Baoband
Health Measures For Malawi

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Abstract

Designing an anthropometric measurement system for hospitals in Malawi. Edwards, Michael, MFA Design and Technology PARSONS THE NEW SCHOOL FOR DESIGN, 2008. Accurate anthropometric measurements are a critical component of healthcare. Errors in reading or recording patients' physical dimensions compromise quality of care. In Malawi, chronic staff, equipment and resource shortages combine to create a situation where maintaining accurate records is difficult, if not impossible. Paper records do not survive well in a busy tropical clinic environment, especially when qualified staff are overworked already with basic patient care.

Furthermore, because of a lack of doctors and nurses, critical patient-care decisions in Malawi increasingly need to be made by less-trained health workers. Sturdy computer-based systems are needed that can guide the decisions of these workers to help them make the right choices based on a complex set of collected medical data.

Using a suite of simple technologies, I have partnered with a Malawi-based NGO, Baobab Health Partnership, to electronically measure and record potentially malnourished children's middle-upper arm circumference (MUAC), an important indicator of a child's nutritional status. This data is quickly and reliably stored in a clinical database using a bar-code scanner connected to their touchscreen-based clinical workstation appliances. By doing this, fewer errors in measurement and transcription will arise. In addition, health-care providers will have access to cumulative, permanent patient measurement histories.

Patients' physical measurements are read via a simple device called Baoband. Baoband consists of a thin strip of flexible plastic, the majority of which is covered with a series of UPC-E bar codes. Each bar code is printed with a specific height, anywhere from 2 to 10 mm, and encodes the length of the strip from the bar code itself to a cut-out "window" at the end of the strip. By making a loop with the device to form an arm band, clinicians can rapidly and accurately measure the circumference of the child's upper arm by scanning the bar code that appears in the band's window with inexpensive commercial readers.

In addition, the data collected from the Baoband can help guide the clinician. To do this, I made modifications to Baobab Health Partnership's patient-care application. As a result, the screen shows the clinicians the proper course of treatment based on the patient's recorded MUAC. For example, if a child under the age of 5 has a MUAC measurement of less than 11 cm, the clinician is instructed on the appliance screen that the child is severely malnourished and will require a stay in the pediatric therapeutic nutrition ward at Kamuzu Central Hospital.

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1 Introduction

Concept

The Baoband device consists of a thin strip of flexible plastic, the majority of which is covered with a series of bar codes. Each bar code has a specific height, such as 2 mm for the mid-upper arm circumference (MUAC) measuring device, and encodes the length of the strip from the code itself to a cut-out "window" at the end of the strip. All the clinician needs to do is point and fire a standard scanner at the bar code exposed in the window, and the terminal to which it is attached will show and record the measurement in millimeter increments.

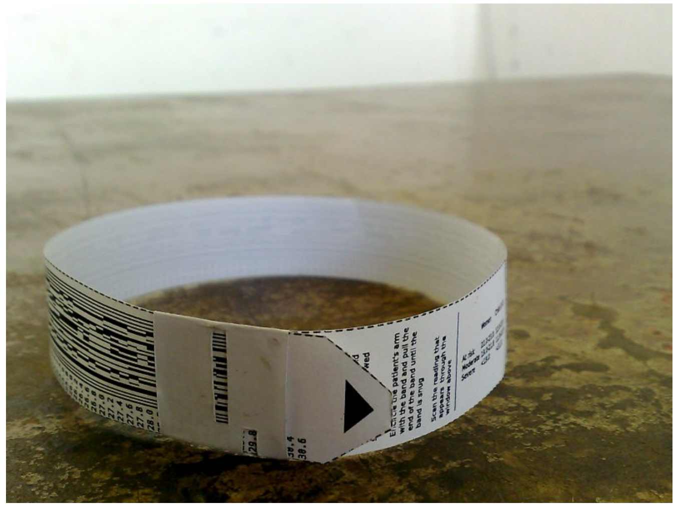

Illustration 1.1: Paper prototype of the Baoband created in Malawi

By making a loop with the band, the technicians with a Baoband can measure the circumference of several parts of the patient's body. The measurement that forms the focus of this study is the MUAC, which is an important indicator of wasting and malnutrition.

Impetus

In June of 2007, the Design and Technology Department and the Open Society Institute sent me on a month-long fellowship to Malawi. My job there was to assist a small healthcare non-governmental organization (NGO), the Malawi Health Equity Network (MHEN) with branding, design, and web presence. In the course of my research with MHEN, I gained an appreciation for the many difficult challenges facing the impoverished nation, especially when it comes to dealing with endemic malnutrition and the recent spread of HIV/AIDS. I also was able to meet a wide range of people working in the health sector in the country and to see firsthand their dedication and courage.

One of the groups I met was the Baobab Health Partnership, which is headquartered next to the Kamuzu Central Hospital in the capital city of Lilongwe. Their goal is to invent and implement new ways of managing health information in a resource-limited environment. One of their most effective tools is a thin-client terminal powered by software hosted on a server. These devices are rugged, low-power, and uncomplicated—all of the software work happens on the remote machine. This system (Illustration 2.1) both greatly reduces the lengthy wait and error associated with managing purely paper-based records and allows for clinicians and staff with less formal training to manage patient care through the use of expert systems.

After talking with members of their team about a range of useful projects where I could assist them, we decided to set me to work on digitally measuring and recording patients' physical dimensions. Doing so would allow for more complete records to be maintained. It would also help drive decision support for clinicians who would need to determine where to route patients who are malnourished or wasting due to HIV/AIDS.

Design Questions

Several important questions were considered at each step of this project: Can the data be read as accurately as conventional means? Will users familiar with existing MUAC measurements recognize the new form? Can the Baoband fit into the existing practice of clinicians? Can it use the technology already deployed and piggyback on those materials to make itself effective? Can it be made on site, with inexpensive materials, and yet still be rugged and reliable?

Rephrasing the above more formally, how can intra- and inter- observer error be reduced for anthropometric measurements? And how can the system deployed in Malawian clinics better collect and transfer data without paper or unnecessary transcriptions? This paper will provide the answers for these questions.

Research

Following a traditional iterative design process required the development of a series of prototypes that were tested by users in terms of their ergonomic properties, usability, readability, durability, material qualities, cultural referents, and aesthetic appeal. As a result, the Baoband prototypes were influenced by industrial design, human-computer interface (HCI) design, materials science, and information architecture (see Chapter 2, Domains and Precedents).

