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Giving Infants an Identity: Fingerprint Sensing and Recognition

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ABSTRACT

There is a growing demand for biometrics-based recognition of children for a number of applications, particularly in developing countries where children do not have any form of identification. These applications include tracking child vaccination schedules, identifying missing children, preventing fraud in food subsidies, and preventing newborn baby swaps in hospitals. Our objective is to develop a fingerprint-based identification system for infants (age range: 0-12 months)[1]. Our ongoing research has addressed the following issues: (i) design of a compact, comfortable, high-resolution (>1,000 ppi) fingerprint reader; (ii) image enhancement algorithms to improve quality of infant fingerprint images; and (iii) collection of longitudinal infant fingerprint data to evaluate identification accuracy over time. This collaboration between Michigan State University, Dayalbagh Educational Institute, Saran Ashram Hospital, Agra, India and NEC Corporation, has demonstrated the feasibility of recognizing infants older than 4 weeks using fingerprints.

CCS Concepts

•**Applied computing** → *Health care information systems;*

Keywords

fingerprint recognition; infant identification; healthcare

1. INTRODUCTION

According to UNICEF, each year, 25 million children do not receive proper vaccines and consequently, 6.6 million children die from vaccine-preventable diseases [1]. It is estimated that about 80% of these deaths occur in the developing regions of Sub-Saharan Africa and South Asia [1]. Routine vaccination programs have been initiated nationwide in many developing countries to increase vaccination[2] coverage (e.g. Mission Indradhanush in India[3]), however, vaccine wastage rates are still estimated to be higher than 50% in some of the most challenging geographies[4]. One of the main reasons for this confounding statistic is the lack of an effective method to track vaccination schedules of infants, primarily because in most developing countries infants and, in most cases, even parents, do not have any form of identification documents.

Swapping of newborns after birth is another major problem because of overcrowded hospitals and inadequate maternity ward provisioning. To alleviate this problem, it is necessary to identify newborns and associate their identities to their mothers. In the United States, it is estimated that 800,000 children go missing every year - a child every 40 seconds[5]. Many of them cannot be easily located and identified because there is no known method to reliably identify infants.

Given the growing demand for a method to identify infants in several healthcare and social welfare applications, a number of international healthcare organizations, non-governmental organizations and government agencies are interested in finding a solution to the following problem: *How to identify a child over time using his biometric traits, e.g., fingerprint, iris, face, etc.* Our interest is in infant recognition because of the need to track the vaccination schedules of children (while Hepatitis-B is administered at birth, most other vaccinations typically start at the age of 1-2 months[6]).

There are two challenges in identifying infants using their biometric traits: (i) biometric data acquisition, and (ii) biometric matching (comparison). Among the potential biometric modalities (fingerprints, face, iris, footprints, and palmprints), we believe fingerprint is the best modality for infant identification. Fingerprint readers are compact, and sensing is fast, causes little to no discomfort to the child, and has relatively low parental concern. In contrast, iris capture is difficult if the child is asleep or crying, facial characteristics are known to change over time, footprint capture may require removal of socks and shoes, and palmprint capture is challenging because infants tend to keep their fists closed.

Fingerprint identification dates back to the 19th century

[1]http://www.cdc.gov/ncbddd/childdevelopment/positiveparenting/infants.html

[2]We use the terms vaccination and immunization interchangeably.
[3]http://www.nhp.gov.in/mission-indradhanush
[4]http://vaxtrac.com
[5]http://www.childidprogram.com/about-us
[6]ttp://www.cdc.gov/vaccines/parents/downloads/parent-ver-sc-0-6yrs.pdf

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(a) (b) (c)

Figure 1: Fingerprint capture of infants. (a) The compact (7cm × 3cm × 7.5 mm) and high-resolution (1,270 ppi) custom fingerprint reader, (b) fingerprint capture of an infant using the reader, and (c) fingerprint capture at two data collection stations in Dr. Bhatnagar's clinic in Saran Ashram Hospital, Agra, India.

