Development of 2,400ppi Fingerprint Sensor for Capturing Neonate Fingerprint within 24 Hours after Birth

Yoshinori Koda[1], Ai Takahashi[2], Koichi Ito[3], Takafumi Aoki[4], Satoshi Kaneko[5], Samson Muuo Nzou[6]

Abstract: United Nations adopted the resolution "Sustainable Development Goals (SDGs)," which aims at solving the eradicating the poverty in all its forms and dimensions. One of the action plans is listed at "Goal 16 Target 16.9," which clearly directs "By 2030, provide legal identity for all, including birth registration." A fingerprint identification technology is one of the best solutions from the viewpoint of making a reliable identification system for the birth registration. However, collecting the fingerprint data from neonates is currently considered as one of the most difficult technology areas. Addressing this problem, we develop a novel high-resolution fingerprint sensor, whose image resolution is 2,400ppi. We collect fingerprint images from neonates within 24 hours after birth through the field research in Kenya. The experiments using our dataset demonstrates the effectiveness of our fingerprint sensor in neonate identification compared with 500ppi and 1,270ppi fingerprint sensors.

Keywords: Neonate Fingerprint, High-resolution Fingerprint Sensor, Birth Registration.

1 Introduction

The resolution, which was adopted by the General Assembly at United Nations on 25 September 2015, is one of the famous keywords for all, "Sustainable Development Goals (SDGs)" [Un15]. This global agenda was made of 17 sustainable development goals and 169 associated targets and was setting out an ambitious and transformational vision. Each goal has the large perspective and each target has the things to be done in detail. One of the targets related to biometrics is "Target 16.9," which clearly mentions that "By 2030, provide legal identity for all, including birth registration."

There are many national ID systems utilizing biometric technologies in the world. These national ID systems greatly contribute to deliver the several appropriate social welfare

[1] Graduate School of Information Sciences, Tohoku University, 6-6-05, Aramaki Aza Aoba, Sendai, 9808579, Japan, koda@aoki.ecei.tohoku.ac.jp
Biometrics Research Laboratories, NEC Corporation, 1753, Shimonumabe, Kawasaki, 2118666, Japan, y_koda@ak.jp.nec.com
[2] Graduate School of Information Sciences, Tohoku University, 6-6-05, Aramaki Aza Aoba, Sendai, 9808579, Japan, ai@aoki.ecei.tohoku.ac.jp
[3] Graduate School of Information Sciences, Tohoku University, 6-6-05, Aramaki Aza Aoba, Sendai, 9808579, Japan, ito@aoki.ecei.tohoku.ac.jp
[4] Graduate School of Information Sciences, Tohoku University, 6-6-05, Aramaki Aza Aoba, Sendai, 9808579, Japan, aoki@ecei.tohoku.ac.jp
[5] Institute of Tropical Medicine, Nagasaki University, 1-12-4, Sakamoto, Nagasaki, 8528523, Japan, skaneko@nagasaki-u.ac.jp
[6] Kenya Medical Research Institute, Off Mbagathi Road, Nairobi, Kenya, nzoumuuo@gmail.com

service schemes to citizens in their countries. Social welfare services of course should be properly delivered to the poor part of citizens who struggle against poverty and also to the young children who need unconditional love. This is one of the reasons that to manage and understand the number of birth registration for the civil registration and vital statistics (CRVS) guided by WHO (World Health Organization) [Wo18] is an important key point to help the citizens who need to obtain supports from authorities.

Even in 2019, national ID systems do not cover the young children especially younger than 5 years old. For example, in the case of Aadhaar system in Republic of India, a child above 5 years old can get his/her own Aadhaar card after registering the biometric data [Una] and in the case of National ID in Republic of Kenya, the registration age is defined at the age of 18 years old [Wo16]. One of the backgrounds of such coverage limitations comes from a current technology level of a sensing capability of capturing devices. Many national ID systems utilize the fingerprint identification technology as its core unit because of its high accuracy. A fingerprint identification technology is one of the best solutions from the view point of making a reliable identification system for the birth registration, since a fingerprint identification system is used in national ID systems. However, market-ready fingerprint devices could not correctly capture the proper fingerprint images from babies, especially from neonates who need to register their identity into birth registration. Collecting fingerprint images from neonates has difficulties because of uniqueness like a slim, small, thin and moist condition. The uniqueness of neonate fingers causes difficulties at achieving the high-accuracy level comparable with adults at the fingerprint identification system.

