Biometrics For Babies- Human Centered Technology Design to support infant immunization and healthcare delivery in resource limited settings.

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Abstract

Identifying Infants can be harder than it seems. Particularly in remote and limited resources settings, rapid and accurate identification of infants presents an unsolved complex sociotechnical problem. Imagine a long line of caregivers, each carrying several children, waiting outside in heat and humidity for required vaccinations. Caregivers may only know the infant's given names: how can the they be identified for record keeping? Vaccination cards are notoriously unreliably and easily lost, mistakes abound. Recent technology-centered attempts that used adult solutions to identify children have failed.

In order to develop a new, infant-centered solution from the ground up, we assembled a diverse team of engineers, clinicians, ethnographers and designers and followed a Human Centered Design (HCD) approach of ethnography, rapid prototyping and testing. We examined all common modalities used in adult biometrics-- ear, iris, retina, face, foot, palm and finger recognition and compared technical feasibility, usability and acceptability for the infant use case. We prototyped many infant-centric devices and arrived at lead candidates using modified contact vs non-contact palm and finger scanning. Frequent design-test cycles were critical as the complexity and changing nature of infant physiology, behavior and caregiver dynamics could not be predicted, only tested with subjects. This was compounded by moving targets of evolving infant-centric software, hardware and device design.

In summary, we report here an HCD based approach to infant biometrics. We developed and tested robust, socially acceptable technologies that adapt to the tiny, sensitive yet changing fingers of very young infants.

Keywords: infant biometrics, fingerprinting, vaccinations, human-centered design, prototyping, image analytics

Infant are not little adults. They cannot tell you their name and despite significant effort they are misidentified at an alarming rate during critical interventions such as immunizations and healthcare delivery. While each year 85% of children around the globe receive vaccines, saving many millions of lives, lack of methods to tackle the identity problem continues to jeopardize the health of millions more children. This problem is compounded in poor or remote settings that often have the greatest needs yet the least resources.

Adult biometrics technologies such as modern fingerprint scanners have been proposed as potential solutions. To date these approaches have met with limited success. Infant hands are not just smaller versions of an adult-or even a toddler-hand. Proportions, subcutaneous fat distribution, feature flattening and developmentally-dependent reflexes make children significantly different from adults. Capture methods in infancy present interaction challenges. Neonates wiggle a lot. They do not understand language. Caretakers are not always comfortable with medical personnel and technology. Techniques that work in the laboratory often will not work in the field.

Table 1. Biometric traits evaltuation

BIOMETRIC TRAIT	SUBJECT COOPERATION	PERSISTENCE	PARENTAL CONCERNS	PREVIOUS ATTEMPT REFERENCES
FACE	MODERATE (NEUTRAL EXPRESSION)	LOW (FACIAL AGING)	MINOR	TIWARI ET AL. 2012
IRIS	HIGH (OPEN EYES AND STARE TOWARDS CAMERA)	POTENTIALLY HIGH	MAJOR (IR ILLUMINATION AND OBTRUSIVE CAPTURE PROCESS)	BHARADWAJ ET AL., 2010
PALM-PRINT	MODERATE (OPEN FIST AND ALLOW OPERATOR TO HOLD PALM)	POTENTIALLY HIGH	MODERATE	WEINGAERTNER, ET AL. 1960
FOOT PRINT	LOW (REMOVAL OF SHOES AND OPERATOR HOLD FOOT)	UNKNOWN	MINOR (U.S. HOSPITAL PROTOCOL)	WEINGAERTNER, ET AL. 1960
EAR	LOW (PICTURE OF EAR REQUIRED)	POTENTIALLY HIGH	MINOR	FIELDS ET AL., 1960
DORSAL VEINS	MODERATE (OPEN FIST AND OPERATOR HOLD THE PALM)	POTENTIALLY HIGH	MODERATE	CAO ET AL.,2016
FINGERPRINT	HIGH (OPERATOR NEEDS TO HOLDS CHILD' S FINGER)	POTENTIALLY HIGH	MODERATE	GALTON, 1899

Kalisky (2017), following Jain et al. (2004) and others, summarized research efforts on various biometric traits that were tried or at least considered as appropriate for infants (Table 1). Traits that may be very successful in identifying individuals across their lifespan (e.g., iris) are difficult to obtain in field clinic settings where cooperation of infant and acceptance of caregivers are critical. After extensive review of previous work by others in addition to our own exploration, including an international online survey of vaccination clinics, we took a fingerprints-first approach, while developing palm printing methods in parallel and capturing ear and facial data to be examined as needed.