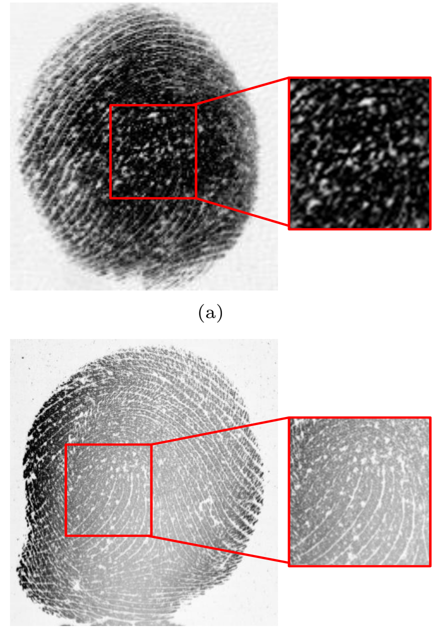
with the pioneering work of Faulds, Henry and Galton [9]. Automatic Fingerprint Identification Systems (AFIS) are now being used by virtually every law enforcement and forensics agency in the world. With advances in sensing, processor, and storage technologies, fingerprint identification has become ubiquitous, from national registry (Aadhaar program in India) to consumer devices (mobile phone unlock and payment)[7,8]. While India's Aadhaar program[9] collects fingerprints (and iris images) of children as young as 5 years old, there is no fingerprint system, to our knowledge, capable of establishing the identity of infants for their welfare.

Galton, in 1989, was the first to study fingerprint recognition of children [6]. He obtained inked fingerprint impressions of a single child, from birth until 4.5 years of age, and conjectured that the minimum age for infant fingerprint recognition is 2.5 years. To our knowledge, our ongoing work is one of only a few follow-ups [2], [10], [3], [7] which have pursued Galton's initiative on a large scale.

Despite a lack of proper supporting evidence, the scientific community and user agencies generally believe that infants cannot be recognized based on fingerprints. Our efforts over the past two years have been directed at addressing the following two questions: (i) can infants be recognized based on fingerprints, and (ii) if so, what is the minimum age at which we can claim sufficient recognition accuracy for field deployment? The contributions of our ongoing research are:

- Design and fabrication of a compact, low-cost, high-resolution (1,270 ppi) fingerprint reader, developed in collaboration with NEC corporation.
- An image enhancement algorithm to improve the quality of the infant fingerprint images.
- Collection of a longitudinal infant fingerprint database in the field spanning 12 months to evaluate infant identification accuracy over time.
- Proof of concept of fingerprint based identification of infants in operational settings in Dayalbagh, India.

[7]http://www.apple.com/apple-pay/
[8]http://www.samsung.com/us/samsung-pay/
[9]Unique Identification Authority of India (http://uidai.gov.in/)



(a) (b)

Figure 2: Fingerprint images of the left thumb of a 6 weeks old infant captured using (a) a 500 ppi commercial fingerprint reader, and (b) the custom 1,270 ppi fingeprint reader used in this study. Corresponding fingerprint regions marked in red have been enlarged to show the ridge details. The 1,270 ppi reader is better in capturing the minute details (e.g. ridge endings and bifurcations) present in an infant fingerprint compared to 500 ppi reader.

2. CUSTOM FINGERPRINT READER

Our earlier efforts to capture infant and toddler fingerprints [8] [7] used an off-the-shelf 500 ppi reader, which did not provide images with sufficient fidelity for identification. In collaboration with NEC corporation, we have developed a compact and high-resolution fingerprint reader that is better suited to capture and match infant fingerprint images (see Figures 1 (a) and (b)). Key features of this fingerprint reader are as follows:

- *Compact*: reader dimensions are 7 cm × 3 cm × 7.5 mm. This enables the reader to be easily inserted between the tiny infant fingers to capture fingerprint images.
- *Tapered edge design*: This reduces discomfort to the infants during fingerprint capture.
- *High-resolution*: reader resolution of 1,270 ppi is able to capture minute details (e.g. ridge endings and bifurcations) in infant fingerprints. Figure 2 shows the fingerprint images of the same finger captured using a 500 ppi off-the-shelf reader and the custom 1,270 ppi reader.