The Baoband is the result of an admixture of design and scientific research. In a design sense, the Baoband is an artifact of "research by making." The result, however, had to hew closely to the body of evidence accumulated by medical researchers into the appropriate forms and applications of anthropometric measurements. As such, the Baoband comes out of a series of prototypes evaluated by a wide variety of users inside and out of the medical professions, while nevertheless responding to the requirements laid down by scientific studies and examining the appropriate measures of malnutrition in the local population (see Chapter 3, Methodology).

Once the development of prototypes stabilized enough to test a working Baoband, user testing began in earnest. The Baoband was put through trials against a control band, similar to the kind used in clinics today. I evaluated the effectiveness of the band versus the current device and came to the conclusion that the Baoband could, with more testing, become an effective tool for measuring a patient's MUAC (see Chaper 4, Evaluation).

2 Domains and Precedents

Domain Disciplines

This project crosses a number of traditional academic boundaries. On the one hand are the engineering sciences. Accuracy counts for a great deal when a health-care worker needs to make a diagnosis. Even small variations, introduced at the worst possible step in data collection, can lead to misdiagnoses by even the best physicians. Because of this, great care must be taking with any apparatus and recording system that seeks to draw physical data from the conditions of the human body.

Engineering received close attention in this project, particularly for creating devices. Instrument design and quality assurance were needed to create robust measuring tools. Software engineering was required to make data integrate more smoothly. Ergonomics was needed to accommodate the human form factor in anything to be worn or applied to a patient's body.

On the other hand, the humanistic disciplines could not be forgotten. To measure a body, you must understand the owner of that body. You must have empathy for his or her condition, for the patient's pain and fear. Particularly in Malawi, where patients tend to visit doctors only when absolutely necessary, you must approach treatment as something more than attaching technology to flesh. You must not forget that "as physical pain destroys the mental content and language of the person in pain, so it also tends to appropriate and destroy the conceptualization abilities and language of the person who only observe the pain" (Scarry 1985). Blinding oneself to the pain of another, even for the most noble reasons, is seldom, if ever, acceptable. It is my belief that only by understanding the whole person can a treatment be considered a humane intervention.

To this end, anthropology was applicable to this project in its physical, social, and applied sub- disciplines. Physical anthropology was, of course, needed to assist in creating anthropometric devices. It was important to know the physical properties of the human body. No less importantly, however, the tools of social anthropology were required to analyze the patient and clinician populations, to comprehend their lifeways, their systems of value, their sense of what is and is not appropriate. Also, applied anthropology was needed put theory into practice as successive phases of the project developed. Only be paying close attention to how the work was received by the community could any measure of success be meaningful. Social work is key—no intervention of this type exists without the support system put in place by the hospital and affected communities. HIV/AIDS counseling and family planning are also factors in design decisions here.

Obviously, out of all the disciplines involved, the medical field was extremely important. Epidemiology, pediatrics, OB-GYN, the various HIV/AIDS specialties, and tropical medicine were all areas affected by this kind of work. Maintaining a continuing and open dialog with the medical community, in Malawi and in the States, was an important check on the design iterations. Only when doctors and other health care workers endorse the benefits of using the proposed measuring techniques should the device come near a patient in need.

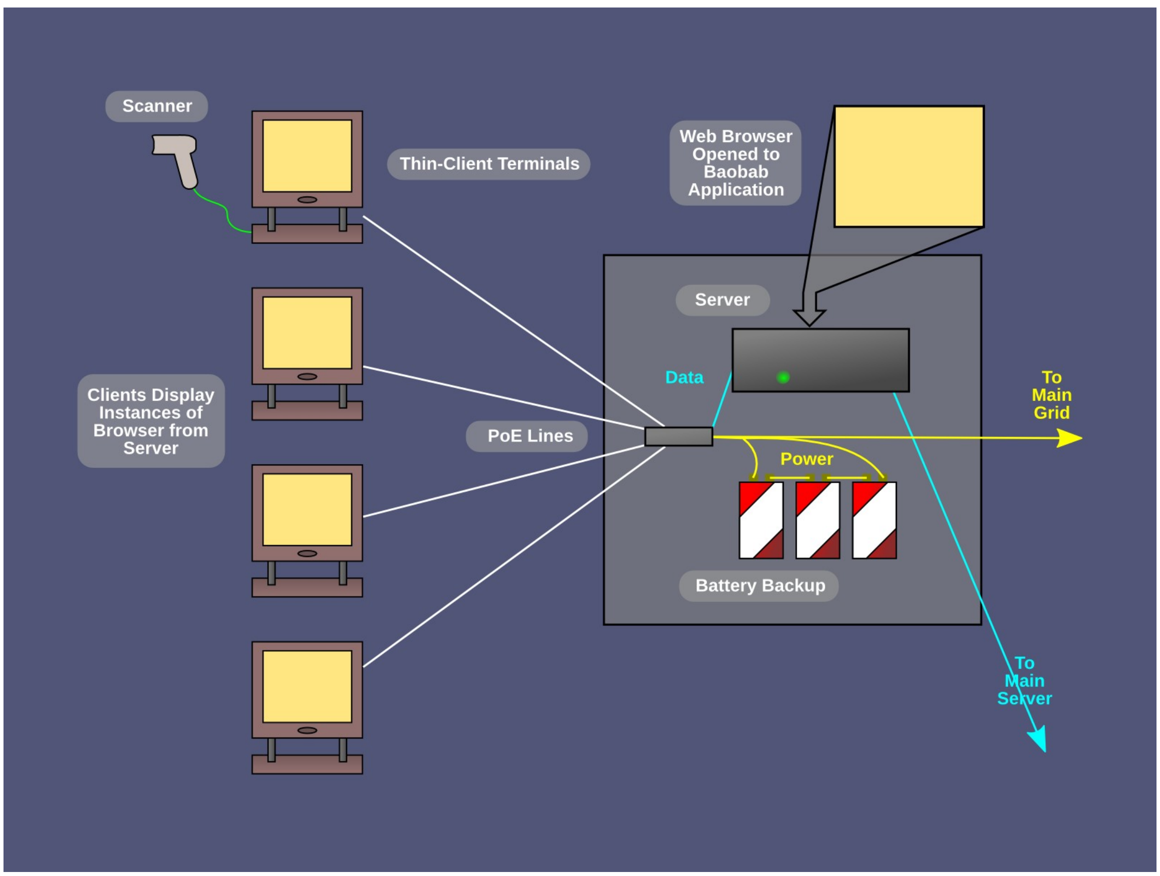

Illustration 2.1: The main components of Baobab Health Partnership's system

Baobab Health Partnership

The main precedent for this project is the system developed by Baobab Health Partnership, an organization working with the Kamuzu Central Hospital and other clinics in Lilongwe and across Malawi. Their patient-management system is the result of at least 10 years of testing with patients and health-care workers in the hospital. The system provides decision support to clinicians stationed within the hospital, as well as nearby HIV/AIDS clinics, such as Lighthouse and the Martin Preuss Center. With the system, workers can interview patients according to prompts on the screen and feed back patients' responses to guide the process to the next step. This has allowed for increases in speed and accuracy in the treatment of patients, as well as patient admissions, pharmacy management, and lab-specimen tracking (Illustration 2.2).