Design Approach

The project was based on two premises. The first was the necessity to interact with infants and caregivers at every stage of the ideation and prototype development. The second was the realization that the success or failure of this system would be determined by the efficient coupling of design and development with trackable, quantitative data. Evidence-based design required measurables, yet these were interconnected and evolving, in part dependent on cumulative data collection and analysis, in part dependent on the quality of the given prototype, in part dependent on the quality of the matching software, in part dependent on the infants actually being tested at that time. A wicked problem. The design of the device, of the data analytics, and of the interaction with infants and caregivers had to develop together (Figure 1).

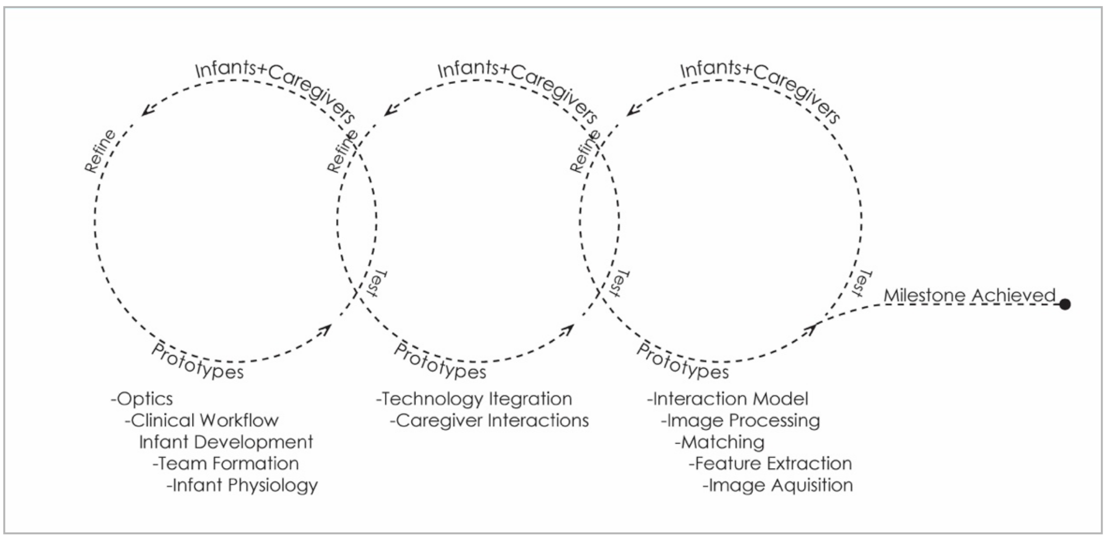

Figure 1: Overall design approach

Design Research Activities

The continuous cycle of test and refine can also be seen as a braiding of three distinct yet utterly co-dependent threads of expertise: (1) interaction design during the fingerprint capture sessions, (2) hardware prototype development, and (3) the software pipeline.

(1) Interaction Design

Palm / Fingerprint Capture Session – Minimum Viable Socio-Technical Complex Setting. The fingerprint capture sessions during the pre-pilot phase took place in an office-like environment that maintained the lab-infrastructure required to monitor, record and troubleshoot. We required from the outset that recruited caregivers return with their infants to multiple sessions – both in order to mimic the potential return for vaccinations in the target setting, to study the changes in age, and to receive input on the interaction design process from experienced users.

