Biometrics Systems Include Users

Mary Frances Theofanos, Ross J. Micheals, and Brian C. Stanton

***Abstract*—As system designers, do we sometimes forget where biometrics come from? The "usual" standard biometric system model includes the biometric *presentation* and a biometric *sensor* but not users themselves. Having this model facilitates having shared vocabulary and abstraction for technologists and systems developers. However, advancing the *systems* science of biometric systems will require a shift towards a user-centered viewpoint. After all, without a *user* there can be no biometric. In this paper, we argue that it is not only appropriate, but *necessary* to consider users—their behavior, cognition, perception and anthropometrics—as a component of a biometric system.**

***Index Terms*—Biometrics, process model, usability, user-centered design.**

I. Introduction

BIOMETRIC system performance has traditionally been tested, measured and reported independently of the human factors, including the user [1]. The user is viewed as a passive source of the biometric sample instead of an interactive and integrated component of the biometric system. Consider for example the collection process and determining the capture time of a biometric device in order to establish the system throughput. What does a capture time of "three seconds" really mean? One might expect that the entire process of capturing three "slap"-style images would therefore take nine seconds. Such a viewpoint does not take into account the users' behaviors. The human factors and user's behaviors must be considered as part of the system to truly measure biometric system performance.

There have been a number of general studies and surveys that examine the use of biometrics from a social and acceptance perspective [1], [2]. However, few experiments have been performed that study specific interactions between the user and a biometric technology [4]–[6].

How do a user's behavior, cognition, perception, and anthropometric qualities impact system performance metrics and error estimates? In order to improve the performance of biometric technologies, it is critical to take a systems approach that integrates the needs of users as well as the entire experience users will have with the hardware, software and other components of a system. Adopting a system view that includes the user in the biometric process is not only beneficial to the end users, but a user-integrated view can also help to improve the performance and effectiveness of the biometric system.

The National Institute of Standards and Technology (NIST) biometrics usability team has established a research program that integrates the user and human factors in biometric systems.[1] The team studies user characteristics with scientific rigor. The team strives to improve the usability and the user interface of biometric systems and examines how these characteristics impact biometric system performance.

This paper presents a biometric system process model that fully integrates the user and incorporates user behavior and characteristics. Closing the paper is a case study that illustrates the application of the biometric system process model for fielding a ten-print fingerprint system.

II. Background

A. Usability

The International Organization of Standards (ISO) in ISO 13407 defines usability as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use*" [7]. Based on this definition, it is clear that usability is not simply "look and feel." In fact this definition advocates that usability is measurable and provides an outline for how to evaluate a product's usability. The definition identifies three factors that must be considered prior to evaluation.

1) **Users**—Who are the users of the systems? In a biometric environment the primary users include the person presenting the biometric sample to a sensor (including persons with disabilities), operators (the user responsible for orchestrating the biometric capture) and examiners (experts that manually verify the output of an automated matcher).
2) **Context of Use**—What is the environment, motivation, cognitive load of the users? For example, in a point-of-entry (PoE) application the presenter is a traveler who is probably tired, stressed, carrying luggage, may not speak the native language, and impatient.
3) **Goals**—What are the user's goals or tasks? For instance, the operator is interested in the acquisition or capture of images. How does training impact the user's goals? What might be some competing goals (such a PoE officer performing threat detection)?

The ISO definition also provides the framework for measuring the usability by identifying the following measures.

Manuscript received January 15, 2009; revised September 25, 2009. First published December 22, 2009; current version published January 27, 2010.

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Digital Object Identifier 10.1109/JSYST.2009.2037792

[1] These tests were supported by the Department of Homeland Security. Specific hardware and software products identified in this report were used in order to perform the evaluations described. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose.

- **Effectiveness**—a measure of the accuracy and completeness. How well can the product be used? Metrics in a biometric application may include quality, errors, and accuracy.
- **Efficiency**—a measure of the resources expended. Metrics here might include task time or throughput.
- **User satisfaction**—the degree to which the product meets the users' expectations—a subjective response of comfort or frustration.

Experiments at NIST have demonstrated that usability and human factors affect biometric performance—both the quality of the captured images and the time required to collect the images. In turn, these impact system performance including throughput, matching, and ultimately cost. From these experiments the team has identified a number of user characteristics which impact biometric performance including

- age, gender, height (anthropometrics)—What are the inherent characteristics of the person [8], [9]?
- acclimation—Is the user familiar with the device or the technology? [8]
- accessibility—Does the person have a disability? [10]
- perception—Is the user uncomfortable with the process or the equipment? [11]

Advancing biometric systems will require that during the entire biometric design, development, and implementation lifecycle, the following human factors are considered.