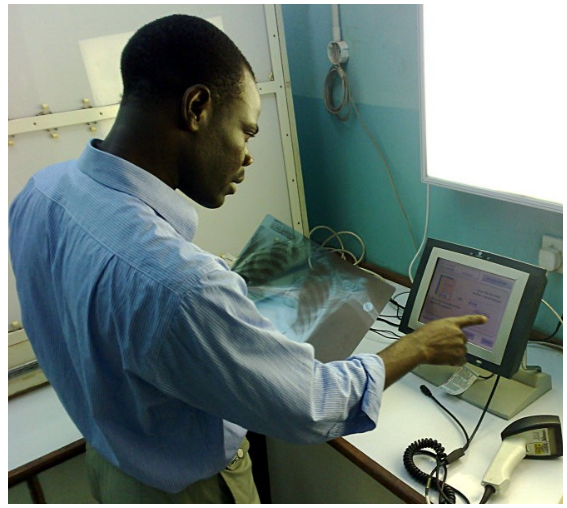

Illustration 2.2: Baobab Health Partnership's client terminal successfully used for managing X-rays

The Baoband project is a means of extending Baobab Health Partnership's system to capture physical data from patients, without excessive transcription or delay. As such, current methods for taking these measurements in hospitals and clinics today have been examined. The mid-upper arm circumference (MUAC) was identified by informants as a good starting place, since it is currently a measurement made at many of the locations served by Baobab, but is outside of the critical path for most of the current work. This allows for the parallel development of a new measuring system that can be incorporated into future

Illustration 2.3: A nurse compares a UNICEF-style band and a Baoband prototype

deployments by Baobab Health Partnership without interfering with day-to-day maintenance or current development projects.

Current MUAC measuring devices

Research undertaken by the United Nations has indicated that MUAC is an appropriate method used to screen for malnutrition in children and adults (Woodruff and Duffield 2007). Because pediatrics has been identified as an area of concern at the Baobab locations, I looked at what UNICEF has done to take MUAC measurements. As part of a supplemental equipment pack for their "New emergency health kit", UNICEF provides an arm circumference insertion tape. The tape is made from plasticized paper, has high contrast for easy readability, and is color-coded to indicate varying levels of malnutrition (UNICEF 2007). The UNICEF piece focuses on an easy-to-comprehend design, which has been emulated in the Baoband design (Illustration 2.3).

In addition, Perspective Enterprises, which specializes in infant and juvenile measurement equipment, has a series of plastic insertion bands, similar to UNICEF's, that measure head and limb circumference (Perspective Enterprises 2007). Though they do not have color coding, they do share material properties with the UNICEF band, as well as a thinness in the measuring strip. Keeping these physical properties in mind has informed iterations of the Baoband design.

In the Martin Preuss Center in Lilongwe, the MUAC bands present at the vital-sign station were those provided by Action Contre La Faim (Illustration 2.4).

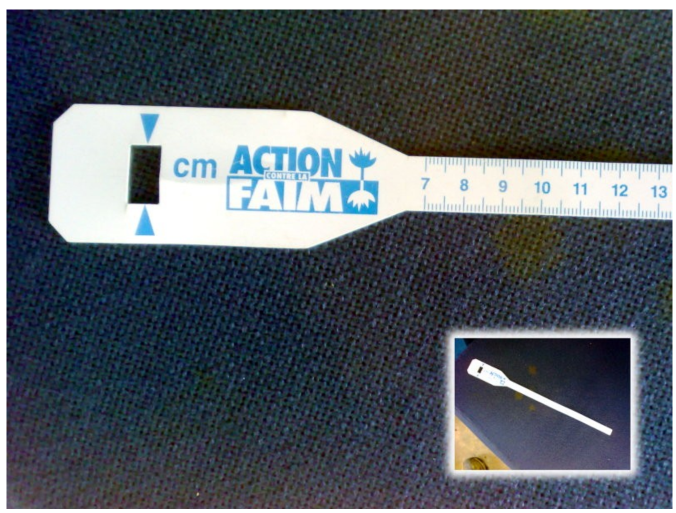

Illustration 2.4: Action Contre La Faim MUAC strip

This type of band is likely the same used in ACF studies in other areas of the world. In ACF's report from Nepal, for example, the methodology section indicates measurement cutoff points between 110mm for severely malnourished children and a 265mm for healthy adult women (Emeriau 2006), which corresponds to the range available for measurement on the bands deployed in Malawi.

Related Patents

As with any invention, it is important to investigate which approaches to measurement have been taken by previous researchers that might resemble this project. The research for this design, conducted through the U.S. patent system, has focused mostly on devices that record linear measurement data and that transform it into human- or machine-readable data, as opposed to more conventional measuring tapes and bands.

A patent for a "digital distance measuring instrument" appears to be the predecessor of many of the other attempts at working with linear measurement (Johnson and Lederer 1979). It uses a simple binary encoding scheme that can be read by a relatively small series of phototransistors as the band travels beneath them. It lacks the error checking commonly found in current bar-code encoding schemes and does not have any means for transmitting the data beyond the device itself. Nevertheless, it is very helpful to review the circuitry involved, as well as to establish an early history for work in this field.

One of the most cited inventions found was for a digital tape measure that could read from its tape using optical sensors (Crane 1991). The measure uses a custom "2 of 5" encoding for each increment of the tape and passively returns the results to an LED/LCD readout on the top of the device. This is very similar to the Baoband idea, in that it places bar codes along a strip of measuring tape in positions where the content of the encoded data is equivalent to some representation of the physical measurement. It does require that the tape move out from within the body of the device, however, and does not provide a means for recording the data permanently. A similar invention that used a simpler encoding scheme has the same limitations and perhaps less reliability (Okumura 1987).