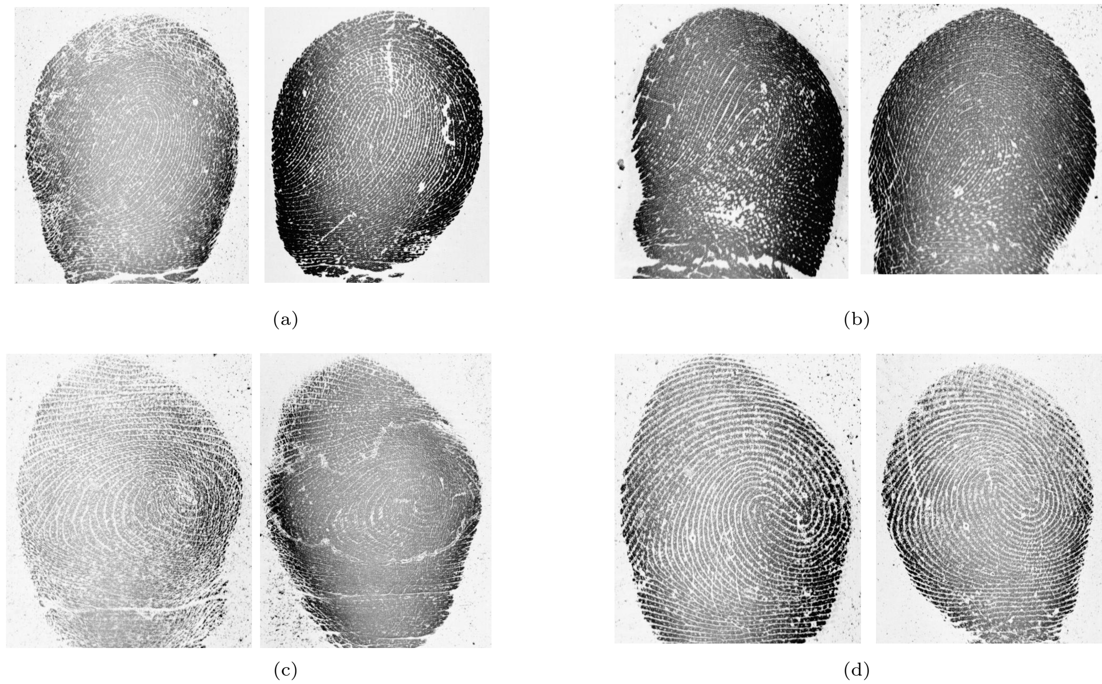


Figure 3: Fingerprint images of the right thumbs of 4 different infants of different ages: (a) 6 hours old, (b) 1 week old, (c) 3 weeks old, and (d) 6 weeks old. The left and right images in each pair were captured on two different days (two to four days apart). These examples show that fingerprint ridge structure becomes clear as the child grows.

- *Manual capture button*: This allows the operator to capture the image based on realtime visual feedback.

3. FINGERPRINT DATA COLLECTION

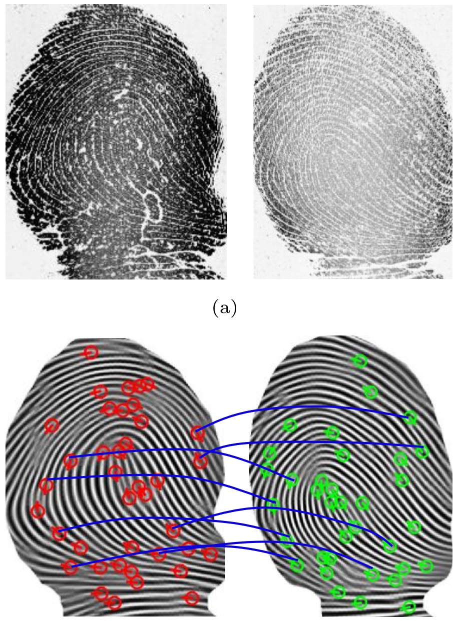
The prototype reader was used to collect fingerprint images of 66 infants in the age range 0-6 months at Saran Ashram Hospital in Agra, India (see Figure 1(c)) taken in September, 2015. The data for each infant was collected twice in two different sessions, 2 to 4 days apart. Three different impressions (images) each of the left and right thumb were captured in each session. This protocol allowed us to have multiple fingerprint impressions of the left and right thumbs of 66 infants over a period of 4 days. See Figure 3 for fingerprint images of 4 different infants of different ages. To our knowledge, this is the first time fingerprint images of a newborn as young as 6 hours old have been captured with visible ridge details (see Figure 3(a)).

4. FINGERPRINT ENHANCEMENT AND MATCHING

Even with a high-resolution (1,270 ppi) fingerprint reader, quality of some of the fingerprints images is insufficient for robust feature extraction (minutia points) and matching (see Figure 4(a)). To improve image quality, we designed an algorithm to enhance infant fingerprint images (see Figure 4(b)), outlined as follows.