- **physical characteristics of the device**—e.g., How high is it? Does the angle matter? What should be the color of the fingerprint platen? Should it feel warm or cold?
- **affordance** (the inherent ability of the device to relay its use)—For a fingerprint scanner, the shape and configuration of the scanner should convey where to place your fingers and that the prints have been captured. A fingerprint scanner that requires lengthy instructions has poor affordance.
- **instructions and learning materials**—What form should the instructions take?
- **accessibility**—How might the technology adapt for people with disabilities?

In its narrowest sense, usability testing involves the evaluation of a system. In its broadest sense, usability testing involves users throughout the system development life-cycle.

B. *User Centered Design (UCD)*

ISO 13407 formalizes human-centered design as an approach to the design and development of a system that enhances efficiency and effectiveness. It seeks to improve the entire system from hardware design to software implementation. It should be applied to all aspects of the technology, including a system's indirect artifacts, such as help documentation and training materials. Fig. 1 depicts the UCD process.

User-centered design [7] is characterized by the following:

- an early focus on users, tasks, and environment;
- the active involvement of users;
- an appropriate allocation of function between user and system;

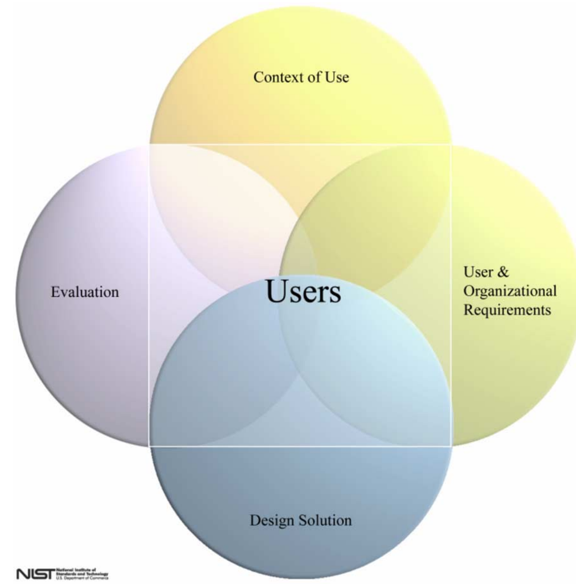

Fig. 1. User-centered design process.

- the incorporation of user-derived feedback into the (biometric) system design;
- an iterative design whereby a prototype is designed, tested and modified.

The user-centered design process involves four activities as illustrated in Fig. 1. The four activities can be summarized as follows.

1) **Defining the Context of Use**—including operational environment, user characteristics, tasks, and social environment.
2) **Determining the User and Organizational Requirements**—including business requirements, user requirements, and technical requirements.
3) **Developing the Design Solution**—including the system design, user interface, and training materials.
4) **Conducting the Evaluation**—including usability, accessibility, and conformance testing.

They are depicted in a unified fashion in the diagram because these activities are expected to be performed both iteratively and in concert. Independent of any system design lifecycle, user-centered design works as part of other development lifecycles and can be used to guide the integration of the user in both system development and feature evaluation.

III. Biometric System Process Models

A. *Current Biometric Process Model*

Historically, the design, development and evaluation of biometric technologies have (understandably) focused on the hardware and software performance, functionality, reliability and precision. Characteristics such as resolution of sampling, speed, accuracy, and matcher error rates have been thoroughly tested. As these new technologies were evolving, it was necessary to focus primarily on the performance of these components.