Very few of the patents in this field seemed to be related to anthropometrics, with the notable exception of an "Anatomical measuring tape with indicator" that is used to record women's bust sizes (Vogt and Porat 1997). This device also lacks the ability to transmit data outside of its housing. But it does represent a precedent for measuring multiple circumferential data points. It also features an innovative combination of mechanical and electronic functioning that, although unnecessary for the work of the Baoband, is nevertheless interesting to consider.

3 Methodology

Prototype Design Process

Designing the Baoband was an iterative process of creating band prototypes, mostly using paper. Twelve versions were created and tested.

The first version used a one millimeter resolution on its scannable area. It had two widely-spaced paper slits to feed the scannable area past the viewing window. The viewing window was narrow, to complement the tight resolution. It was too short, too wide (60 mm), and did not fit well around the arm. It also failed to be read by the bar-code scanner through its viewing window. The bar codes were scannable when the band was not masked by the window, though. The band was tested on both an arm and laying flat on a table (Illustration 3.1).

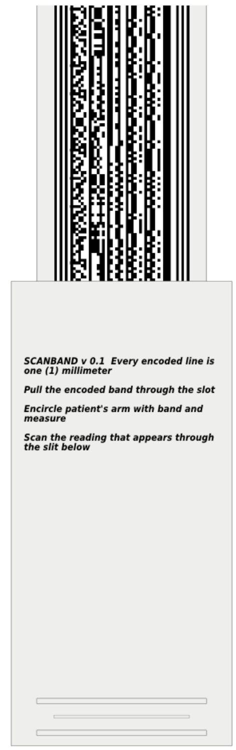

Illustration 3.1: ScanBand version 0.1

The second version adopted a larger (5mm) resolution. It still used the slits in the lower band that allowed the scannable area to be masked by the window, but the slits were more closely spaced to reduce the contact area of the moving band on the skin. The masked bar codes were successfully read and accurately measured the mid-upper arm circumference MUAC. The slits, however, caused the band to bind and made sizing the band difficult. A color bar was added and placed behind its own window to indicate arm circumferences that might be dangerously small, similar to existing MUAC measuring devices produced by UNICEF (UNICEF 2007). This was deemed not to be necessary, however, since the decision-support system provided by Baobab Health Partnership provided more accurate age-related data than a static colored band would provide. This version was tested on several volunteers' arms (Illustration 3.2).

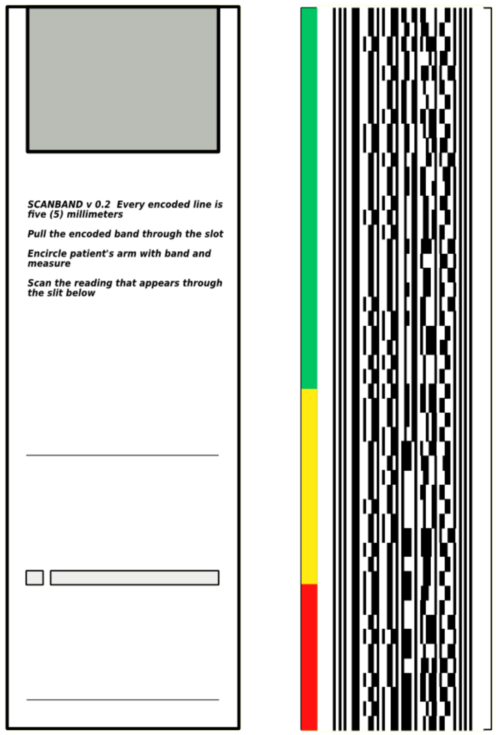

Illustration 3.2: ScanBand version 0.2

The third prototype features a reconfigured scanning window. The window was created from a separate piece of paper, which was glued or taped over the main strip of the band. This allowed the band to slide through more smoothly. Sizing the band was easier, faster, and more accurate. The band was also roughly 60 percent narrower overall, making it closer to the width that was observed in existing MUAC measuring strips. It was still considerably wider than those strips, though. Numbers were also added to the side so that the band could be read without the aid of the bar-code scanner, if need be.

The band was also redesigned to be printed in pairs from a single strip of 4” paper. This size is compatible with the label printers that Baobab has placed around the Kamuzu Central Hospital, with the hope of making it easier to reproduce on site. It was also designed with construction tools such as scalpels and medical tape in mind. These ideas stemmed from conversions with Baobab's Gerry Douglas (Douglas 2007).

The band was again tested successfully on several volunteers. A software prototype, designed with the Processing programming language, read in data from the bar-code scanner and displayed the millimeter measurement to the test observers when it was presented in early October 2007 (Illustration 3.3).

A fourth prototype was completed that focussed on narrowing the band to the minimum size readable by the scanner. This version achieved a thinness that approached a similar device made available by UNICEF (UNICEF 2007) and the medical industry(Perspective Enterprises 2007). It was approximately 25 percent narrower than its predecessor. It could also be printed easily in pairs on a single sheet of 8.5” by 14” legal-sized paper.

The fifth prototype of the series was a further refinement of the previous model. The number scale on the bands was rearranged so that the digits would be read along the length of the strip rather than across it. This allowed for even more narrowing and represented what is probably the minimum allowable width attainable in a device such as this. It also allowed for up to three total strips to be printed from a single legal-sized sheet of paper, which is useful for printing from standard printers instead of roll-type label printers, though both types are available in the clinics in which Baobab is active.

Several other prototypes were created over the next few weeks that experimented with the ways in which the bands could be efficiently printed out on paper. The essential form, however, remained the same for these iterations.

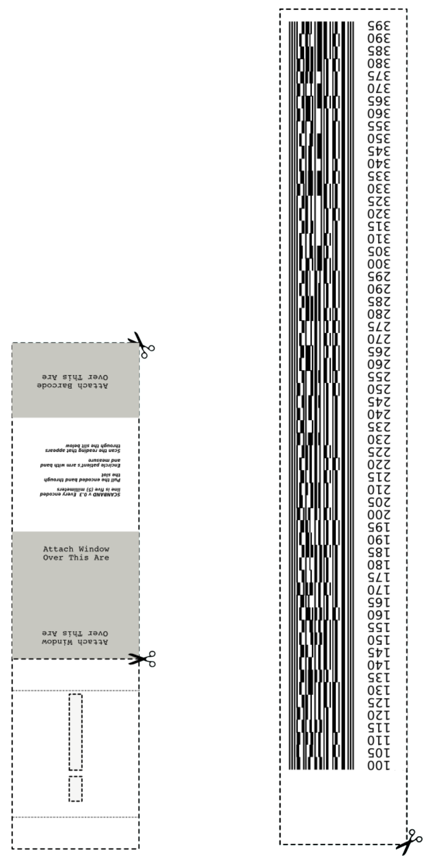

Illustration 3.3: ScanBand version 0.3

Participatory Design

Returning to Malawi in January 2008, I worked out of Baobab's office at Kamuzu Central Hospital and accompanied their staff to clinical sites around Lilongwe. In so doing, a number of key observations were made about the way in which anthropometric measurements are taken on site, why they are taken, and on which patients they are performed.

