Multimodal Biometric Recognition for Toddlers and Pre-School Children

Protichi Basak, Saurabh De, Mallika Agarwal, Aakarsh Malhotra, Mayank Vatsa and Richa Singh
IIIT Delhi, New Delhi, India
{protichi13075, saurabh13092, mallika13055, aakarshm, mayank, rsingh}@iiitd.ac.in

Abstract

In many applications such as law enforcement, attendance systems, and medical services, biometrics is utilized for identifying individuals. However, current systems, in general, do not enroll all possible age groups, particularly, toddlers and pre-school children. This research is the first of its kind attempt to prepare a multimodal biometric database for such potential users of biometric systems. In the proposed database, face, fingerprint, and iris modalities of over 100 children (age range of 18 months to 4 years) are captured in two different sessions, months apart. We also perform benchmarking evaluation of existing tools and algorithms to establish the baseline results for different unimodal and multimodal scenarios. Our experience and results suggest that while iris is highly accurate, it requires constant adult supervision to attain cooperation from children. On the other hand, face is the most easy-to-capture modality but yields very low verification performance. We assert that the availability of this database can instigate research in this important research problem.

1. Introduction

Biometrics has provided unprecedented support to the organizations across the world in a lot of different ways. Law enforcement, banking, access control, and time attendance are some of the most cited and popular ones. However, there are several novel applications and challenges in which biometrics is serving as a beneficial technology. In a recent incident in India, a hearing- and speech-impaired boy in an orphanage was united with his family because of his biometrics captured as part of the Aadhaar project[1]. Biometric devices have helped health workers in developing countries to find patient's records. It has helped the World Food Programme (WFP) of the United Nations to deliver food to the needy people as per the rules of the countries[2]. For instance, Kenya, which hosts more than half a million refugees has the rule that refugees cannot work outside refugee camps for payment. They rely on the sustenance provided by the WFP for their livelihood and food. WFP has used biometrics to ensure that people are not misusing the facilities as well as sometimes ensuring that all the rightful recipients have received the ration and facilities. These applications of biometrics require enrollment, de-duplication, identification, and verification of individuals of all ages, including infants, adults, and elderly.

[1]http://tinyurl.com/mefr6qh
[2]http://www1.wfp.org/countries/kenya

Figure 1: Face images of a kid at different time intervals.

A significant amount of research has been performed for recognizing adults using their biometric features and there are several systems that provide accurate solutions. However, biometric recognition of infants, toddlers, and preschool children is a relatively unexplored area. Early work in identification of children of ages less than five years dates to as early as 1899, when Galton *et al.* [6] recorded inked fingerprint impression of children of ages from 0 to 4.5 years. He conjectured, that the minimum age for children to be identified through their fingerprints is 2.5 years. In 1939, Louise *et al.* [9] tried to identify infants using their palmprints. In 2008, Weingaetar *et al.* [13] compared the performance of footprint against palmprint for 106 newborn kids. They observed that the quality of palmprints was better than footprints. Similarly, Jia *et al.* [8] also showed the effectiveness of footprints. In 2010, Bharadwaj *et al.* [3] showed preliminary approach on infant face recognition and articulated the challenges associated with infant biometrics. As showcased in Figure 1, they suggest that face recognition of young children is an arduous research problem. In 2013, Tiwari *et al.* [11] prepared a multimodal database consisting face, ear and head print of 210 newborns. Recently, Bharadwaj *et al.* [4] and Jain *et al.* [7] show that biometrics recognition is plausible using face and fingerprint modalities respectively. While Bharadwaj *et al.* [4] proposed a domain specific learning approach for infant face recognition, Jain *et al.* [7] focused on data collection using specialized fingerprint sensors, designed for capturing fingerprint images of young children at 1270ppi.

One of the major reason for limited research in this domain is limited availability of benchmark databases for young children. Bharadwaj *et al.* [4] have prepared a face database of newborns with over 1200 images. Jain *et al.* [7] prepared a database of children of age 0 to 5 years, primarily 0 to 3 years. While Bharadwaj *et al.* [4] provide the facial features of standard descriptors upon request, the database in [7] is not available to the research community due to the unavailability of permission from the hospital. Since these databases are not available to the research community, it is challenging to develop children specific biometric systems (using either face or fingerprint modalities) and enhance state-of-the-art in this important problem. Though Tiwari *et al.* [11] did prepare a multimodal database for newborns consisting of face, ear, and headprint, however, the usage of ear and headprint for recognition has not been fully explored. Further, to the best of our knowledge, there is no research study or database which shows the effectiveness of iris recognition with young children. The key contribution of this research is proposing a multimodal public database of face, fingerprint and iris modalities of 106 children in the age group of 18 months to 4 years, captured in two sessions months apart. We further establish the baseline results of face, fingerprint, and iris recognition and their fusion using existing tools and algorithms. Our research illustrates that iris yields 100% verification accuracy and can be considered as a suitable biometric modality for young children.