Addressing this problem, we develop a fingerprint scanner with novel high-resolution fingerprint sensor, whose image resolution is 2,400ppi. We also realizes advantages of a faster fps (frame per second) and of cost effectiveness with this high-resolution sensor. To evaluate the feasibility of our prototype, we collect fingerprint images from neonates within 24 hours after birth through the field research in Kenya. The experiments using our dataset demonstrates the effectiveness of our fingerprint sensor in neonate identification compared with 500ppi and 1,270ppi fingerprint image sensors.

2 Uniqueness of Neonate Fingerprints

At the beginning of this study, in 2014, we planned to utilize the existing fingerprint capturing technologies such as a market-ready fingerprint scanner for neonate fingerprint image collection. However, we did not need to take much time to understand that we have to develop a brand-new fingerprint image capturing device to collect neonate fingerprint data since existing devices could not collect the fingerprint images from neonates appropriately. After having several on-site researches, we found the uniqueness of neonate fingerprints, which causes the difficulties of capturing the data in digital.

The uniqueness of neonate fingerprints is mainly from the following 2 points. The one is an elastic deformation caused by strongly pressing and moving the target finger placing on the sensing surface. Another one is huge sweat pores with a large diameter, which is

Tab. 1: Mean values of TBW, ECW and ICW in % of body weight [FH61]. The following explanation is clearly mentioned at the page of this table in the book: "TBW minus ECW is not in all cases equal to ICW, because both determinations were not carried out in all subjects within each group." "d," "m" and "y" indicate days, months and years, respectively.

Age	0-1d	1-30d	1-3m	3-6m	6-12m	1-2y	2-3y	3-5y	5-10y	10-15y
TBW	78.40	74.00	72.30	70.10	60.40	58.70	63.50	62.20	61.50	57.30
ECW	44.50	39.70	32.20	30.10	27.40	25.60	26.70	21.40	22.00	18.70
ICW	33.90	31.80	43.30	42.10	35.20	33.60	38.30	45.70	42.30	46.70

wider than the inter-ridge distance (i.e., width of valley line). Such uniqueness is not so common in capturing adult fingerprints. Hence, a neonate fingerprint is not just a small-scaled fingerprint of an adult and also a capturing device with a high-resolution sensor is not enough to capture fingerprint images from neonates. As observed above, we thought that the soft skin of neonate and the size of sweat pores were come from the water level of neonate, since a fetus is in the amniotic fluid before childbirth. Therefore, we considered that this fluid makes some influence at the finger skin of neonate and we needed to restart to understand what the neonate finger is.

Medical research reports gave us so many findings about the conditions of neonate fingers. One of the important findings is reported by M.L. Thomson [Th54]. The average number of sweat ground per cm^2 of the skin is 130.00 in European and 127.89 in Africans. Also, Y. Kuno [Ku56b, Ku56a] mentioned the followings. (i) Sweat glands may be activated within about two years after birth, but never later. When an infant is exposed to the tropic weather during the first two years, the activation may be accelerated. Such an activation is no longer possible for children who are immigrated after two years. (ii) The amount of water discharged at rest was found distinctly larger on the palms and soles than that on the chest. (iii) It was found that all the infants were entirely sweatless on the day of birth. 15 neonates out of the 28 neonates began to perspire during the period from the third to the fifth day. It may therefore be said that more than half of maturely born infants became capable of sweating during this period. The other report of body water compartments in children by B. Friis-Hansen [FH61] presented a very impressive result at the comparison of ratio at the average values of total body water (TBW), extracellular water (ECW) and intracellular water (ICW) during the period of 0 day to 15 years as shown in Table 1. TBW decreased approximately 11% in 90 days (3 months after birth) as 78.4% at 0–1 day, 74.0% at 1–30 days 72.3% at 1–3 months and 70.1% at 3–6 months. ECW decreased approximately 33% in the same period as 44.5% at 0–1 day, 39.7% at 1–30 days, 32.2% at 1–3 months and 30.1% at 3–6 months. From the above, the extracellular water seems decreased by sweat and/or excretion. The ratio of TBW seems much stable 6 months after birth. TBW shows as 60.4% at 6–12 months, 58.7% at 1–2 years, 63.5% at 2–3 years, 62.2% at 3–5 years, 61.5% at 5–10 years and 57.3% at 10–15 years.