Martin Preuss Clinic Observations

The first research excursion was to the Martin Preuss Clinic (MPC), which is an HIV/AIDS and tuberculosis center. At MPC, there are a series of stations staffed by clerks and clinicians that patients proceed through for their treatment. The very first is the registration desk, which works much in the same way I had observed previously. The next station, where vital signs are taken, however, did not receive as much notice on my first visit and presented valuable new data. At the vitals station, patients are measured for height (if they are over 18 and have not previously been measured), weight (every time), and MUAC. Surprisingly, MUAC is measured under very specific conditions. If the patient is an adult female and is either pregnant or lactating, the arm circumference is measured. It is also measured if the patient is a child between the ages of 1 and 5 years old.

The instrument for measuring the arm was the aforementioned Action Contre La Faim strip (Illustration 2.4). The strip consists of a polyester plastic about 7 or 8 mil in thickness with a wide head surrounding a slot through which the tale of the band is supposed to pass. An arrow indicates the position on the tail of the band from where the length should be recorded. As stated above, the band records from 7 cm to 30.5 cm.

In addition to the band, criteria for determining the patient's nutritional status was posted in a nearby nurse's station. Other measurement tables were observed in the prior literature, but this was the first observation of the criteria used by the clinicians at this specific site. Since policies vary widely from clinic to clinic, and even from ward to ward, this was an important finding.

MPC Design Iteration

As a result of this trip, a new version of the prototype was produced that incorporated a form similar to the Action Contre La Faim strip and used the data found posted at MPC. The eighth prototype featured a measuring surfaces that extends from 7 to 30.5 centimeters, a printed table with the nutritional status criteria (Illustration 3.4), a 2 mm resolution, and a tapered head for ease of insertion past the measurement window. This was also the first prototype to be printed on HP LaserJet "Tough Paper," a kind of printable film that is waterproof and highly resistant to tearing (see Materials). The staff at Baobab were able to print four of these at a time on the kind of printer (HP 1320 or 1300) that is found at a number of their sites. As such, it

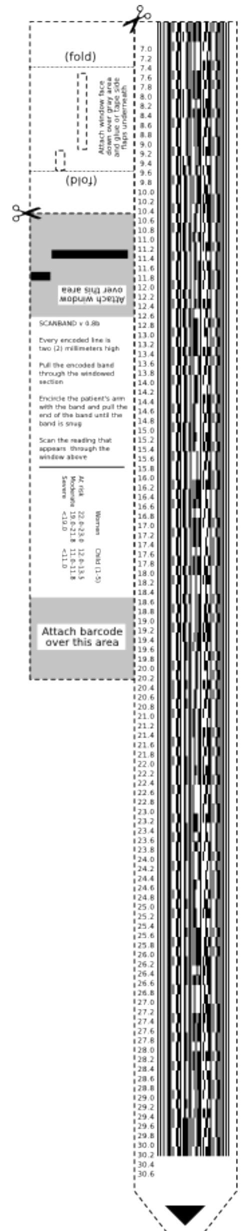

Illustration 3.4: ScanBand version 0.8b

represents not only a more precise, more accurate version of previous work, it also demonstrated that manufacturing the bands on site could be accomplished.

Lighthouse Observations

The next observations took place at the Lighthouse clinic, an HIV/AIDS center adjacent to Kamuzu Central Hospital. I spent an afternoon positioned near the vitals station, watching how patients were measured. The very first observation was of a severely ill man bound to his wheelchair. Andreas, a doctor at the site who heads the clinic's monitoring and evaluation (M&E) department, pointed out that the measurement was being taken incorrectly by the clinician—the patient should have had his arm extended down to his side and should have been standing. This ideal position was made considerably difficult to achieve because of the patient's frailty. Nevertheless, it was a valuable piece of knowledge to acquire, as it indicated the preferred measuring method understood by the clinicians at this facility.

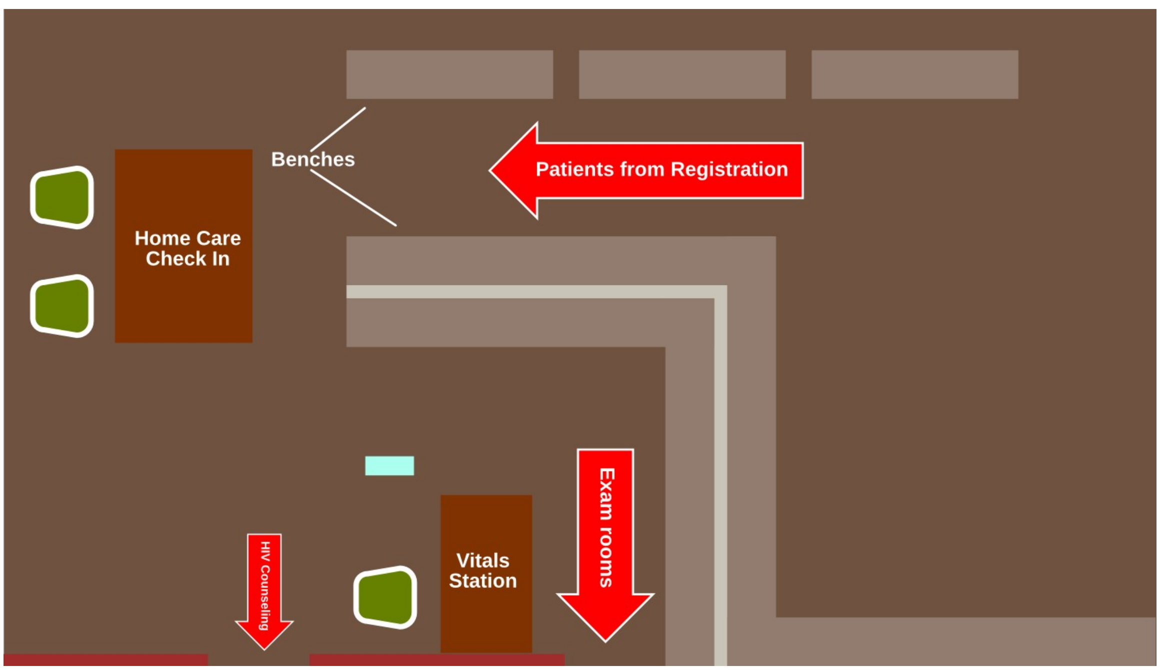

Illustration 3.5: The flow of patients from registration through the vitals station at the Lighthouse Clinic

Ward C Observations

On a third observation trip, I was accompanied by Rashid, a clinician at KCH who also works part of the time with Baobab. Most of the time was spent at the outpatient center, where children are brought in, as well as at the children's ward, particularly Ward C, which handles nutritional therapy.

