period, provide antenatal advice and health education, treat complications due to miscarriages and/or unsafe abortions, and other responsibilities [6]. In some communities where outside referral is not possible, midwives must also attend to the psychological health of their patients, or even perform surgical procedures [7]. In industrialized nations, a network of doctors, nurses, and specialists share these responsibilities, but in developing world settings, a midwife typically fulfills all of them. Since midwives provide the majority of primary care for women, they are trusted, respected figures in their communities and have a privileged, influential relationship with patients. This potential of this relationship to encourage more women to enter the antenatal care system has made supporting midwives an emerging focus of maternal and child health initiatives [8].

Unfortunately, many midwives lack fundamental diagnostic tools that could assist them in providing effective antenatal care. Ultrasound, for example, has been used to monitor high-risk pregnancies in most industrialized nations since the 1960s. In these countries, ultrasound scanning is a common and routine procedure, and it is well known for its ability to diagnose common high-risk conditions both safely and effectively [9]. In developing world settings, ultrasound has the potential to provide midwives with imaging data that could complement data from a patient history and physical, and help midwives assess the mother's risk of death from obstetrical complications. For instance, multiple gestations and placenta previa both predispose women to hemorrhage, which can cause maternal death, but up to 50% of multiple gestations and the vast majority of placenta previa are missed without ultrasound imaging [10]. If these complications are diagnosed in the prenatal period with ultrasound, a woman can be referred to a health center where she can receive a timely, safe caesarean section rather than undergoing a potentially dangerous vaginal delivery.

Existing studies have reinforced the viability and usefulness of ultrasound in resource-constrained environments, both for maternal health and other health complications. In a field trial in the Lugufu refugee camp in the Kigoma District, Tanzania, for example, four physicians and six clinical officers were trained to use ultrasound for a variety of conditions and contexts, including: trauma, renal ultrasound, pregnancy evaluation, echocardiography, and ultrasound guided procedures. Over a two-year deployment, the medical staff in the camp performed 547 ultrasound scans on 460 patients. Although this work evaluated ultrasound usage more broadly (for a variety of medical conditions), the results showed that ultrasound was also useful for female pelvic and obstetrical issues: 46% of the scans were of the female pelvis and half of these were directly related to pregnancy issues [11]. Another preliminary study in Siuna, Nicaragua has shown that compact ultrasound has the potential to reduce maternal death rates when used by trained physicians [4].

Despite the usefulness of ultrasound imaging, ultrasound systems are relatively absent in low-resource regions. This can be explained, in part, due to its high cost; traditional systems are prohibitively expensive for most developing world medical centers [4]. Over the past ten years, however, there has been a focus on developing lower-cost, portable ultrasound machines instead of expensive stationary machines, most notably by SonoSite, GE, and Philips. These portable machines range from about $15,000-$30,000, which can still be too costly for many public health budgets. Additionally, a new class of mobile ultrasounds machines are emerging (e.g. GE's VScan, Siemens P10), costing between $7000-$9000. However, these small devices only have a ~3-inch screen size (sub-optimal for performing obstetrical diagnostics) and no network connectivity. MobiSante [12] uses a mechanical probe (similar to our system) connected to a smartphone. While this solves the connectivity issues, it is not clear that performing obstetrical ultrasound on a smartphone is desirable because of limited screen space, limited processing ability, and limited battery life/power.

While ultrasound is a promising technology, other projects have looked at addressing maternal and neonatal mortality from different perspectives. Ramachandran et al. [13] employed short videos on mobile phones designed to persuade village women in India to adopt new health practices. This work showed that videos were useful in promoting dialogue among village women about health practices and showed positive effects toward health worker motivation and learning. The researchers also recognized the importance of designing interventions that take into account family and village power structures, noting, for example, that village women were often expected to follow the will of their mother-in-law in terms of seeking healthcare during pregnancy. In Ghana, the MoTeCH project [14] is developing appropriate services to provide relevant health information to pregnant women over mobile phones and encourage them to seek antenatal care at local facilities. They found that women were open to hearing information in a male voice and preferred messages given in a local accent. Other organizations like ARTH and PATH have employed a variety of interventions to influence maternal and neonatal health. ARTH [15] has worked in Rajasthan in midwife training, reviewing circumstances of maternal deaths, safer abortions and contraception education and assistance. PATH [16] has developed low tech approaches like the clean delivery kit, designed to reduce infection at birth. While our project looks at the utility of ultrasound, by no means would we argue it is the only effective means of improving maternal and neonatal health.