As observed above, TBW at older than 6 month-old babies (6-12m at the Table 1) has almost the same level as the age range of 5-10 years old child at the Table 1. This represents that the age of 6 months old could be considered as a starting age point of registration for existing National ID by using existing fingerprint technologies reported by A. K. Jain et al. [Ja17]. However, registration for the existing National ID at the age of 6 months can not support the most of scheduled and required events for neonates and infants younger than 6 months. In the case of vaccination, UNICEF clearly reported the seven-ninth of recommended routine immunizations shall be done till the age of 14 weeks [Unb]. Also, parents in many countries are obliged to register a birth record within the designated period. For example, in the case of Republic of Kenya, parents are obliged to complete the birth registration within 3 months after birth [Wo16]. The motivation of this study is to find the guideline of technical requirement of collecting the fingerprint images from neonates at the period of within 24 hours after birth, which covers the typical time of leaving from the hospital in Kenya and also to find the capability of collecting the appropriate fingerprint images from neonate fingers which change its skin conditions day by day.

2.1 Elastic deformation of neonate fingerprint

We need to add some additional features onto the capturing device to catch up the changes at the finger skin of neonate. In the case of younger than 6 months, the fingerprint having higher total body water level is easily deformed by the force coming from the outside, where we confirmed this fact at on-site research. Hence, smashes were occurred by strong pressure at fingerprint images. To avoid such improper operations, the guide wall near the sensing area has to be added to prevent pressing the target finger stronger than required level. In addition, A sensing area has to be limited so as to provide an appropriate sensing area size to limit a space allowing to move the target finger while touching the sensing surface. Fig. 1 shows some fingerprint images, which were falsely captured during the on-site research. The left image includes unnecessary portion, which has middle and proximal phalanx segments and the right image captures 2 fingers, index finger and middle finger. Such miss-operations happened when we used the sensor size for capturing adult fingerprint images. This is the reason and background why we develop a special exclusive model which has proper sensing area for neonate use.

2.2 Sweat pores of neonate fingerprint

Some of fingerprint images were partially smashed by moisture like foreign objects especially at the valley line area by confirming the data collected from 20 neonates (1–30days after delivery). This moisture like foreign objects come from body water and sweat. As described above, a neonate needs to reduce his/her total body water, resulting in higher activation of sweating by making sweat pore bigger. A diameter of sweat pores at neonate fingerprint is around 83.57μm in average and a width of inter-ridge is 47.38μm in average from our observation. This shows that the negative influence may occur due to the opposite condition at the case of neonate since existing fingerprint feature extractors are based on adult fingerprints, which consider that the diameter of sweat pore is smaller than the width of valley lines. For example, the sweat pores are connected and the false valley

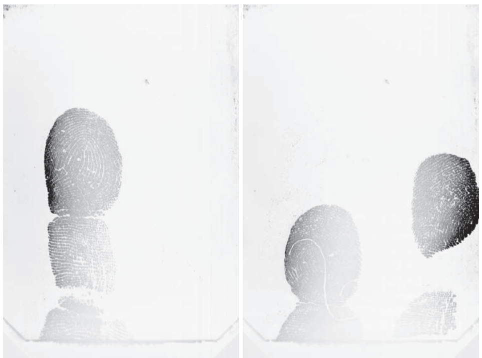


Fig. 1: Falsely captured neonate fingerprint images using the fingerprint sensor for adults.

line is generated at the middle of ridge line, since sweat pores are considered as split valley line in some fingerprint matching libraries, which misunderstand the sweat pores as a split valley line. This split was completely unacceptable malfunction for fingerprint identification. Therefore, high-resolution sensor is required to obtain high-quality fingerprint images, which makes easy image processing before feature extraction process.