At the outpatient center, I observed the specific set of steps taken for patients as they enter. Since the visit occurred on a Thursday, the day in the center when nutritional therapy is given, the clinician in attendance, Mrs. Banda, demonstrated the measurement routine. Young patients are weighed in a table scale, then laid down on a length-measurement platform. Since they need to be held down, this was the patients' least favorite part of the exam. Then the MUAC was taken. The specific technique was valuable to observe. First, the unlooped band is drawn from the shoulder to the bent elbow, locating the midpoint in between. Then the band is deftly turned 90 degrees, the arm is straightened, and the looped band displays the reading at the tail is passed through the window. This version of the MUAC band was the color coded UNICEF type (UNICEF 2007). Finally, the weight and height are referenced on a set of weight for height charts that determine the percentile W/H. All of the above data is written by hand into the child's health passport, the document that every patient in the hospital carries with them. The passport contains written notes from visits. It also features a barcode on the front that the Baobab system uses to track and enable patient registrations.

In the children's ward, the head nurse at the vitals station demonstrated their process. They also used the UNICEF bands (Illustration 2.3). This results in a complication, because the ward is specifically set up for children under 5, but older children are also admitted. The bands, however, are color coded for the older children's arms. Another posted table describes the appropriate measurements for children under 5. The nurse stated that there should have been two different bands present, but they only had the one in use. The nurse also described when the patients are measured: on admittance (under 11 cm gets the younger children admitted, as well as low W/H and the presence of pitted oedema), every 7 days thereafter, and at discharge. If the staff gets too busy to measure every 7 days, the measurement at discharge at least provides an indication of how well the child has recovered. Hearing this provided a much-needed perspective on how, when, and why this data is taken, recorded, and analyzed.

Working at Baobab Health Partnership

In addition to field work, a great deal of time was spent talking with the developers at Baobab. They provided the source code of their system, as well as instructions on how the hardware needs to be set up and how to integrate the software with it.

Based on these discussions, a version of their existing system at MPC was modified to accept bar-code input. In so doing, the decision-support procedure was also changed so that, if the patient is an adult female of child-bearing age, she is asked whether she is pregnant or lactating. If either of these are true, or the patient is a child under 5 years old, the clinician is prompted to take the patient's MUAC using the Baoband and a bar-code scanner attached to the terminal. By doing this, the first end-to-end tests of the prototype were conducted that not only used parts available or produced entirely on site, but also simulated the conditions of the actual vitals stations at the clinics.

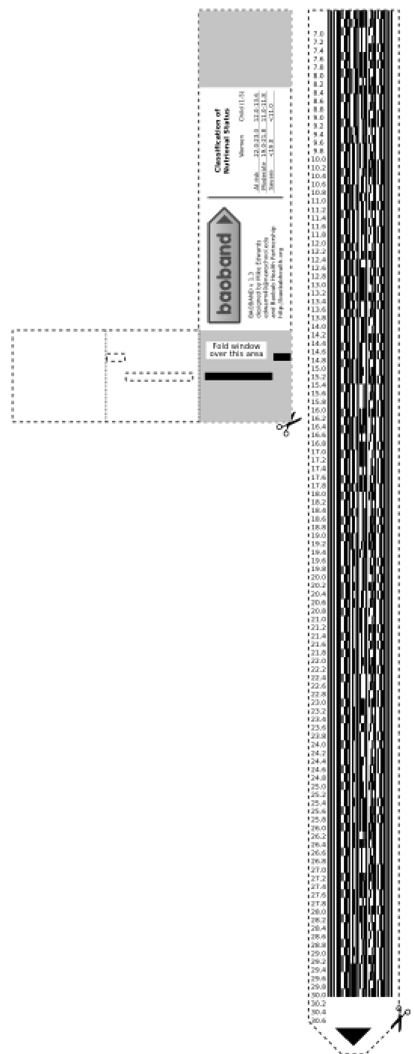

Illustration 3.6: Baoband version 1.3

Baobab Prototype Iteration

A series of prototypes produced on site and shortly after returning back to the United States attempted to make the Baoband easier to produce (Illustration 3.6). Later revisions used a series of new folding marks that produced the necessary structures for creating the measuring window but did so with less need for glue, which was cumbersome, and maintained the physical connections of the various parts of the band, making the device more stable and durable. These prototypes were tested in several sessions both in Malawi and in the U.S. In addition, using the laser bar-code scanners found in the Malawian clinics allowed for greater accuracy and speed with the band-reading tasks.

Materials

I would be remiss not to step back and spend a few paragraphs discussing the specific media incorporated in the final prototype and how I came to use them. The choice of material for the Baoband was important development step in the design process. For example, paper bands would seem to be appropriate for cases where it is unsanitary to use the same strip twice, but this never arose as a constraint among the clinicians I interviewed. Instead, the clinical situation required that the band remain in place for long periods of time and be cleaned periodically with water or bleach solution. This more permanent approach initially stemmed from a discussion with Sven Travis about materials (Travis 2007) and was validated by the field research in Malawi.

For more permanent uses, therefore, a dimensionally stable plastic made sense, like Mylar or Melinex, which are both DuPont brand names of the same kind of polyester film (DuPont Teijin 2007). This kind of plastic resists deformation due to heat or tension. It is also a fairly common material in professional print shops, if production needed to be scaled up.

Unfortunately, Mylar is not readily available for the kind of small-scale printers on hand in the clinics. It is not sold in forms that would allow it to be printed on a desktop LaserJet, not is it cheap or easily obtained, even in the United States. Several experiments were conducted at Parsons with the help of faculty member Maurice Sherman (Sherman 2008). Even using a high-end roll printer, satisfactory prints that could not be accurately read by a bar-code scanner due to too much "bleed" from the ink.