III. METHODOLOGY

To understand how diagnostic technology such as ultrasound could be integrated into a midwife's workflow, we partnered with the University of Washington Radiology department. This department has a Ugandan midwife ultrasound-training program. Currently, the training program teaches midwives to use ultrasound to diagnose three conditions (placenta previa, multiple gestations, and breech presentation) that contribute to maternal mortality. The focus of their study is to perform preliminary testing on the impact of training midwives in resource-poor regions to use portable ultrasound units to diagnose high-risk complications. Once a condition is identified, midwives refer at-risk patients to give birth in mid-level clinics. This project is intended to help fulfill the fifth United Nations' Millennium Development Goal (MDG), which advocates reducing maternal death rates by three-quarters between 1990 and 2015. We have partnered with radiology colleagues to develop a technology appropriate for their efforts. In our research to create an ultrasound system for midwives in Uganda, we have focused on the technology itself, socio-technical elements, and socio-cultural factors.

The work described in this paper is based on conversations with radiologists and sonographers in the United States, usability testing of the system in the U.S., surveys with the Ugandan midwives, findings from multiple field visits in Uganda by the radiology team with whom we work, and our own fieldwork in March 2011 in Uganda where we observed current work practices of midwives using ultrasound and performed iterative design work. Additionally, we conducted semi-structured interviews with radiologists, sonographers, and midwives familiar with the use of ultrasound by midwives in low-resource settings.

IV. CREATING AN APPROPRIATE ULTRASOUND SYSTEM

The appropriate technology literature and the work of researchers in the field of social construction of technology provide numerous examples of exquisitely designed technologies that fail to be adopted or to have their desired effects [17, 18]. The literature advocates for design that meets ethical, cultural, social, political and economic standards in the community for which it is intended. Leveraging existing systems, processes, and resources rather than trying to introduce radically new ones can help researchers design and deploy appropriate technology. It was with this in mind that we approached the design of an appropriate low-cost ultrasound system (called the Ultrasound PLUS — Portable Learning and User-centered System) to leverage Uganda's existing midwife-based healthcare system. Our initial work was focused on understanding the technical constraints of low-cost ultrasound systems and then determining which functionality was essential and which could be omitted in order to reduce cost and simplify our overall system design. As we proceeded, however, our fieldwork alerted us to various socio-technical factors that caused us to modify our system design to better match the technical skillsets of Ugandan midwives. Our design approach emphasizes work context and how technical functionality scaffolds certain work practices. To this end, our designs compensate for limited collaboration potential by building a novel medical help system within the ultrasound device to support existing work practices.

A. *Simplified Design*

We sent surveys to Ugandan midwives participating in the University of Washington Radiology department study to gain insight into their experiences with ultrasound. The study used portable GE LOGIQ Book ultrasound units, and the feedback from the midwives' surveys informed us that they had difficulty with some ultrasound features such as Time-Gain Control (TGC), which is a feature that allows the user to take an image of consistent brightness (from top to bottom of image). From our discussions with sonographers and radiologists, we learned that TGC, among other features such as harmonics control, were unnecessary to diagnose high-risk complications. Most compact ultrasound systems are designed specifically for experts with at least two years of ultrasound training [19]. Midwives in developing countries train for shorter amounts of time. Anecdotal data, in fact, has shown that midwives can learn how to properly diagnose high-risk complications within two weeks [4]. But based on early feedback from midwives and sonographers in the U.S., we made some initial decisions to simplify overall system functionality and the user interface (UI).