2. Children Multimodal Biometric Database

To the extent of our knowledge, there is no publicly available database which captures the three major modalities - face, iris, and fingerprint together for children of age group 2-4 years. In this paper, we present a novel Children Multimodal Biometric Database (CMBD)[3] to the biometric research community that contains images of toddlers and pre-school children. The database is primarily collected from students of kindergarten classes of two schools in India and few home-schooled young children. Regarding the gender, the database has no special requirements and hence, the gender information of the subjects is not collected. The database collection process is approved by the school administrations and Ethics board approval is also obtained.

[3]http://iab-rubric.org/resources/CMBD.html

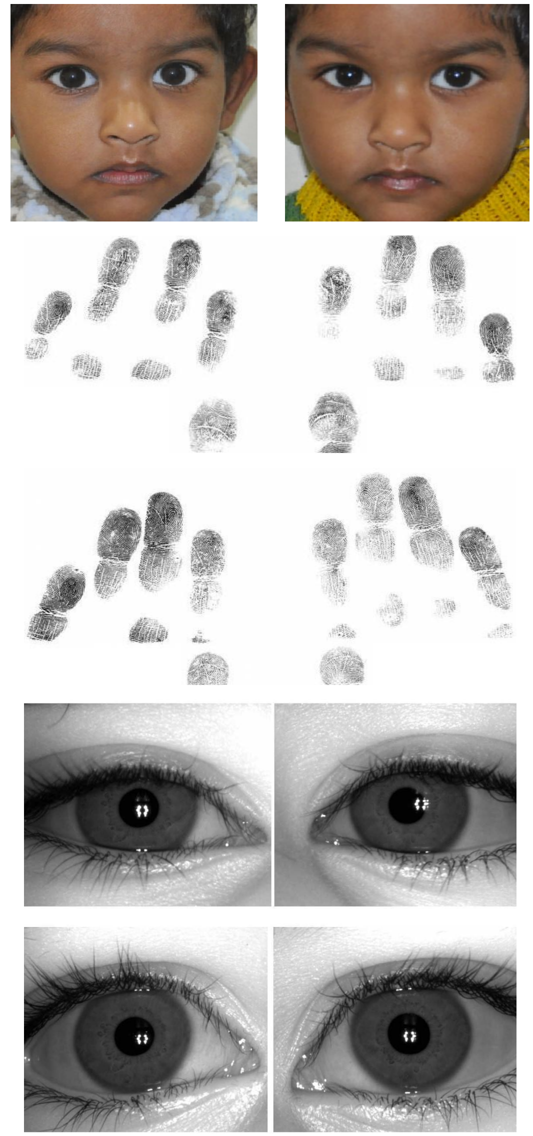


Figure 2: Sample images from the three biometric modalities across both the sessions.

2.1. Acquisition

With over 6 months timespan, the 2-sessions data collection process captures three modalities (face, fingerprint, and iris) for each subject. Details of the acquisition process are:

- **Iris**: Iris images are collected using Cross-Match iris scanner[4] where both left and right iris samples are recorded simultaneously.
- **Fingerprint**: Cross Match L-Scan slap fingerprint scanner[5] is used for database collection. Resolution of the

[4]http://www.crossmatch.com/i-scan-2/

[5]http://www.crossmatch.com/Guardian-USB/

Table 1: Summary of the Children Multimodal Biometric Database (CMBD).

Modality	No. of Subjects		Total Images	
	Session 1	Session 2	Session 1	Session 2
Fingerprint (L Scan Patrol)	119	108	5950	5400
Iris (Cross Match Iris Scanner)	142	124	1420	1240
Face (Nikon D-90 DSLR)	141	118	1410	1180

scanner is 500 ppi and five samples are recorded for the left hand, right hand, and two thumbs respectively. While storing, each finger impression is stored separately in the database.

• **Face**: A Nikon D90 DSLR camera is used to capture the face images at a resolution of 12.3 MP. The frontal images are captured in natural daytime lighting (without flash) with optimal quality settings.