As a result, the biometric process model typically focuses solely on the technology. The model indicates only what the

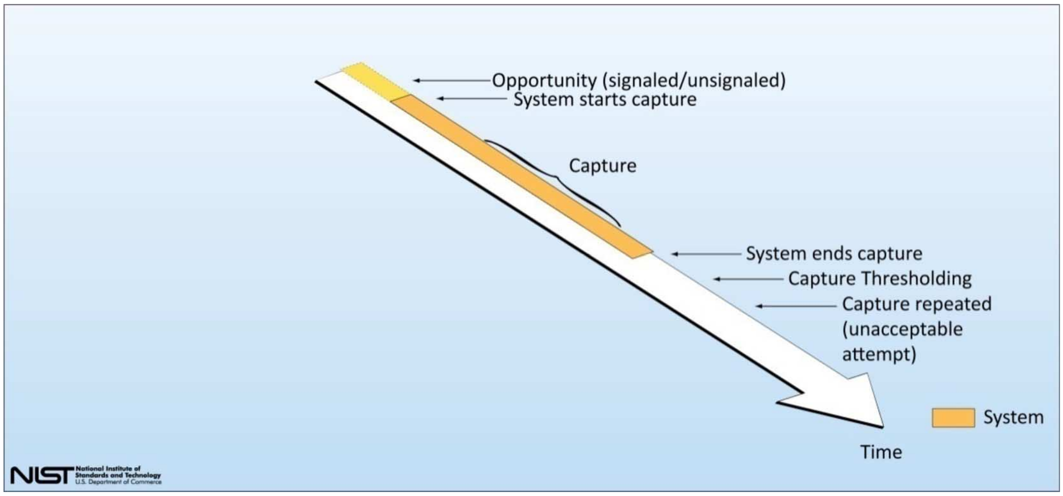

Fig. 2. Biometric system process model.

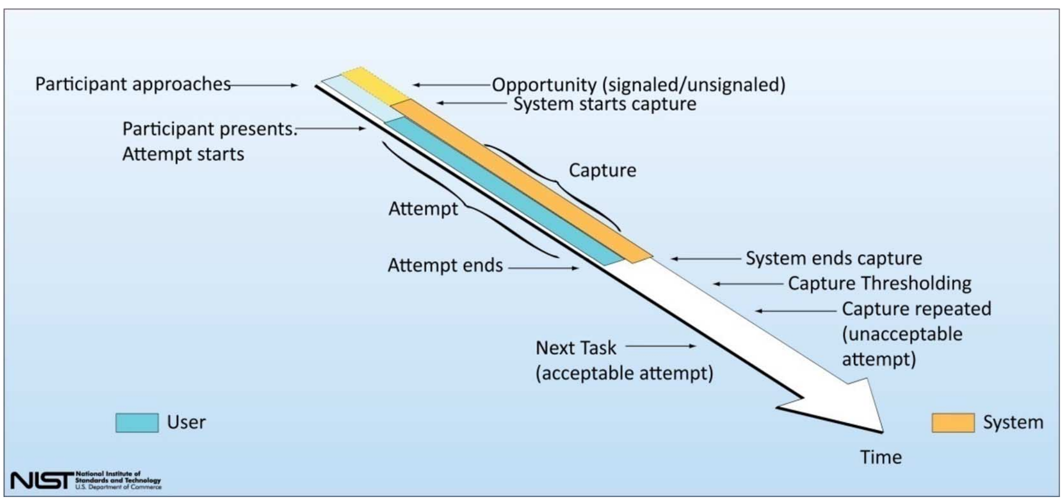

Fig. 3. Biometric systems process model (user integrated).

biometric hardware and software are doing. This view of the model is presented in Fig. 2.

However as technologies mature, it is critical that all system factors are considered and evaluated. One component of biometric systems that has not been traditionally considered is the *user*. As the carrier of the biometric, the user brings innate qualities and experiences to the interaction that affects performance. With careful consideration of the user interaction, biometric system designers and evaluators will be able to achieve significant improvements in overall system performance, much more so than technology advances alone will achieve.

B. A User Integrated Process Model

Presenting users are the originator of the biometric process. These users begin the process with a presentation and ideally end the process by submitting a high-quality, accurate sample. Their interaction with the hardware/software is essential to a holistic and full-system understanding of the biometric process.

Fig. 3. illustrates the two-way interaction, or relationship, between the user's observable behavior and the hardware and software during the biometric process. Unfortunately, many biometric systems have focused solely on the limitations and capabilities of a technology (i.e., the left side of the arrow in the Fig. 3), without truly considering the impact a user's characteristics (the right side of the arrow), experience levels and abilities will have on a biometric system. This model recognizes the essential role a user plays in the biometric process and views the process as a two-way relationship in which the hardware, software and user are *partners* with the same goal in mind.