Our simplified UI design provides users with only the functionality necessary to diagnose high-risk conditions. Our design was also informed by semi-structured interviews with midwives trained in ultrasound, sonographers and radiologists familiar with use of ultrasound in low-resource settings, and observations of midwives using ultrasound technology in Uganda. Radiologists watching midwives use the GE machines in Uganda noticed that knobology—the ability to connect the behavior of knobs and sliders with on-screen functionality—was a significant struggle for the midwives. As a result, we designed our device so that while scanning, the touchscreen only displays three buttons, four image adjustment sliders, and a depth selection control. To compare, the GE LOGIQ Book UI is more complicated, with over fifty buttons and sliders that our target users do not need in order to detect basic pregnancy complications (See Figure 1). The GE LOGIQ Book is designed for expert ultrasound users and it maximizes the functionality of the machine; while an excellent device for clinical settings with highly trained practitioners, it is less appropriate for midwives with abbreviated ultrasound training.

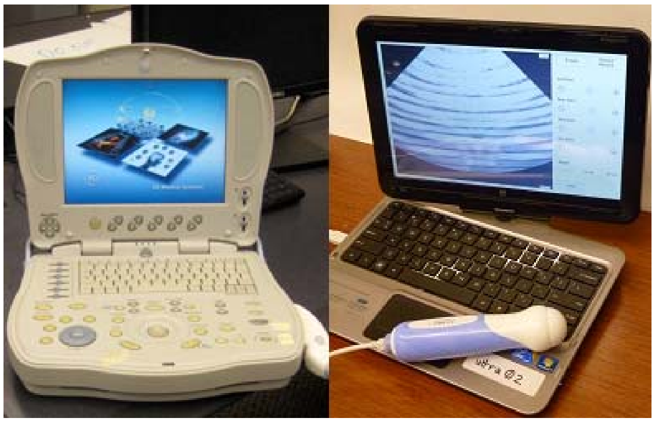

Figure 1. GE LOGIQ Book (left) and our system (right)

When we conducted fieldwork in March 2011, we discovered other socio-technical issues that affect the usability of our system design, including midwives' limited familiarity with personal computers and difficulty typing. In particular, these issues have implications for knobology and the design of our integrated patient data system. After observing the time it took midwives to fill out patient data forms that precede the examination, we attempted to reduce the number of fields to what was essential. In addition, we created drop down menus in place of open fields to facilitate more efficient use. Making the system more efficient makes it more likely that midwives will use it regularly in exams. Additionally, we do not want the midwives to have only limited knowledge of ultrasound. To increase midwives' ability to diagnose common complications and to supplement their abbreviated training, we designed a robust help system, which will be discussed later in section D. In the current version of our system, for example, if a midwife is confused while scanning a woman, she can click "Help" and choose among topics that are relevant to obstetrical ultrasound.

B. *Work Environment*

Understanding midwives and their current work experiences is paramount for designing a socially appropriate device for communities in resource-poor settings. All 12 midwives interviewed in Uganda in March 2011 reported that they worked long shifts at the clinics, frequently up to 12 hours in duration, and were almost always the only midwife on duty. In addition to using ultrasound to screen women for high-risk pregnancy conditions, midwives' other responsibilities include patient education and communication, delivering babies, and providing other types of care, including vaccination. At clinics, the number of babies delivered per month ranged from 30 per month at the smallest clinic, to 150 per month at the largest clinic. Realizing that clinics are under-staffed and midwives fulfill a variety of roles within their community, our focus was to minimize the amount of time the midwife has to spend with the device. Since they have a high patient load and other responsibilities competing for their attention, it was crucial to make our device as simple to use as possible. This was achieved by shortening the patient data form and eliminating unnecessary functionality (as described in the previous sections).

An important consideration in the design was the larger technology and work ecosystems. Internet connectivity was mostly non-existent throughout the clinics we visited in Uganda. GPRS modems provided some limited connectivity, though cell service was sparse in outlying areas. Recognizing that connectivity is nonexistent, or prohibitively expensive, led us to determine that teleradiology (where ultrasound images are sent to a remote radiologist for interpretation and diagnosis) was not an appropriate solution. However, in looking at the potential of teleradiology, we realized how the midwife being the sole practitioner raises additional challenges for ultrasound use, including the inability to consult colleagues when images are difficult to interpret. To address this challenge we created a contextual help system. This help system is designed to encourage midwives to explore the UI and increase their understanding of pregnancy complications and best practices of diagnostic ultrasound. Additionally, as discussed in [20], in order to usefully adapt mobile ultrasound technology to fit traditional midwifery work practices one must also understand the work settings within which ultrasound technology has been developed and widely deployed.