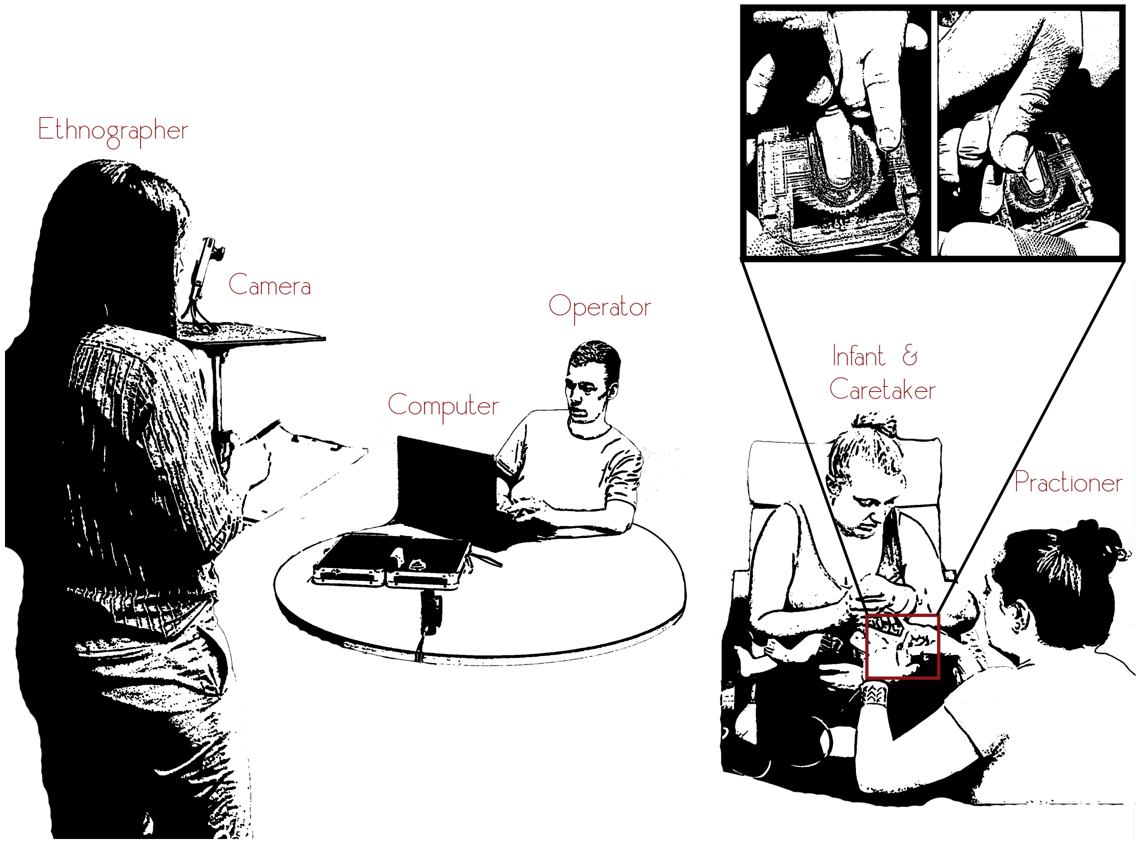

Figure 2: Current Print capture session in lab-office

The print capture setting during the research and development phase in the lab-office differs from the clinical settings in the local hospitals and will differ from field pilots. To begin with these capture sessions were crowded with other team members and expert observers from various domains (neonatal doctors, optics specialists, mechanical engineering, external design consultants). Figure 2 represents the current setting in the lab-office. The final field deployable system will be managed by a single, locally trained nurse / health practitioner.

Ethnography for design At the outset of the project, prior to Institutional Review Board approval to work with infants, the greatest challenge for the team was to understand the interactions of the infant hand with a device, in the absence of infant hands. We used anatomically realistic neonate dolls of various races, we 3D printed and cast phantoms to simulate real children. We studied the kinds of interactions possible between a person and the infant (doll) and produced hand drawn renderings (Figure 3). These were displayed in the design studio as a constant reminder of the challenges being faced, and ultimately of the realization that frequent and constant testing with representative samples of real infants was the only viable solution.