C. UCD and the Biometric Systems Process Model

We have found that not only does the user's interaction play an integral role in the submission of a sample, a user's innate characteristics have a substantial impact on the ultimate success of a biometric system. Therefore, one can take a user-centered view of the system. Using this approach the user-centered process applies to all facets of the biometric system. UCD is not limited to observable behavior but seeks to identify user characteristics that influence design in order to improve overall system success. This holistic view includes the inherent qualities of users and their interaction with the biometric system.

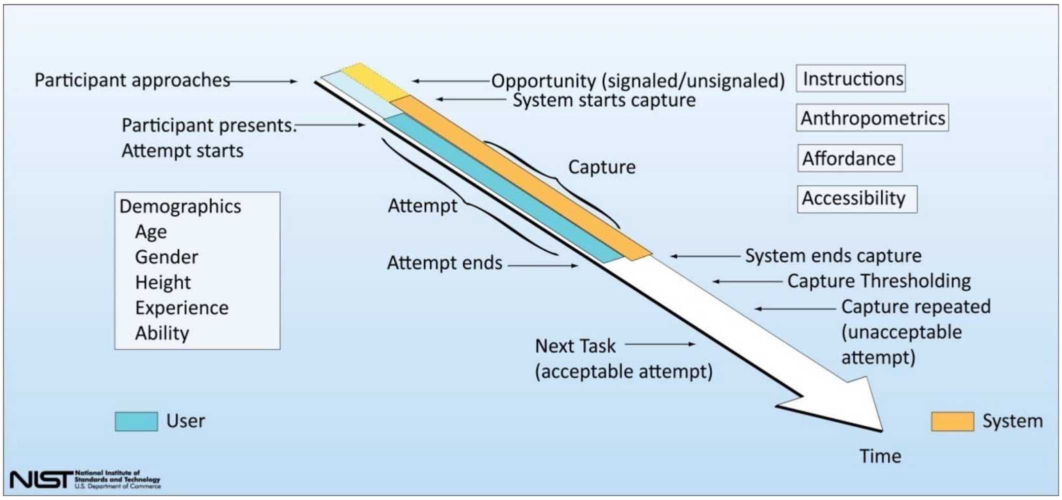

Fig. 4. System model with user attributes and characteristics.

Fig. 4 identifies these essential usability components to illustrate a truly user-centered process that takes into account the needs and characteristics of users instead of simply regarding users as inactive bystanders. By understanding the inherent characteristics and interactions users have with a system, design teams can make better informed decisions, eliminating the guesswork of the biometric design process.

Adopting an integrated user view of the biometric process is not only beneficial to the end users, but this user-centric view can also help to improve the performance and effectiveness of a system.

IV. A Case Study

The following case study demonstrates the use of the integrated biometric system process model and the user-centered design process.

A. The Problem

The Department of Homeland Security's (DHS) United States Visitor and Immigrant Status Indicator Technology (US-VISIT) program has located biometrically-enhanced identification systems at points of entry such as airports. Visitors are fingerprinted as they enter the country. The US-VISIT program is migrating from two (flat) index fingerprints to all ten (slap) fingerprint images. Based on previous usability testing performed at NIST [9], there is a concern that the existing counters that house the fingerprint scanners are too tall to support ten print collection processes.

B. Context of Use

The first step of the UCD process is to determine the context of use by identifying the characteristics of the operational environment, the users, and the tasks. DHS had selected ten airports to pilot the new system. The counter heights at these airports ranged from ranged from 838 mm (33 in) to 1245 mm (49 in). The most commonly occurring counter height was 991 mm (39 in). They were planning to pilot two slap fingerprint scanners at ten airports. Each scanner was 152 mm (6 in) tall.

The primary users were travelers. US-VISIT only fingerprints travelers from 14 to 79 years of age. According to the World Health Organization the mean male height is 5 ft 8 in and the mean female height is 5 ft 2 in. The users speak many different languages and are multi-cultural.

The user's primary goal was to quickly complete the immigration process and enter the country. In order to accomplish this goal, the user would have to complete four tasks: a right slap, a left slap, and either both thumbs or a right thumb and left thumb.

C. User and Organizational Requirements

During consultation, US-VISIT team members enumerated two primary goals. First was increasing system throughput (the number of people who can be processed). The second was increasing the quality of the captured images (collecting the "best" possible fingerprint images). They also had a focus on customer service and were concerned for the travelers comfort and safety. Finally they identified one constraint—lowering all of the counters in all of the facilities was not possible at this time.