C. *Technology and Cost Balance*

We selected the Interson SeeMore USB ultrasound probe [21] (based on [22]) that uses older mechanical scanning technology for our platform because it was significantly cheaper than phased array probes. The image quality provided by the mechanical probe was verified by trained sonographers and radiologists in our previous work as being sufficient for detecting basic pregnancy complications including multiple gestations, placenta previa, and malpresentation [5]. While the cheaper mechanical probe reduced the cost, midwives using the phased array probe from the GE LOGIQ Book noticed the difference in image quality and decrease in frame rate of our system. We are currently searching for low cost hardware that will not only improve image quality and frame rate but also allow us to implement our streamlined UI. Both of these image improvements, though not strictly necessary to diagnose our target conditions, would make our system easier to use for novices who may have limited pattern recognition and image interpretation skills. Ultimately, these technological changes would make the system more appropriate for practitioners with limited training and imaging expertise, and who also do not have ready access to experts for regular consultation about exam results.

An important part of our system, which differentiates it from other mobile ultrasound platforms using a USB-connected probe (like Mobisante[12]) is the large screen size. Initially, our system included a netbook computer with a small screen size, which we chose in an attempt to optimize for portability and cost. From our interviews with radiologists and sonographers in the United States, we have discovered that a small screen size is not ideal for obstetric ultrasound for a variety of reasons. Because our system incorporates a USB ultrasound probe with an off-the-shelf laptop, it is relatively easy to incorporate new components as needed. Based on this feedback, we switched to a low-cost touchscreen notebook (~$800) with a 12 inch screen to improve the frame rate (increased CPU capabilities) and enlarge the viewing area. Obstetric ultrasound requires a large field of view imaging, and a small screen makes large field of view images smaller and more difficult to interpret. The small screen also miniaturizes fetal structures, making them more of a challenge to identify and measure accurately. This becomes more of a challenge when users have little ultrasound training.

Our March 2011 fieldwork revealed that printed ultrasound images may be desirable to women coming to clinics for prenatal care. In Uganda, many women must receive permission from their husbands to go to the hospital or take other trips which may interfere with their work at home; a printed ultrasound image would allow women to show their husbands proof of medical issues. Our laptop-based system easily allows for a printer attachment. Indeed, the ability to plug in peripherals also allows the system to be paired with a larger external display or new kinds of input modes. For example, a handheld peripheral device, with a few physical knobs and sliders, could make the process of optimizing ultrasound images easier. Additionally, because the system runs on a laptop, it is open and modifiable in a way that an all-in-one commercial system cannot be. New UI or context-driven help systems can be developed by users, health ministries, or others. The ability to customize the software elements of the system makes it extensible and more widely applicable.

D. *Scaffolding In Situ Use with a Robust Help System*

Interviews with Ugandan midwives regarding their training experiences revealed deficiencies with continuing education resources. All of the midwives we interviewed expressed frustration with the dearth of continuing education materials and programs available to them about both midwifery and ultrasound. For the midwives we interviewed, who work as the sole practitioner in their remote clinics, the option to consult colleagues when they have questions or attend continuing education classes is limited. In response, we designed an expanded help system to operate as an integrated teaching tool within the ultrasound system. The goal is to provide a resource to answer questions in the middle of exams and to guide midwives through best practices in diagnostic ultrasound. Other portable ultrasound systems have help systems, but these tools are often complicated, not embedded within the current workflow, and lack the additional support necessary to help midwives with low literacy. For example, the GE machine has a help system, but it takes the user completely out of her exam. Our help system generated enthusiasm when we first showed it to Ugandan midwives in March 2011; one midwife even asked if we could integrate this help system into the GE device she was already using so she would not have to find her textbooks in the middle of an exam when she had questions.