I also interviewed artist Jeff Crouse, who, at the time, worked with large sheets of printable Tyvek (Crouse 2008). Tyvek is a material that has been suggested by several people (Douglas 2007) (Travis 2007), since it is sturdy and dimensionally stable. Several copies of the band prototypes were printed by a commercial-grade plotter off of a large roll. They were longer than I had previously been able to print, the ink did not run when exposed to water, oil, or alcohol, and the material had a sturdy, cloth-like feel to it.

Finding more Tyvek material and the printer required to use it, however, was as difficult as obtaining the Mylar. Importing a practical amount of Tyvek to Malawi would not work. As a result, the next best option became the aforementioned HP "Tough Paper," which could only be used for smaller prints but had the same material advantages of Tyvek and Mylar. In addition, it could be used with a desktop LaserJet printer, was relatively cheap and was easy to carry over to Malawi in my luggage.

Usability Testing

Upon returning to the US, preparations were made to test the Baoband for its accuracy and ease of use. Because the test group would not be experts in the use of traditional MUAC measurements, however, testing on human beings would create measurement errors that would go beyond those introduced by the various devices. Furthermore, testing on human subjects in a clinical setting would require a degree of IRB approval beyond what is called for in a simple pilot study of the Baoband's design.

As a result, a mannequin of a male juvenile was purchased that featured a straight arm (Illustration 3.7). The size of the mannequin is roughly that of a 7 to 8 year old child, slightly beyond the range of the 1 to 5 year old for whom I had determined standard arm measurements. But Ward C at Kamuzu Central treated a large number of older children, so a proxy for patients this age seemed appropriate for at least some of the user cases I encountered. Furthermore, the mannequin was a standing model with a straight right arm, which would perfectly simulate the pose needed for taking the MUAC accurately. Finally, the mannequin's arm is not malleable, which would allow for more consistent results from novice users as well as make the establishment of a baseline easier and more reliable.

Illustration 3.7: "BaoBob", the testing dummy

Users were drawn at random from the student population in the Parsons Design and Technology program. Each student was given one of two standard sets of instruction. For the standard MUAC measuring band cohort:

> "This [point to the dummy] is a potentially malnourished patient. To find out if he is, we need to measure his upper arm circumference [indicate upper arm]. To measure this, we first take this device [show MUAC strip] and, from the arrows, measure from the tip of the shoulder [place band on shoulder] to the tip of the elbow [draw strip down to elbow]. By reading the length, we find the midpoint of the arm [indicate], draw the band around the arm, pull the band through the window, and draw it tight. Then you read the number that lines up with the arrow on the band and call it out to me. Do you understand?"

And for the Baoband cohort:

> "This [point to the dummy] is a potentially malnourished patient. To find out if he is, we need to measure his upper arm circumference [indicate upper arm]. To measure this, we first take this device [show MUAC strip] and, from the black bar here [point to measuring window], measure from the tip of the shoulder [place band on shoulder] to the tip of the elbow [draw strip down to elbow]. By reading the length, we find the midpoint of the arm [indicate], draw the band around the arm, pull the band through the window, and draw it tight. Then you take the scanner, press the button, and scan the bar code in the window here. Do you understand?"

Those chosen to use the standard band were given a mock up of exactly the kinds of devices documented in Malawi. The rest were given Baoband version 1.3.

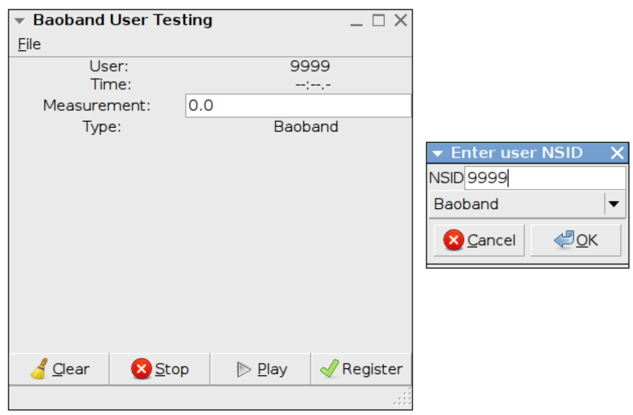

Illustration 3.8: The interface for usability testing

The user tests were designed to record the accuracy of each user's measurement attempt as well as the speed with which the task was completed. I developed custom software that would allow me to keep track of this user data that was both easy to use and unobtrusive, making time and recording into tasks, for me, that would not distract the user or cause me to have to divert my attention for the trial to deal with mechanical or recording issues. If this project has taught me anything, it is that letting machines do the work best suited to them can hold great benefits if applied correctly.

Before the tests began, users gave the last four digits of their student identification numbers, which were entered into the test rig. Then the users were assigned to their group and the test rig was set to ready. Both cohorts were timed from the moment they touched their band to the patient dummy's shoulder (Illustration 3.9). Timing began by hitting the “Play” button. Timing stopped for the standard cohort when the users called out the number. Then their measurement was recorded in the text field. For Baoband users, when the user scanned in his or her measurement, the test rig automatically stopped and recorded their measurement data (Illustration 3.10). For the record, this made testing much easier for me. Hopefully, my experience with this data recording wil translate well in clinical situations.

Illustration 3.9: A test subject begins the standard MUAC measuring task

I recorded a total of 19 standard users and 16 Baoband users. No member of either group failed to complete the task. The measurement mean for the standard group was 19.2 cm (1.6 cm standard deviation) and the time to completion mean was 42.4 seconds (14.2 s standard deviation). The measurement mean for the Baoband group was 19.0 cm (0.2 cm standard deviation) and the time to completion mean was 53.0 seconds (22.0 s standard deviation). The correct measurement of the MUAC was 18.8 cm, which allowed for calculating the residuals (see Chapter 4, Evaluation).

Measurement	*Mean*	*Std. Dev.*
Standard	19.2 cm	1.6 cm
Baoband	19.0 cm	0.2 cm
Time to Completion		
Standard	42.4 s	14.2 s
Baoband	53.0 s	22.0 s

Table 3.1: Results for user testing

Illustration 3.10: A test subject scans the arm of the test mannequin using the Baoband method

4 Evaluation

Accuracy and Speed

On the testing mannequin, the circumference of the arm at its midpoint was 18.8 cm. Judging by the means alone, the Baoband appears more accurate. And, taking into account the differences in the standard deviations between the two cohorts, the Baoband would seems to be more precise as well.