Figure 3: Hand drawing of infant hands by team research assistant Lynn Hao

The interaction arc. Once work with infants began it became clear that it was not enough to consider the position of the infant before contact with the capturing device. The infant’s response was more critical. Limp fingers reacted by curling, flattened hands recoiled. When the tips of finger pressed against the flat surfaces of our devices, they bunched up. Each of these represented a potential failure mode.

Not only did the ethnographer observe and record each session, other team members recorded close-ups and video clips of these dance like sequences of big hands and small hands, surfaces and body parts. The practitioners – the persons managing the device to capture the fingerprint – were often not aware of their own micro-dynamics, yet gradually developed sensibilities they could articulate. We began to understand the nuances of pressure and movement and maneuvering that were critical to prototype development. The ethnographers created collages of closeups taken during the capture session to display on large vertical boards – annotated with emerging insights re patterns of holding and infant / caregiver reactions. These displays, and a large screen on which video clips and images of the print captures were routinely examined offered a shared space that spanned the expertise represented in the group.

(2) Hardware - Early Prototype Development

A major hurdle to obtaining good fingerprints is that the skin of the infants deforms when in contact with a rigid surface, e.g. the glass “platen” of a traditional fingerprinting device. As a result of these observations, we developed and tested imaging methods that did not require physical contact. The evolution of contact vs non-contact prototypes is shown in Figure 4.

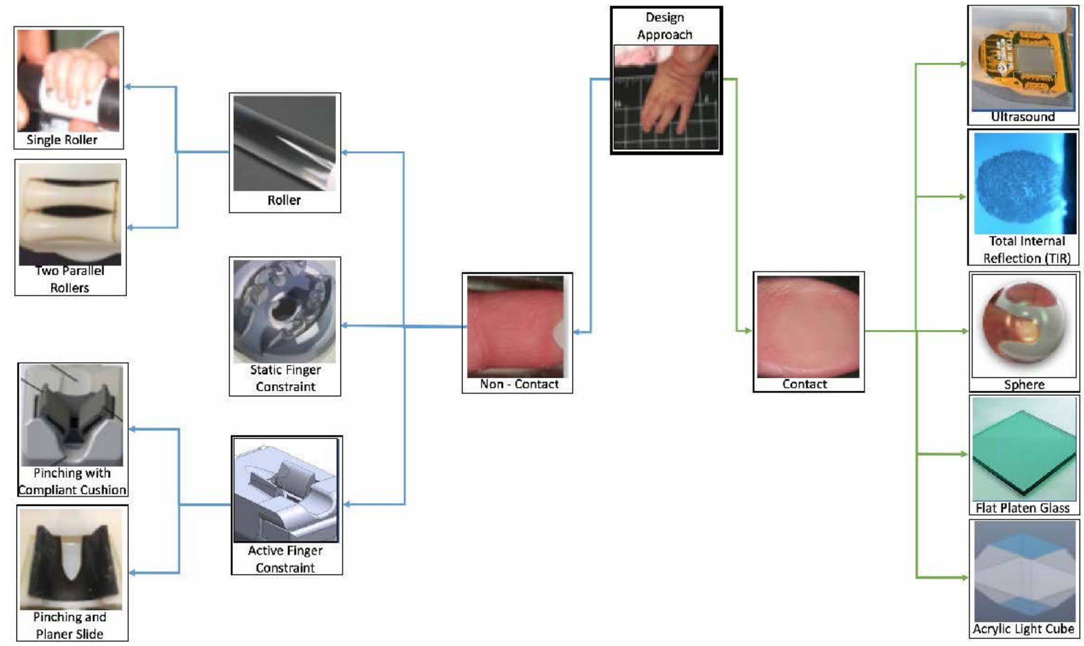

Figure 4: Design Evolution Approach Taxonomy, illustrating, to the right, contact method approaches, and, to the left, non-contact approaches (adapted from Kalisky, unpublished)

(3) Software Pipeline – Rate, Process, Enroll & Match

As the success of the system depends on the image quality and its acceptance in both *enroll* and *match* phases, what transpires in any given print capture session has to be evaluated against a complex processing and analytic pipeline. We devoted significant and early effort to develop a software processing and matching pipeline to supply ground truth of progress towards accurate print capture and matching (Figure 5a-b).