D. Design Solution

Angling the fingerprint scanners on the counters may alleviate the concern that the scanners might be placed too high. Using computer aided design (CAD) software we modeled the counter heights with angles against the boundaries of the study's target population using the heights of the 95th percentile male and 5th percentile female [12]. This range accounts for 95% of the population. The models revealed that angles greater than 30° would be extremely difficult for participants 6 feet (183 cm) and taller. The models suggested the following four angles: 0°, 10°, 20° and 30°, where 0° indicates a level work surface. (Sloping the scanner away from the user was not deemed a viable option due to the large amount of physical modifications that would have to occur to do this.)

E. Evaluation

A usability test was performed to determine "What is the impact on fingerprint performance of angling the scanners at the existing counter heights?" In other words given the current surface heights, what is the "best" angle? Note that this is *not* quite the same question as "What is the best angle for fingerprint capture?" "Best" would be determined by examining the three ISO measures of usability.

1) **Efficiency**—the time to complete the tasks. Does the angle affect the time required to capture fingerprint images?
2) **Effectiveness**—what is the utility of the prints? Does angle affect the quality of the captured images?
3) **Satisfaction**—traveler comfort. Do users prefer a particular fingerprint scanner angle?

The design solution determined that there were four angles to test: 0° (or flat), 10°, 20° and 30°. Previous research on work surface heights [9] and fingerprint capture recommended a counter height of 914 mm (36 in) for a 6 in scanner. Taking into account the previous recommendations, this study was designed to test the most common counter height of 991 mm (39 in), the tallest counter height of 1245 mm (49 in) and the practical midpoint of 1143 mm (45 in). We use the term "practical" midpoint since there were no counter heights at the true midpoint of 1117 mm (45 in).

1) Experimental Design: Each participant was instructed to complete five tasks. Instructions were scripted and given in a consistent manner across all participants. Participants were asked to present a left slap, left thumb, right slap, right thumb, and both thumb prints (simultaneously). Fingerprint images were collected from each participant at the four different angles for one counter height. Each participant presented fingerprint images for each angle but only one counter height and one scanner. The angles were counterbalanced and the right and left start conditions were randomly selected. A right slap was always followed by the right thumb and a left slap was always followed by the left thumb. The order of the slaps was provided to the participants as voice prompts generated by the software.

2) Materials: The experiment consisted of two digital slap fingerprint scanners, custom software that captured images from the scanners, an adjustable platform for the scanners that allowed for the scanner to be positioned at various angles using pegs, and adjustable tables that allowed for accurate positioning of the counter height. The counter height was measured from the floor to the base of the scanner. Both scanners were 6 in (152 mm) tall. Thus the effective height of the scanner platen is 6 in above the counter. The angles were measured with respect to the platen and the counter top using a protractor. As discussed the three heights were 39 in, 45 in, and 49 in and the four angles were 0°, 10°, 20° and 30°. One of the scanners had a 6° slope built into the platen. US-VISIT indicated that they would not negatively angle the scanner to adjust for that slope in the field. Therefore, we did not compensate for that scanner at 0° but did account for the 6° in the remaining angle calculations and positioning.

A custom capture application provided for controlled capture of images from a given user at the various counter heights and angles.

3) Results:

a) Participant demographics: The participants were 126 NIST employees who volunteered to participate. Although the NIST population may not be representative for some experiments, the NIST population was representative and appropriate since this study focused on anthropometrics with particular emphasis on subject height. There were 66 participants for Scanner A (22 for each height) 31 women and 35 men, ranging in age from 17 to 73 years. Demographics for Scanner B include: 60 participants (20 for each height), 27 women and 33 men ranging in age from 17 to 76. There were a relatively equal number of men and women who participated. Ages were fairly uniformly distributed.

The participants ranged in height with shoes from 4 ft 11 in (150 cm) to 6 ft 6 in (198 cm). The mean height for Scanner A was 5 ft 5 in (165 cm) for women and 5 ft 10 in (175 cm) for men, for Scanner B: 5 ft 6 in and 5 ft 9 in for women and men respectively. The measured heights were fairly normally distributed.

b) Efficiency: Efficiency was measured as the time required to complete a task. The design included five tasks: a right-slap, left-slap, both thumbs, or single thumbs. Fig. 5 illustrates the system view of the capture process. Each task was initiated by a voice prompt and a timestamp was recorded when the software prompted the user to "please place your hand on the scanner". The software native to the scanner detected the image and determined if the image was acceptable. When the scanner signaled that it had an image our software ended the capture, recorded an end-capture timestamp and prompted the user to remove his/her hand. Timestamps were recorded in milliseconds.