3 Fingerprint Sensor for Neonates

Recently, there are various fingerprint scanners available at the market, for example, smartphones, access controllers and PCs. The background of market expansion is technology innovations at the sensing methods like capacitive, optical, TFT and OCT material technologies with the trends of higher resolution and also smaller size of the scan area. Among them, we can see the drastic innovations in CMOS image sensors. This innovation mainly comes from focusing on achieving the higher resolution capability for digital single lens reflex cameras and also to achieve the higher speed capability for factory inspection cameras. We can utilize innovations of CMOS image sensors for developing a fingerprint sensor for neonates.

3.1 1,270ppi CMOS sensor

We developed a new fingerprint scanner having a 1,270ppi CMOS image sensor with 20μm pitch image sensor elements, an $\phi 12\mu$m pitch image enhance fiber glass and an additional design feature of the elastic deformation prevention wall. The above configuration was reported by the field research of Y. Koda et. al and was successfully captured the fingerprint images from 6-hour newborn baby [KHJ16]. The new design of this fingerprint scanner intended to capture a distal phalanx segment correctly. We calculated the average size of the distal phalanx segment of neonate fingers and we found the average height is 12mm and the average width is 10mm. Then, we defined the sensing area of

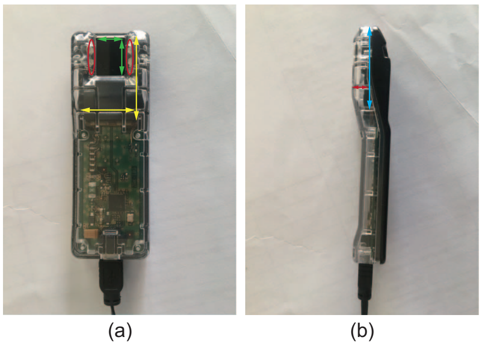
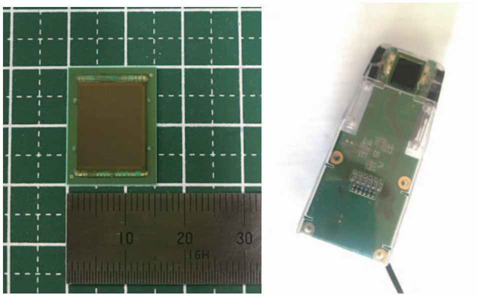


Fig. 2: 1,270ppi fingerprint sensor: (a) sensing area of 1,270ppi CMOS image sensor and (b) physical guide of 1,270ppi CMOS image sensor.

15mm (height)×12mm (width) as shown in green arrows of Fig. 2 (a). This new design reduced the sensing area around 70% from the original sensing area (30mm height×20mm width) of 1,270ppi CMOS image sensor as shown in yellow arrows of Fig. 2 (a). This area rescaling also aimed at providing the effectiveness to prevent the elastic deformation during a capturing process. A small area allowed operators to place the target finger onto the sensing surface and was not allowed to freely move the target finger while target finger is on the sensing surface. This area limitation additionally provided an effective power consumption. In the case of the original design, 4 NIR-LEDs at the both sides were required to radiate the NIR to the target finger, while only 2 NIR-LEDs were required to obtain a proper lighting level in the new design. After changing the sensing area, approximately 70% reduction of a sensing area provided 50% reduction of NIR-LED. These NIR-LEDs are mounted inside of physical guides, which were located at the both sides of the sensing area. The height of these physical guides are 5mm. The purpose of this physical object is not to allow operators to press the target finger with strong pressure to the surfasce.