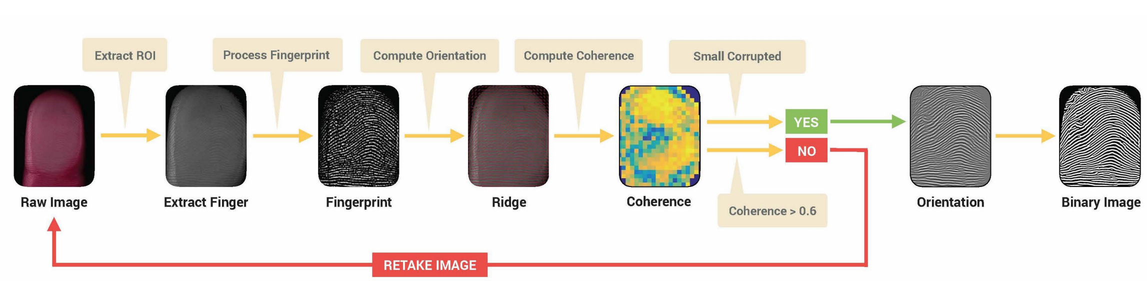

Figure 5a: Processing pipeline – image analysis: an example of an early version of a processing pipeline for a single image

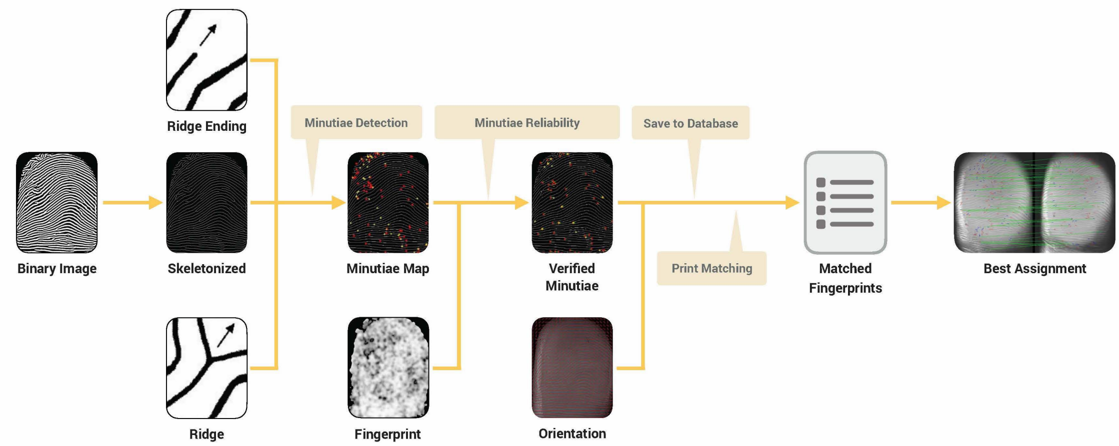

Figure 5b: Processing pipeline – matching: an early proof-of-concept that such a pipeline would allow us to re-match a fingerprint at a later capture event

Design Research Activities - Summary

The shared understanding necessary to carry through the complex design cycle required multiple (and often disparate) specializations to work together. Despite obvious grouping during work- such as engineers and interaction experts working together in different settings, every expert had to be willing to be aware of and sometimes contributing to other facets of the project. This required more frequent communication and task switching than might be promoted by traditional teamwork models. Tools such as Slack promoted shared workflow awareness, yet breakthroughs began only as engineers handled the infants and interaction designers were forced to use software while actually testing children.