Our help system is designed to be used within the context of the exam so that the midwife's normal exam workflow does not have to be disrupted. If a midwife selects the "Help" button, a small panel appears on the bottom of the screen with a list of topics from which she can choose. Once the midwife has selected a topic, she can view relevant medical definitions or get step-by-step instructions that detail best practices in diagnostic ultrasound. Additionally, the help system offers side-by-side comparison with images taken by professional sonographers as shown in Figure 2. This could serve as an easily accessible supplement to materials in an ultrasound textbook, but would not require the midwife to turn her attention away from the exam in progress. For example, the help system could guide a midwife through the steps required to capture a head circumference measurement, or show her several example images of placenta previa with which to compare her own image. The integrated help system incorporates various types of media to facilitate understanding of ultrasound scanning procedures. Pictures and video are important to the training process because ultrasound interpretation requires practitioners to recognize and interpret visual patterns. In the future, we hope to expand our system to include persuasive media such as those used in Ramachandran et al.'s work, which demonstrated how videos can be useful in engaging village women in dialogue about health practices. These videos also showed positive effects on health worker motivation and learning [13].

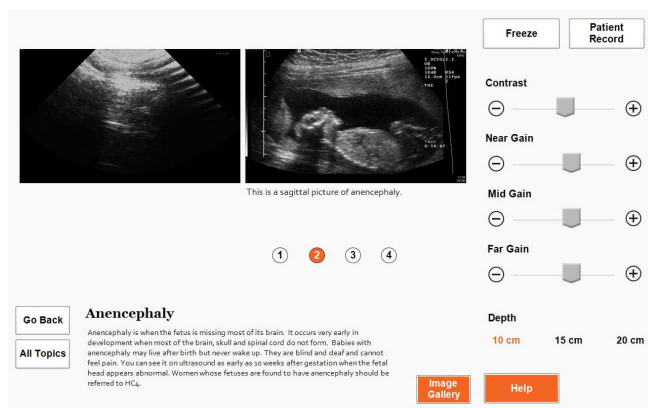

Figure 2. Screenshot of side-by-side image comparison in help system.

To develop appropriate content for our help system (text, images, and step-by-step directions), we worked with radiologists and sonographers who had experiences teaching novice sonographers and working in developing world settings. With these experts, we worked to simplify the language and the directions in order to best meet the needs of midwives who, although they may have a great deal of knowledge about anatomy, have very little training on ultrasound specifically. Additionally, the overall system design includes features to provide assistance to users of varying literacy levels. For example, the help system includes speak-aloud functionality, which will allow users to listen to blocks of text spoken in a native accent instead of having to read them. Graphical icons are also used to indicate functionality whenever possible, instead of relying solely on buttons with text labels. For example, the "Save picture" button includes a camera icon, and the "Annotations" button (used to add notes directly to the ultrasound image) includes a pencil icon. The icons were chosen with the intention of making the functionality more transparent; however, further research is needed to verify the symbols chosen have enough cultural significance to be recognizable.

Developing a help system that functions as a teaching tool addresses two project goals: 1) facilitating the understanding of high-risk conditions and best practices in diagnostic ultrasound and, 2) enhancing the sustainability of the device within resource-poor regions so the midwife can rely less on foreign assistance. Relying less on foreign or long-distance assistance is important for the midwives to retain their autonomy as central, trusted medical figures in their communities.

V. CONCLUSION AND FUTURE WORK

We developed an ultrasound platform designed for midwives working in rural developing regions. To make our design appropriate for rural medical settings we had to: create a simplified interface, provide for a solitary work environment, reduce the cost, and add a teaching help system. However, simply introducing an ultrasound technology is not enough to reduce the high maternal death rates in poor countries, thus our work examined the socio-cultural environments for which the device is intended. A more in-depth study is necessary to fully understand the cultural barriers to ultrasound and prenatal care. In the future we plan to examine pregnant women's perceptions of midwives and the relationship between the pregnant woman and her surrounding family (such as the mother-in-law and husband) as these factors can influence whether a mother receives care. We also plan to continue our efforts to make our system easier to use by expanding the help system and finding an ultrasound probe that can produce higher quality images at a low price point.

By creating an appropriate ultrasound system we aim to reduce the costs and barriers to performing a longitudinal study on the impact of ultrasound in low-resource settings. But ultrasound alone will not lessen high maternal mortality rates; maternal and neonatal deaths are multi-factorial problems that require multifaceted solutions. By investigating socio-cultural elements, we are contributing to a more nuanced understanding of how to effectively introduce ultrasound to low resource environments.

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