During data acquisition, it is ensured that subjects are not wearing contact lenses. To capture the fingerprint impressions, a small quantity of moisturizer has been applied to the fingertips of children with dry fingers. During this process, it is ensured that the children are at ease without any physical discomfort. Figure 2 shows sample images from the proposed Children Multimodal Biometric Database.

2.2. Data Statistics

For each subject, ten samples are recorded for face modality, five samples are collected for right slap fingerprints, left slap fingerprints, and two thumb-impressions, and five samples for both left and right irises. Table 1 summarizes the statistics of the proposed database and details are provided below.

• The first session of the database is collected from August to September 2016. A total of 141 subjects with face images, 142 subjects with iris images, and 119 subjects with fingerprint images are collected. There are 110 subjects with all three modalities in this session, 114 subjects with fingerprint and iris, 113 subjects with fingerprint and face, and 127 subjects with face and iris samples.

• The second session is collected from December 2016 to February 2017. Face images are collected from a total of 118 subjects, iris images from 124 subjects, and fingerprint images are collected from 108 subjects. There are 108 subjects with all three modalities, 108 subjects with fingerprint and iris, 108 subjects with fingerprint and face, and 118 subjects with face and iris images.

• The number of subjects with all three modalities in session one is 110 and session two is 108. Out of these, 106 subjects are common across both the sessions. In this research, this part of the database is used for comparison among modalities and fusion approaches.

2.3. Challenges Faced During Data Collection

During the database collection process, several unconventional challenges are encountered which can serve as learning outcomes during operational procedures.

• **Iris**: Iris sensor requires participant cooperation; however, due to the inquisitive nature of young children, capturing good images is a challenge. They need constant adult supervision to be motivated to look inside the camera and not blink or move their eyes for a couple of seconds. We observe that due to the sudden eye or head movement, some sample collection requires more time as sensor in-built quality threshold prohibits to capture poor quality. On an average, it took approximately a minute to acquire an iris sample (both left and right sample acquired simultaneously).

• **Fingerprint**: Capturing fingerprints for children less than three years is hard due to very small fingerprint area, smooth skin, and thin fingers. For children with excessive dry skin, we apply a little amount of moisturizer so that the sensor can detect the fine features. Similar to iris, their inquisitive nature requires special attention and adult supervision during data capture. At times, light external pressure helps in collecting better quality impressions. On an average, it took approximately 45 seconds to capture one slap fingerprint impression.

• **Face**: Since the children are generally in a playful mode, it leads to expression and pose variations. Though adult supervision and motivation helps in improved quality data capture, the attention span of young children is very limited and therefore, patience during data collection is very important. Thus, only expression variation is allowed during the frontal face acquisition. If any other variations such as pose, illumination, or blurriness are observed by visual inspection of captured images, the image is re-acquired. In terms of the acquisition, around 20 seconds is required for each sample.

3. Experimental Protocol

We have collected the multimodal data in two sessions with a time lapse of at least four months; therefore, an inter-session experimental protocol is proposed to evaluate how well children can be verified through the face, iris, and fingerprint with some time interval. The database pertaining to 106 children (common in both the sessions across three modalities) is split according to identities and all the images pertaining to 50 subjects are used for training while the remaining 56 subjects are used for testing. Verification experiments are performed with five times random subsample based cross-validation. During testing, samples from

Table 2: Summarizing the experiment protocols on the proposed Kids Multimodal Biometric Database.

Experiment	Gallery Set		Probe Set		Modality
	Session	Images	Session	Images	
Experiment 1	1	1	2	5	Face
					Fingerprints (individually 10 fingers and intra-modality fusion)
					Iris (Individually left and right and intra-modality fusion)
Experiment 2	1	5	2	5	Face
					Fingerprints (individually 10 fingers and intra-modality fusion)
					Iris (Individually left and right and intra-modality fusion)
Experiment 3	1	1	2	5	Face, Left Index Finger, Right Index Finger
					Face, 10 Fingerprints
					Face, 10 Fingerprints, 2 Iris

the first session comprise the gallery and samples from the second session are used as the probe (or query images) for the following three experiments. In unimodal experiments, left and right irises are treated as separate modalities and experiments are performed individually on both of them. Similarly, for fingerprint, each finger is treated as different modality and experiments are performed on each of the 10 fingers separately. Fusion experiments are performed to fuse information from (i) both the irises, (ii) multiple fingerprints, and (iii) two or three modalities (multimodal). Table 2 summarizes the experiment protocol and details are given below:

• **Experiment 1 - Single Gallery**: In this experiment, the first sample out of the five samples collected for fingerprint and iris in Session 1 is considered as gallery while all five samples from Session 2 are considered as the probe. Similarly for face, the first sample out of ten samples from Session 1 is considered as gallery while five samples out of ten samples from Session 2 are considered as the probe. Selection of five face images out of ten are performed so that we can compare the performance of different modalities with the same number of probes.