Design Research Insights

The interdependent work ethic that developed in the team challenges the distinctions between expert threads of (1) interaction design, (2) hardware and (3) software development, yet it is important to consider each thread in turn as its own entry point into the complex socio-technical system.

(1) Interaction Design Insights – Understanding Failure Modes

Detailed observations and documentation of each print capture session could not on their own suffice to predict the outcome measures that counted as evidence – image quality measures such as contrast, coherence etc. Thus understanding failure modes took us beyond what any sub-group would have to contend with in isolation. A basic failure analysis is shown in (Figure 6), It establishes the interdependency of factors that must be co-managed for successful capture of prints.

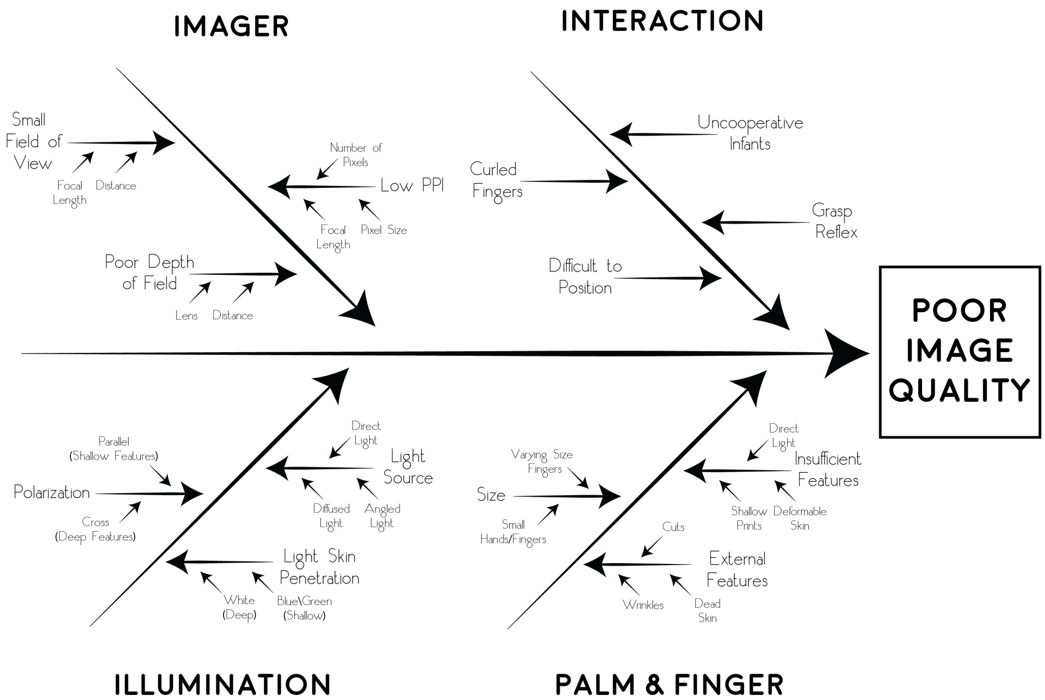

Figure 6: Image Quality – Failure Modes

(2) Hardware Insights – Device Modularity

Over time we learned to distinguish optics and illumination issues and image processing from interaction design challenges which allowed for parallel prototype production (Figure 7.) Our development trajectory evolved toward a modular *technology stack* on which a variety of *caps* could fit interchangeably to test contact and non-contact approaches and make affordances for the changing physiology, shape and behavior of the infant hand.