3.2 2,400ppi CMOS Sensor

The new designed 1,270ppi fingerprint sensor mentined in the above was sometimes not enough to capture the clear fingerprint images from neonates during our on-site research due to the lack of image resolution. Therefore, we developed a new sensor for neonates with higher image sensor elements and narrow image enhancement fiber glass. The new device was designed to use (i) CMOS sensor with the higher capability than 2,000ppi to realize an appropriate resolution for neonates, (ii) CMOS sensor with higher fps (frames per seconds) for stable capturing and (iii) market ready components to reduce the production cost. We selected a combination of the 2,400ppi CMOS image sensor having new 10μm pitch image sensor elements/7fps CMOS image sensor and the modified ϕ12μm pitch image enhancement fiber glass as a sensor for new capturing device after several internal evaluations. The sensing area is 13.6mm (height)×10.9mm (width), which completely matches the required fingerprint size of a distal phalanx segment as shown in Fig.



(a) (b)

Fig. 3: 2,400ppi fingerprint sensor: (a) 2,400ppi CMOS image sensor with fiber glass and (b) overview of 2,400ppi CMOS image sensor.

3 (a). The price of this CMOS image sensor is inexpensive than other candidate of CMOS image sensors even having high-resolution capturing capability, since the CMOS image sensor was originally designed for another mass production product. The 2,400ppi CMOS image sensor for fingerprint device was required to use together with the technology of NIR-LED radiation method as well as the 1,270ppi sensor, although the different design was selected to find a better usability for operators. We also considered that a hardware design shall include some helps for operators to understand how to use the device without lectures. We adopted the thinner entry point and wide grip for operators to confirm which size is preferable for the stable operation as shown in Fig. 3 (b). Also, we adopted a video-based data capturing method, since a 2,400ppi CMOS image sensor has faster fps than a 1,270ppi CMOS image sensor.

3.3 Neonate Fingerprint Jig

We created a jig modeled on neonate fingerprints to evaluate the capturing capability of fingerprint sensors as shown in Fig. 4 (a). This jig has 20μm and 30μm lines as a valley line and many holes with a several diameter from 10μm to 80μm as a sweat pore. This jig was quite useful for our development, since we can easily evaluate the capability of new sensor for neonate without visiting the hospital. Fig. 4 (b)–(d) shows the comparison of captured images using 500ppi (U.are.U4500), 1,270ppi (handcrafted original) and 2,400ppi (handcrafted original) sensors. The jig image captured by 2,400ppi sensor clearly exhibits higher capturing capability than 500ppi and 1,270ppi sensors. Capturing neonate fingerprints requires at least more than 1,000ppi resolution and capturing clear neonate fingerprint requires more than 2,000ppi resolution.

4 Field Research in Kenya

Our field research in Kenya was started from 2019. The purpose of this field research is to collect the several biometrics data and the moisture level of the fingerprint area, focusing

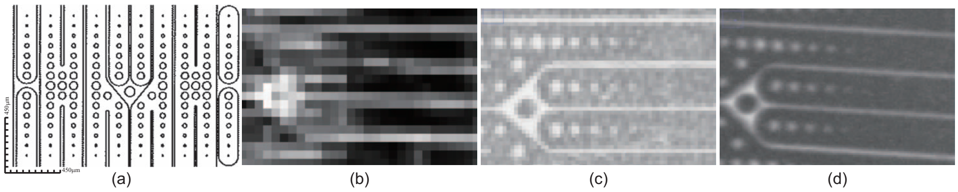


Fig. 4: (a) Jig pattern with lines and circles and image comparison for 500ppi (b), 1,270ppi (c) and 2,400ppi (d) fingerprint sensors

on neonates from 0 day to 14 weeks after birth. We particularly added neonates within 24 hours after birth to this field research, since Y. Kuno reported the sweatless on the day of birth [Ku56b]. If we could capture the fingerprint data from newborn soon after the delivery, fingerprint image may have less negative influence occurred by sweat. We declare that the parents or guardian of the neonate were properly requested to sign onto a consent form as a permission of their participation for this research, which is approved by ethics committee of Kenya Medical Research Institute (KEMRI) before data collection.