• **Experiment 2 - Multiple Gallery**: In this experiment, all five samples from Session 1 are considered as the gallery and all five samples from Session 2 are considered as the probe for both fingerprint and iris. For face, five samples out of ten samples from Session 1 are considered as gallery and five samples out of ten samples from Session 2 are considered as probe. This experiment is focused towards evaluating the performance with multiple gallery images per person.

• **Experiment 3 - Fusion**: This experiment is focused towards understanding the performance of multimodal fusion at score level. 1 sample from Session 1 is chosen as gallery while 5 samples from Session 2 are taken as probe.

4. Results and Analysis

In order to understand the performance of individual biometric modalities for toddlers and pre-school children, we have used three state-of-the-art matchers. Face images are processed using Verilook face recognition SDK [1] and iris recognition is performed using VeriEye SDK [2]. For fingerprint, NFSEG tool from NBIS [5] is used for slap image segmentation, and feature extraction and matching are performed using MINDTCT and Bozorth3. Around 80% fingerprint samples are correctly segmented with this scheme. The remaining 20% slap fingerprint images are segmented manually. For fusion, the match scores of individual modalities are first normalized using *tanh* score normalization and then sum rule [10] and SVM fusion [12] are used for comparison. The verification results are presented in Tables 3 and 4, and the corresponding receiver operating characteristics (ROC) curves are shown in Figure 3.

4.1. Results of Intra-Modality Experiment

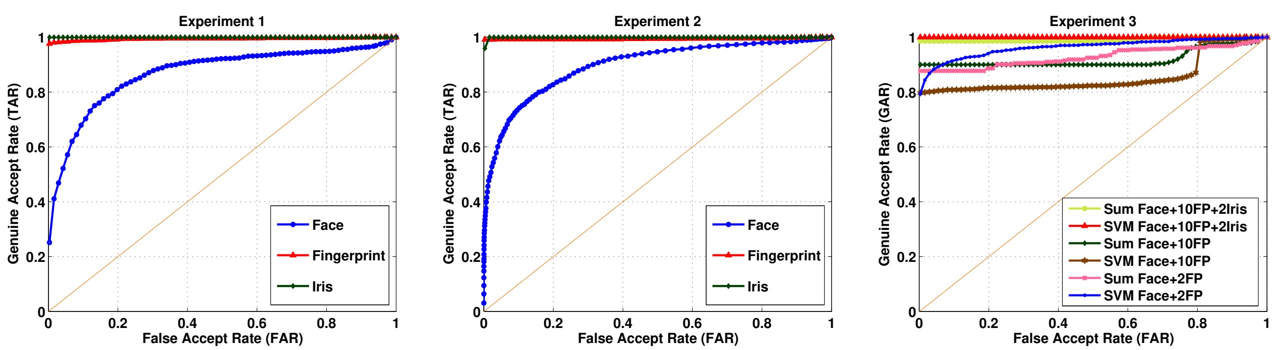
Table 3 shows the results of Experiment 1 and Experiment 2 (intra-modality experiments). With these experiments, we evaluate the performance of each modality (face, iris, and fingerprint) and report the baseline results on CMBD. We also perform sum rule based score level fusion for left and right iris. Similarly, score fusion is also performed for all ten fingers. The major conclusions that can be drawn from the results are:

• For single gallery experiment, the genuine accept rate (GAR) for individual left and the right iris is above 98.9%. Figure 4 shows some sample cases where iris fail to perform accurate verification. These examples highlight that acquisition dependent variations such as blur and illumination play an important role in recognition performance of children with iris images. These few cases are addressed when the score of left iris is combined with right iris and a perfect 100% GAR is obtained at 0.1% FAR.

• With multiple gallery experiment (Experiment 2), the chances of a mismatch when one of the gallery images is of poor quality is reduced, thereby improving the performance for both left and right irises. This yields a GAR of 100% for right iris and 99.82% for left iris at 0.1% FAR. Similarly, in other two modalities as well, an improvement of at

Table 3: Summarizing the results in terms of GAR at 0.1% and 1% FAR.