For each response variable of time for each task, we examined the factors of angle, counter height and subject height (Table I.). The timing data was not normally distributed therefore we used non-parametric tests. For Scanner A, we found no statistically significant differences for the factors of angle, counter height, and subject height Significance is indicated by "+" for $\mathrm{p} < 0.05$ and not significant by "−".

For Scanner B, the factors of angle and counter height were also found to have no statistically significant differences in the test results except for Task 4: left thumb. The Kruskal-Wallis test indicated that the effect of counter height was significant with $\mathrm{p} = 0.01$. In addition, the subject height was significant for Task 1: right slap, Task 3: left slap, and Task 5: both thumbs.

To summarize, the data indicates there is no significant effect due to angle with respect to the time required to complete a fingerprint task.

c) Effectiveness: The effectiveness or the quality of the captured images was analyzed using the NIST Fingerprint Image Quality metric, or NFIQ [13]. The NIST fingerprint imaging software segmented the slap images into individual fingerprint images and computed the NFIQ score for each image. Two approaches were used to evaluate the slap quality. The first approach examined the NFIQ scores of individual fingers. Using this method, the median NFIQ score is calculated for each finger for each task. Because NFIQ scores are discrete values from 1 to 5, there is some concern that it may not be appropriate to calculate the medians. Therefore, the frequency of

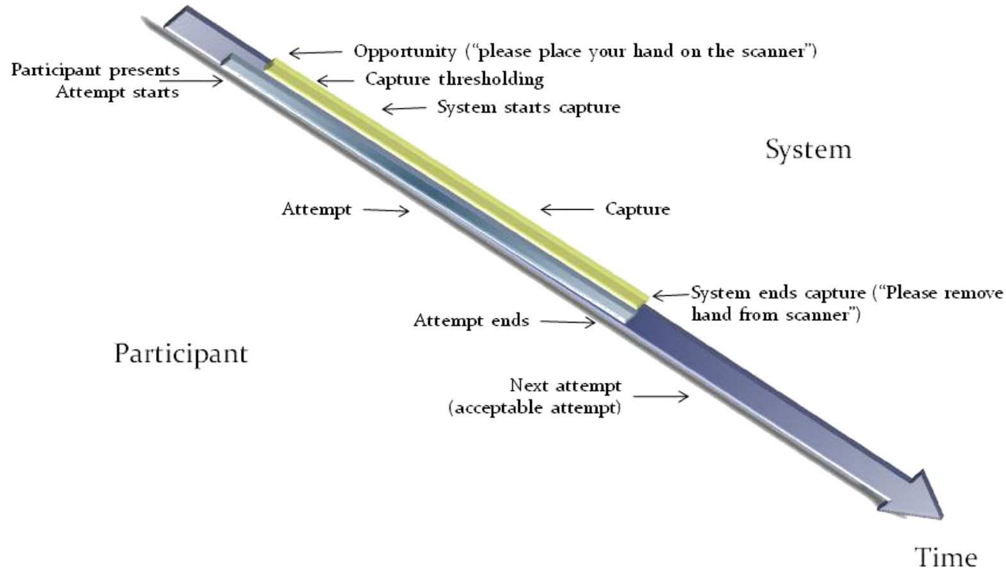

Fig. 5. System model of case study.

Fig. 6. Left: A taller participant presents to a sensor at a 30 degree angle on a 39 in high counter. Right—A shorter participant presents to a flat sensor on a 49 in high counter. Note that the shorter participant cannot keep their feet flat on the ground.

TABLE I
EFFICIENCY MEASURES FROM CASE STUDY

	Scanner A	Scanner B
angle	–	–
counter height	–	+
subject height	–	+ (right slap, left slap, both thumbs)
median capture times (per task)	~10 s per task	~11–16 s

NFIQ values for individual fingers were also evaluated. Using this approach the distribution of the frequencies is examined to determine quality differences.