4.1 Data collection tool

We developed the data collection tool including 2 additional functions for this field research. This data collection tool mainly used to collect fingerprint images from 4 fingers (both thumb and index) by 4 times (= 16 fingerprint images per collection), face images (3 poses (Front shot plus left and right in 45 degrees) per collection) and voices (crying). Research assistants use this tool to collect the 3 kinds of biometrics data for our research from mother and neonate. The additional uniqueness of this tool is that we prepared the page for a mother-child relationship confirmation and the page for immunization history. At the time of leaving the hospital, this tool displays the relationship between mother and neonate with biometrics data such as face image collected during our research. After leaving the hospital, mother and baby need to come to hospital for immunization. This tool can store their visit on the day of vaccination, if required. Their visit and the name of vaccines will be stored as immunization history records together with their updated biometrics information. This immunization history function will store the record from birthday to 14 weeks. Vaccination items to be stored at this page are BCG, Polio, Inactivated Polio vaccine (IPV), Diphtheria, Pertussis, Tetanus, Hepatitis B, Haemophilus Influenza Type B, Pneumococcal Vaccine and Rota Virus Vaccine. The reason of containing these functions is to make the workers at hospital such as nurses understand this research is not only for researchers but also for workers at hospital, for mother and for child. We need to remember that this field research is volunteer cooperation basis and this means that researchers need to provide a benefit as much as we can during the field research.

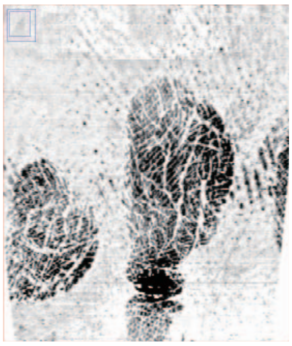


Fig. 5: Image taken by 500ppi fingerprint sensor.

4.2 Fingerprint image collection

The expected daily birth rate at the selected hospital was 3 neonates a day, although no one can estimate when it happens. Therefore, we have hired 5 research assistants to create the dataset. 4 research assistants stay at the hospital 24-hour basis (6 hours per person) to collect the data using the data collection tool and 1 research assistant visits the home to collect the data from the next day of their leaving from the hospital to 14 weeks. We collected more than 3,000 fingerprint images from 50 neonates within 15 days after starting this research. This dataset includes 50 sets of biometric data including the case of twins and triplet, taken within 24 hours after birth. Field research of fingerprint image collection was designed to capture images by using 500ppi (Crossmatch U.ARE.U 4500)[2], 1,270ppi (NEC ZAK-109) and 2,400ppi (NEC ZAK-X02) scanners to confirm the preferable resolution for neonate fingerprint capturing and also to calculate the accuracy level. However, we reconsidered the plan on first day, since a 500ppi sensor could not capture the fingerprint images from 6 hours neonate as shown in Fig. 5. The distal phalanx segment of 6 hours newborn was too small to activate the automated capturing function. We had to place 3 fingers at the same time to trigger a capturing function. We unfortunately had to abandon the use of the 500ppi scanner and to use 1,270ppi and 2,400ppi sensors for this field research.

We captured the biometrics data from the babies after mothers' physical recovery. Through the field research, we collected the data from 2 hours, 3 hours, 4 hours, 6 hours and 24 hours babies. The average width of inter-ridge lines calculated from 40 random sample distances of a 2 hour-old baby is 30.5μm. The important point of defining the required scanning capability for neonates fingerprint data collection is the size of image sensor elements and also the size of sensing cell for neonate. We confirmed that 10μm image sensor elements can draw the valley line clearly. Fig. 6 shows fingerprint images captured by 1,270ppi and 2,400ppi sensors from neonates within 24 hours from birth during the field research in Kenya. This is the first case in the world to capture fingerprint images

[2] `https://www.hidglobal.com/products/readers/single-finger-readers/4500-fingerprint-reader`