More sophisticated statistical tools tell a different story, though. By calculating the residuals (the absolute difference between the user results and the actual size), we can see the severity of users' departure from the correct answer. Again, the Baoband is doing better. But when the two cohorts are compared using a two-tailed Student's t-Test, the differences do not appear statistically significant. The t-Test result for the arm measurements is 0.3, while a significant result, for social sciences, ought to appear below 0.05. For medical sciences, it should be lower still.

The time-to-completion measurements yield similar results. The mean time for the standard band was roughly 11 seconds faster than the Baoband. But the standard deviations, for both cohorts, were quite large. Further, the t-Test for the time to completion was .1, which is *approaching* significance but it still not statistically significant.

In addition, the time-to-completion scores for the standard band are artificially low. Users were asked to call out the number they measured as soon as they saw it. I entered their responses and stopped the test immediately. In a clinical situation, the user would need to obtain the measurement and record the result on paper in two separate steps. This testing situation is by design, though. I wanted to compare only measuring times and measuring errors between the standard and Baoband devices. Cutting out the transcription step for the standard band helped isolate the measuring errors as such. A second set of tests would need to be conducted to test the transcription error. In the end, I believe that the 11 second lag of the Baoband could easily be made up in the time it takes the user to transcribe their data. But this remains to be tested in earnest.

A positive note about the statistical analysis is that the Baoband was not shown to be significantly *worse* than the standard measurement. That is, given the two devices, the Baoband does not harm, which is a very good finding. While time and additional testing may prove that the Baoband is more accurate, even being no less accurate is a qualified success. If the Baoband can perform at the level of the standard equipment, and also provide benefits for storing records and guiding the clinician via decision support, then it is worth testing in the field.

Ergonomics

The users were able to handle the band without great difficulty, which was a relief. One concern prior to testing was that the users would have trouble "juggling" the band and the scanning gun at the same time. As it turned out, after an attempt or two, users found a reliable way to hold the band and scan the target. Since users in both cohorts were novices, having seen the operation performed by me only once, some clumsiness is not unexpected. But not one of the users, in either cohort, failed to obtain a measurement or gave up or expressed serious frustration. In fact, several different approaches were found to work, including hold the extended tab against the band, pressing down on the unwindowed portion of the "loop" to maintain friction, and holding the tab while pulling against the band with the knuckles of the same hand. None of these experiments by the users produced seriously degenerate results, leaving open the possibility that future trained users may have several options available to them for manipulating the device effectively.

In part, I credit this to the affordances found in a typical clothing accessory belt. Because of this, the Baoband, which is functionally similar, is not an entirely foreign form to manipulate. The users understood how to "cinch" and hold the Baoband in ways that were familiar to people who have used belts. Because of this prior experience, and because belts offer a range of approaches in their use, people were able to experiment with different grips, pulls, and holds in ways that made measuring with Baoband effective with a little trial and error.

Costs

The Baoband has been designed to fit into existing information technology scenarios that are present in several clinics in the Lilongwe area. As such, I took a number of factors as given for this device to work. For one, the terminals created and maintained by the staff at Baobab Health Partnership are either present or will soon become available at the vitals stations where measurements like MUAC are currently being recorded. Alongside the terminals are commercially available bar-code scanners that are used by the existing system for tasks such as recording labels on patient records, tracking X-rays, and managing the handling of other lab and pharmaceutical items. Finally, the presence of small laser printers on the clinic sites as well as at the Baobab offices is taken for granted, since these are used constantly for a range of administrative tasks by the clinic staff.

With these materials in hand, the additional costs of deploying the Baoband are slim. The most significant cost, and the most limited resource, is the plasticized paper. The HP LaserJet "Tough Paper" is available for purchase at specialty stationary shops in the United States at a cost of US$30 for 50 sheets. Because the latest prototypes can be printed two per sheet, this brings the paper cost of the Baoband to US$0.83. Not insignificantly, like many other technical and medical supplies needed in Malawi, the paper is nearly impossible to find at stores in the country and needed to be brought over in person. Nevertheless, 100 devices can be produced from the quantity of "Tough Paper" stock available now. By my count, only a fraction of that number of traditional MUAC measuring bands are in use in the clinics, so the supply should last for quite a long time. If the paper should run out, however, bands can still be printed on regular paper. These band may not last as long, but they are readily available if the circumstances arise.

Other incidental costs include ink, glue, and scalpel blades, all of which are in plentiful supply and do not add significantly to the cost.

The software modifications made to the existing Baobab system were relatively minor, thanks in no small part to the modular, well-designed software already in place. A software patch has been created and made available to the staff, so adding in the ability to read numerical data from bar-code devices like the Baoband and any future extensions of it should not require more than a few hours work by a trained programmer to integrate into a new clinic implementation given the existing software.

Conclusions and Future Work

The Baoband is the result of an iterative design process that sought to incorporate user feedback and testing at every stage of its development. Several important questions were considered at each step: Can the data be read as accurately as conventional means? Will users familiar with existing MUAC measurements recognize the new form? Can the Baoband fit into the existing practice of clinicians? Can it use the technology already deployed and piggyback on those materials to make itself effective? Can it be made on site, with inexpensive materials, and yet still be rugged and reliable?

The answer to these questions, at this stage, appears to be “yes”, with several crucial caveats and considerations.

As a material artifact, the Baoband is in many ways identical to existing implementations. It uses a very similar plastic material, is waterproof and resistant to wear, maintains the shape and roughly the same usage as conventional means, and leverages as much of the resources available on site as possible.

As for its accuracy and usability, more needs to be done to verify these claims. Limited rgonomic testing was conducted with the Baoband in the United States, with the device being pitted against a mockup of the Action Contre La Faim device. Subjects were timed and observed, and their measurements analyzed, as they carried out a MUAC reading on a patient dummy. In so doing, the advantages and pitfalls of the Baoband were compared to a standard device in a controlled experiment. The Baoband was no less accurate than the standard measuring device and may prove to be more accurate in future tests.

Moving forward, clinical testing needs to be done in Malawi. Several sites have been identified as good candidates for testing the MUAC Baoband. Furthermore, requests have been made for a longer Baoband that can measure the circumference of a young child's head to check for hydrocephalus. Without results from clinical trials, however, the Baoband remains a hopeful but unproven technology for measuring and recording anthropometric data digitally.

A more definite conclusion from this process is that the development of digital measurement devices at the sites where they are most needed can be done. The use of stock commercial equipment, like bar-code scanners, paper prototyping, iterative design, combined with the work of talented and dedicated local experts, has produced a promising new technology using very few resources that may yet solve a significant problem in patient care.

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