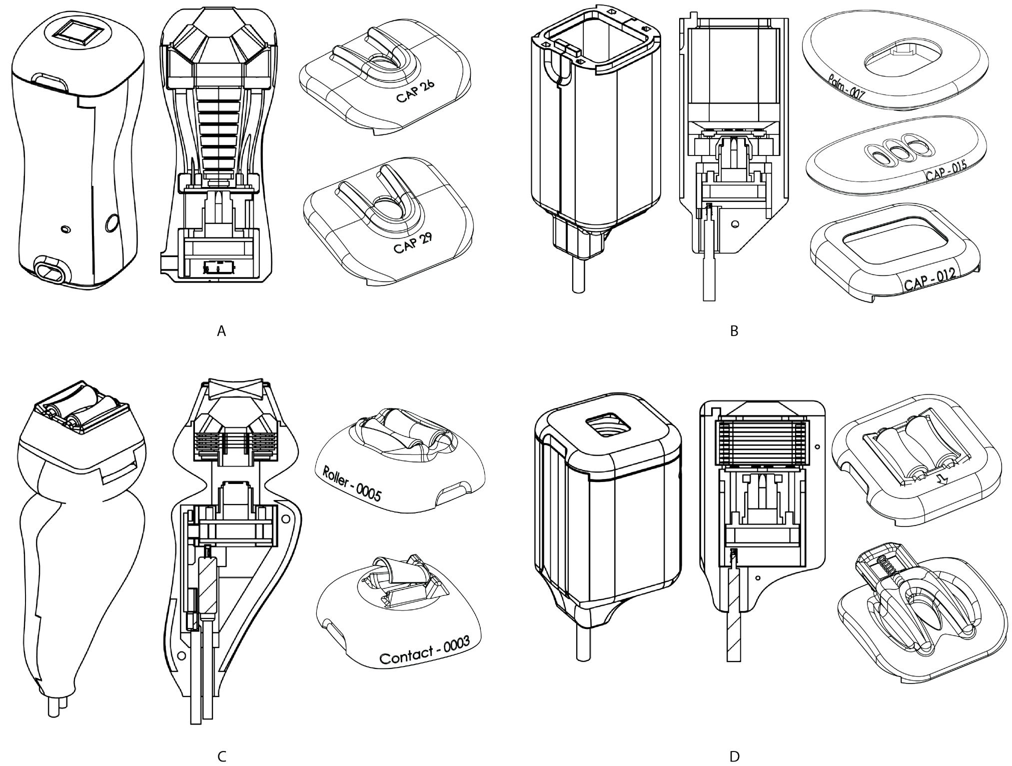

Figure 7: Device Matrix. (A) early prototype contact & non-contact

A. Early prototype – contact and non-contact caps. The device includes fiber optics designed to be closer to the camera – and to absorb stray light – by providing angled illumination, and adding a diffuser.
B. Design for non-contact capture of an infant's palm – includes large field of view but low resolution and direct lighting.
C. Razor handle, shaped for both contact and noncontact capture. The device form intended for better ergonomics for the practitioner. It includes a polarizer / analyzer – the use of a variable lens made it possible to do both contact and noncontact with the same device. It featured angled light illumination (like in A.)
D. Noncontact only with direct light – larger field of view with high resolution – fixed focal length – not a lot of flexibility but effective in noncontact capture Tops – include rollers, spring mechanism to accommodate for varying sizes.

(3) Software Insights - Extending and Integrating Pipeline

After the arduous development of a software processing and analytics pipeline – the software experts focused on integrating the print capture, processing and data management directly into the capture process by developing a unified Graphical User Interface (GUI) (Figure 8) that simplified data capture and gave real time feedback on print quality and matching.