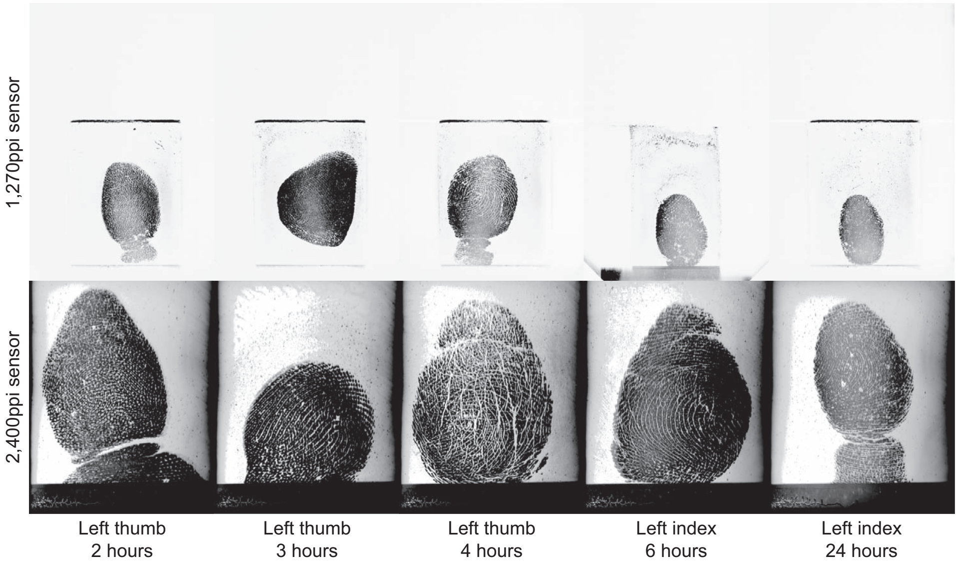


Fig. 6: Example of fingerprint images captured during the field research in Kenya. The upper row indicates fingerprint images captured by the 1,270ppi sensor and the lower row indicates those by the 2,400ppi sensor, where a finger area is cropped from the captured image and the pixel value of 2,400ppi images is reversed so as to have white pixels on the background for easy-to-understand representation. Images in each column are captured from the same finger. This is the first case in the world to capture fingerprint images in digital from the 2 hour-old baby.

in digital from the 2 hour-old baby to the best of our knowledge. This also shows that a 1,270ppi sensor with 20μm image sensor elements divides the valley line into 2 pixels and was not enough to draw the valley line by gray scale. On the other hand, a 2,400ppi sensor with 10μm image sensor elements can divide the valley line into 4 pixels and provides the smooth line by gray scale. From the above, the size of image sensor elements is more important than resolution, since higher resolution with larger image sensor elements is difficult to capture the data from neonate.

We also found that the sensing surface is much soiled by a substance like a sebum by confirming the image taken by a 2,400ppi fingerprint scanner as shown in Fig. 7. This is a first time to visually confirm the image and size of substance like a sebum, since the 1,270ppi fingerprint scanner could not capture the image of remaining at the sensing surface clearly. The size of substance is from $\phi 20\mu$m to $\phi 100\mu$m. The size of remaining substance can fill the valley lines up and such sebum provides a negative influence, resulting in making a low-quality fingerprint image capturing. From the above, we also find that a 2,400ppi sensor can inform operators of the timing to wipe the capturing surface by visual information.

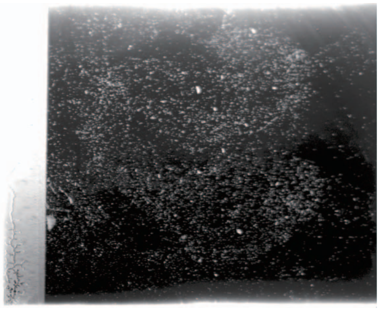


Fig. 7: Substances on the sensing surface in the 2,400ppi sensor.

4.3 Performance on fingerprint matching

We evaluated the performance of 1,270ppi and 2,400ppi sensors using the dataset collecting in the field research in Kenya. The dataset consists of fingerprint images captured from 28 neonates, who are within 24 hours after birth, using 1,270ppi and 2,400ppi sensors. The commercial fingerprint identification engine, Verifinger 10.0[3], is used to evaluate the performance of sensors in the experiment. The matching scores of all genuine pairs and impostor pairs are calculated by Verifinger, and FMR and FNMR are calculated for both 1,270ppi and 2,400ppi datasets. The 1,270ppi fingerprint scanner exhibited FNMR=1.4% at FMR=0.1%, while the 2,400ppi fingerprint scanner exhibited FNMR=0.3% at FMR=0.1%. This result obviously shows that the size of an image sensor element is very important factor to capture the fingerprint image from neonate clearly. From this evaluation, we are confident that the combination of the 10μm image sensor element and the $\phi 12\mu$m image enhance fiberglass is suitable to collect fingerprint image from neonates.