Using both approaches we found no statistically significant differences for angle for Scanner A or Scanner B. However, counter height was found to be significant using the Kruskal–Wallis test with p-values ≤ 0.05 for several fingers for both Scanner A and Scanner B—right thumb, right middle, right ring, and left little. The data was not consistent enough between the two scanners to indicate any clear trends that a particular height/angle/task was always most effective.

d) User satisfaction: Each user was given a satisfaction survey after completing the experiment. The survey consisted of six questions that addressed which angles the participants preferred. In general, more people preferred a steeper angle as the counter height increased. The least comfortable angle was more dependent on the participant's height. The 0° angle was the least comfortable for shorter participants, while the 30° angle was least comfortable for taller participants. Fig. 6 (left) illustrates the difficulty a taller individual experienced at the 39″ counter height and an angle of 30°. In contrast Fig. 6 (right) shows a participant that was 5 ft 2 in (158 cm) struggling to position both thumbs at the 49 in counter height and 0°.

Participants positioned themselves using one of two methods to capture their two thumbs simultaneously. For Scanner A most participants held their fists together with their thumbs extended as illustrated in Fig. 7. In general, pressing the wrists or the

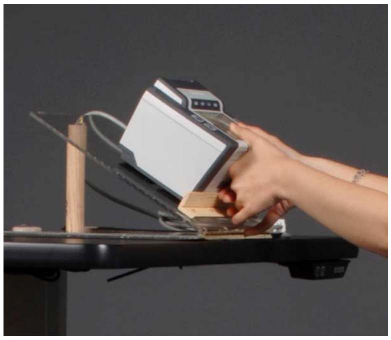

Fig. 7. Hands pressed together.

Fig. 8. Grasping the scanner.

Fig. 9. Rotated thumb print example.

thenar region of the hands together provided balance and stability as the images were collected. For Scanner B most participants were unable to press their thenars together; we observed many participants extending their four fingers on each side of the scanner (Fig. 8) for stability and comfort during the scan. We observed that this behavior resulted in the rotation of the thumbs from perpendicular (Fig. 9). This rotation may prevent accurate segmentation for algorithms that assume upright thumbs. Thus, we examined and measured the rotation of the thumbs. Using the FBI standard we measured thumb rotation using the crease of the thumb to determine perpendicular. The thumb rotation for Scanner A was consistent across all heights and angles as shown in Fig. 10. Thumb rotation for Scanner B was not consistent across all counter heights and angles. As the height increased the number of participants who rotated their thumbs increased and the amount of rotation increased. One person positioned his thumbs completely backwards or 180°.

e) Conclusions: The usability study found the following.

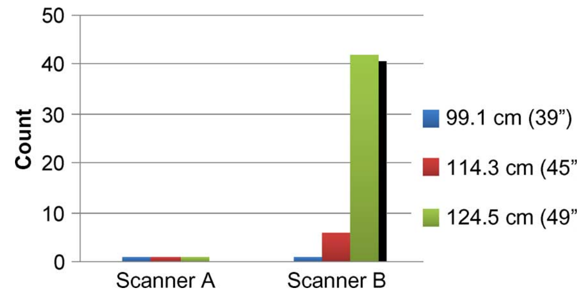

Fig. 10. Frequency of thumbprint rotation.

- **Efficiency**: There was no significant effect on transaction time due to angling the fingerprint scanners or counter height.
- **Effectiveness**: There was no significant effect on image quality due to the angles for either scanner. Counter height did impact quality of the captured images, but it appears that the influence of counter height on quality is scanner dependent.
- **User satisfaction**: The effect is a function of the participant height, counter height and angle. Participants overwhelmingly preferred the 20° and 30° angles as the counter heights increased. Single thumbs should be collected versus simultaneous thumbs.

Since retrofitting the existing counters with adjustable height mechanisms to accommodate visitors of different heights was not possible at the time, for the taller counters, we felt confident that angling the scanner to improve user satisfaction (i.e., customer service) would not adversely affect system performance. Although this recommendation may seem obvious, without proper user testing to determine any negative impact on image quality and other attributes one should not change the angle of the scanner. Finally, the slaps collected should include right, left, and individual thumbs. For more details on the experiment see [14].

V. Conclusions

This paper represents first steps in what the authors hope will ultimately be a paradigm shift in the way successful biometric systems are developed. The most successful systems will be those designed with a vision that spans more than just the core technology. As shown in the case study, incorporating user-centered design is not simply a new methodology—it expands the overall solution space available to system designers. However, an optimal design can only be achieved with measurements made with scientific rigor. While pilot testing is a common deployment strategy, it often lacks controls necessary for exploring particular design decisions. In the case study, formal usability testing helped isolate the effects of particular design decisions.

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