1. Foreground region containing the fingerprint is detected by thresholding the individual pixel values.
2. Fingerprint is divided into overlapping patches of size 160×160 pixels. Each patch is input to a convolutional neural network (CNN) trained for estimating ridge flow in the fingerprint [4].
3. Fingerprint image is enhanced by reconstructing patches of size 32×32 pixels using a ridge structure dictionary (similar to the method proposed in [5]).

Given enhanced fingerprint images, we conduct both verification (1:1 comparison) and identification (1:N comparisons) experiments using a commercial fingerprint SDK. The three fingerprints captured on the first day are assumed to be enrolled in the database (obtained during infant's first visit for vaccination) and each of the three prints captured on the second day are taken as the query prints (e.g., obtained, for instance, during subsequent follow-up visits). Similarity scores obtained by comparing a query print to the three enrolled templates for each of the two fingers (left and right thumbs) are combined (sum fusion rule) to compute the final similarity score. To evaluate the verification performance, two different metrics are computed, (i) *true accepts*: number of subjects, which can be correctly verified to have been previously enrolled, and (ii) *false accepts*: number of subjects, which are incorrectly verified as previously enrolled. True accept rate (TAR) and false accept rate (FAR) are then computed to measure how frequently true accepts and false accepts occur. In the identification mode, the captured fingerprint is compared against a background database containing fingerprints of known subjects, and a candidate list of the top-K matches is retrieved from the database. The percentage of fingerprint queries for which the mated fingerprint is retrieved amongst the top-i candidates (rank-i) in the K-candidate list is used as the evaluation criteria. An additional 32,768 fingerprints captured from 16,384 infants (one sample each of the left and right thumb) provided by



(a)

(b)

Figure 4: Image enhancement and matching of infant fingerprints. (a) Fingerprint images of right thumb of a 6 weeks old infant captured on two different days (shown on the left and right), and (b) enhanced fingerprint images using the proposed method. Minutiae points (ridge endings and bifurcations) extracted from the two enhanced fingerprint images in (b) are marked in red and green, respectively. Minutiae correspondences generated using a commercial fingerprint SDK are marked in blue. A similarity (comparison) score of 2,147 is obtained between the two fingerprints which is above the threshold of 101 computed at 0.1% FAR. Thus, we can claim that these two impressions were made by the same finger.

VaxTrac[4] are included in the background database for the identification (1:N comparisons) experiments.

In verification experiments, *TARs of 79.72% and 83.55% are obtained at FARs of 0.1% (1 in 1,000) and 1% (1 in 100), respectively, for infants older than 4 weeks* (see Table 1). In identification experiments, *rank-1 (rank-10) identification accuracy of 73.98% (79.95%) is obtained for infants older than 4 weeks* (see Table 2). Since most infant vaccinations are administered after the age of 4 weeks, these results show that it is viable to identify infants based on fingerprints of their two thumbs for a variety of healthcare and social welfare applications.

5. SUMMARY

We have addressed the problem of identifying infants for a variety of applications faced by health care and social welfare organizations, particularly in developing countries. Our ongoing work based on custom high-resolution fingerprint reader and fingerprint image enhancement methods has given encouraging identification results for infants older than 4 weeks. The recognition accuracy needs to be further improved in order to bring infant fingerprint identification technology to field operations. To accomplish this goal, we intend to pursue the following tasks:

1. Improve reader capability in terms of (i) faster capture speed and (ii) lower distortion and motion blur.

Table 1: Verification Results (1:1 comparison)

Age Group	TAR (%)	FAR (%)
$\leq$ 4 weeks	43.43	0.1
$>$ 4 weeks	79.72	0.1
$\leq$ 4 weeks	54.55	1
$>$ 4 weeks	83.55	1

Table 2: Identification Results (1:N comparisons)

Age Group	Rank-1 (%)	Rank-10 (%)
$\leq$ 4 weeks	38.44	44.05
$>$ 4 weeks	73.98	79.95

2. Design better fingerprint enhancement and robust matching algorithms.
3. Conduct a longitudinal study for infant identification. This will entail collecting infant fingerprints, say every 3 months, at the Saran Ashram Hospital in Agra, to investigate the persistence of fingerprint identification.
4. Determine the youngest age at which an infant can be identified with acceptable accuracy (e.g., 95% TAR at 0.1% FAR).

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