The amount of data in performance evaluation was quite limited at this time. Therefore, we will demonstrate the effectiveness of the developed fingerprint sensor in neonate fingerprint recognition after making a large-scale dataset.

5 Conclusion

We have developed a fingerprint scanner with 2,400ppi image sensor. We demonstrated FNMR=0.3% accuracy at FMR=0.1% using the dataset collected by 2,400ppi fingerprint scanner from neonate within 24 hours after birth. From this result, we found that a 2,400ppi fingerprint scanner has a great capability of capturing the fingerprint image from a neonate 2 hours after birth and also can provide appropriate images to an existing matcher to identify 24 hour-old neonates. We think that we will be able to suggest a required and an effective digitized operation between childbirth and birth registration from this result, although the accuracy seems lower than the expected accuracy as adults. By July 30, 2019,

[3] `https://www.neurotechnology.com/verifinger.html`

we have collected more than 12,000 fingerprint images taken from 500 neonates. This research will keep till the end of October 2019 and we expect to collect the data from more than 1,000 neonates in Kenya. A field research has just begun. To make this research more appropriate, we may need to collect the data in the northern country (cold) area to confirm the influences occurred by the activated number of sweat pore. It therefore requires more months or years to evaluate the matching accuracy and capturing capability of the developed fingerprint device. In near future, we hope that out technology can support the solution for all countries which struggle to realize a CRVS management especially at the period from childbirth to birth registration. We also hope that our technology will provide everyone a legal identity to receive required welfare for their better life.

References

[FH61] Friis-Hansen, B.: Body water compartments in children: Changes during growth and related changes in body composition. Pediatrics-Official Journal of the American Academy of Pediatrics, 28:169–181, August 1961.

[Ja17] Jain, A. K.; Arora, S. S.; Cao, K.; Best-Rowden, L.; Bhatnagar, A.: Fingerprint Recognition of Young Children. IEEE Trans. Information Forensics and Security, 12(7):1501–1514, July 2017.

[KHJ16] Koda, Y.; Higuchi, T.; Jain, A. K.: Advances in capturing child fingerprints: A high resolution CMOS image sensor with SLDR method. Proc. 15th Int'l Conf. Biometrics Special Interest Group, pp. 329–336, September 2016.

[Ku56a] Kuno, Y.: The acclimatization of the human sweat apparatus to heat. Human Perspiration, pp. 330–331, July 1956.

[Ku56b] Kuno, Y.: The development of the human sweat apparatus and of their functions. Human Perspiration, pp. 128–136, July 1956.

[Th54] Thomson, M. L.: A comparison between the number and distribution of functioning eccrine sweat glands in Europeans and African. The Journal of Physiolog, p. 230, 1954.

[Una] Unique Identification Authority of India: , Biometric data capture Guidelines. https://www.uidai.gov.in/298-faqs/enrolment-update/enrolment-partners-ecosystem-partners/2016-what-are-the-uidai-guidelines-for-biometric-data-capture.html. Accessed on 8 April, 2019.

[Unb] United Nations Children's Fund: , Immunization Schedule Guidelines. https://www.unicef.org/immunization/index_75054.html. Accessed on 8 April, 2019.

[Un15] United Nations: General assembly 15-15900 (E). United Nations, September 2015.

[Wo16] World Bank Group: ID4D Country Diagnostic: Kenya. World Bank Group, January 2016.

[Wo18] World Health Organization: The Future for Women and Children: UNICEF and WHO Joint Statement on Strengthening Civil Registration and Vital Statistics (CRVS). World Health Organization, February 2018.