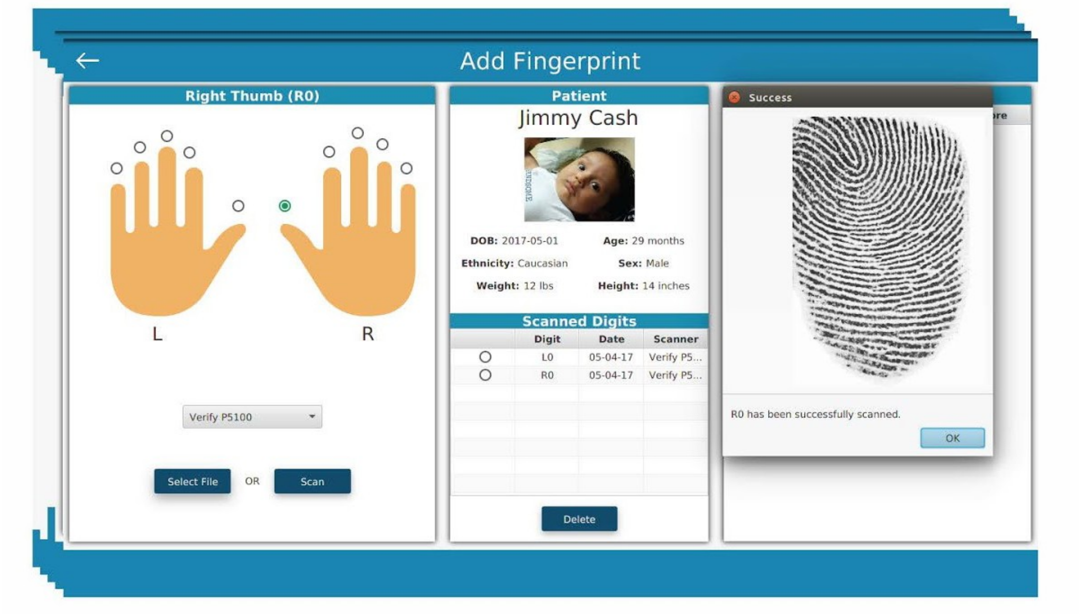

Figure 8: GUI for Fingerprint Capture, Enroll, Match

Design Insights - Summary

Our work required a multidisciplinary team with an organizational structure that allowed for both individual contributions and shared collaboration. This itself required significant consideration and iterations and might be considered its own form of complex sociotechnical problem. This presented the realization that teams assembled to solve "wicked" problems-- may themselves be "wicked" problems. We found that common version control and sharing tools such as GitHub, Slack and Google Drive greatly improved efficiency. Additionally, traditional failure mode analysis and visualization served to align mental models amongst the team and assure directed progress. In the end, frequent testing and iteration by a cohesive team was the only viable course.

Conclusion

This paper describes the complex design challenge of developing biometrics for infants. Unlike prior work that attempted to adapt adult-centric technology, we started before the assumed solution and focused upon a clear goal; identifying very young infants (neonates) in extreme environmental conditions. From the beginning, we sought to build the necessary technology in concert with infant and caregiver preference and interaction and used HCD methods to guide this process. Based on requirements uncovered during field study we targeted development of a robust device that could be used by a community health worker with no specialized training, in any setting and without support. Moreover, the procedures and interactions with children would have to be acceptable to caregivers and reliably capture high quality prints needed for the functioning and trust of the overall systems. Overall the early acknowledgement of the complexity of the problem, the use of Human Centered Design Thinking and a efforts to assure a collaborative, diverse and intentional team led to the project's success. We propose this merging of design thinking, team science and technology design may be applied to similar, complex sociotechnical problems in the future.

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Author Biographies

Key Author Contributions

Carl Demolder: Research Technician in the Prototyping Facility of QI-UCSD. An undergraduate in Mechanical and Aerospace Engineering . Contributed mechanical design and prototyping, electrical engineering and software design and helped with experimental design. Initiated and contributed figures and text to this manuscript.

Tom Kalisky: Masters in Mechanical and Aerospace Engineering. Co-lead mechanical design and prototyping, helped with experimental design and contributed figures and text to this manuscript.

Yunting Zao: Masters in Electrical and Computer Engineering. Co-lead mechanical design and prototyping, helped with experimental design and contributed figures and text to this manuscript.

Daniel Johnson: Masters in Mechanical and Aerospace Engineering. Co-lead mechanical design and prototyping, helped with experimental design and contributed figures and text to this manuscript.

Courtney Avery: Research assistant. Responsible for infant testing, contributed insights and aided with figure design of the manuscripts.

Deborah Forster: Cognitive Scientist and design-context researcher. Led interaction and human centered design and contributed significant text and content to the manuscript.

Eliah Aronoff-Spencer: ID Physician and Health Technology Designer. PI of the study, contributed text and edited the manuscript.