Experiment	**Modality**	**Individual**		**Intra-Modality Fusion**	
		0.1% FAR	**1% FAR**	**0.1% FAR**	**1% FAR**
Experiment 1	Face	18.96 ± 1.60	35.36 ± 3.34	-	-
	Fingerprint - Right Index	61.50 ± 3.69	71.57 ± 3.01	97.07 ± 1.19	98.07 ± 1.17
	Fingerprint - Right Middle	61.35 ± 1.77	70.00 ± 3.78		
	Fingerprint - Right Ring	68.85 ± 5.28	57.71 ± 32.01		
	Fingerprint - Right Small	36.42 ± 6.61	45.28 ± 6.41		
	Fingerprint - Right Thumb	58.06 ± 4.31	68.71 ± 3.88		
	Fingerprint - Left Index	56.92 ± 4.52	66.85 ± 5.94		
	Fingerprint - Left Middle	59.42 ± 3.97	70.71 ± 4.28		
	Fingerprint - Left Ring	61.49 ± 6.05	71.71 ± 4.05		
	Fingerprint - Left Small	40.42 ± 1.51	52.21 ± 1.63		
	Fingerprint - Left Thumb	54.28 ± 7.42	65.78 ± 7.05		
	Iris - Left	98.95 ± 0.72	99.56 ± 0.30	100 ± 0	100 ± 0
	Iris - Right	99.63 ± 0.53	99.86 ± 0.19		
Experiment 2	Face	26.46 ± 3.14	43.50 ± 2.63		
	Fingerprint - Right Index	79.92 ± 1.77	86.71 ± 2.05	99.28 ± 0.85	99.28 ± 0.85
	Fingerprint - Right Middle	79.85 ± 1.54	86.78 ± 2.28		
	Fingerprint - Right Ring	82.78 ± 1.34	89.28 ± 1.42		
	Fingerprint - Right Small	59.35 ± 1.62	70.71 ± 1.00		
	Fingerprint - Right Thumb	77.92 ± 3.05	86.57 ± 2.97		
	Fingerprint - Left Index	77.07 ± 3.51	84.35 ± 3.34		
	Fingerprint - Left Middle	82.28 ± 0.60	89.92 ± 0.77		
	Fingerprint - Left Ring	76.57 ± 2.82	84.92 ± 3.22		
	Fingerprint - Left Small	68.28 ± 1.88	73.49 ± 2.08		
	Fingerprint - Left Thumb	79.35 ± 5.62	85.57 ± 4.74		
	Iris - Left	99.82 ± 0.16	99.94 ± 0.13	100 ± 0	100 ± 0
	Iris - Right	100 ± 0	100 ± 0		



(a) (b) (c)

Figure 3: ROC curves for different experiments on the proposed Children Multimodal Biometrics Database.

least 13.9% for each finger and 7.46% for face, is observed at 0.1% FAR.

• Both fingerprint and face modalities have a lower matching performance than iris. Fingerprint verification performs better of the two and has GAR in the range of 36.42% to 68.85% for different fingers at 0.1% FAR. The lowest accuracy is for the little fingers (36.42% for left little and 40.42% for right little finger), which shows that small sized fingers of children hinder matching performance of fingerprints. Fingers that are relatively larger (index, middle, and thumb) perform substantially better than other fingers. This highlights that fusing scores from multiple fingers can increase the performance. This is indeed true and we observe a significant improvement in matching accuracies when scores from all ten fingers are fused together and verification accuracy of 97.07% at 0.1% FAR is obtained. Similar results

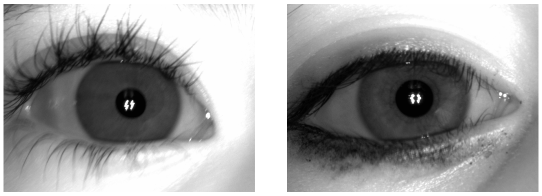


Figure 4: Samples of misclassified iris images.

Table 4: Summarizing the results of inter-modality fusion algorithms (Experiment 3) in terms of GAR at 0.1% FAR.

Fusion	Modality	GAR (%)
Sum	Face + Left Index Finger + Right Index Finger	87.71 ± 6.06
	Face + Fingerprints (10 Fingers)	89.96 ± 4.14
	Face + Fingerprints (10) + Iris (2)	98.06 ± 0.19
SVM	Face + Left Index Finger + Right Index Finger	76.42 ± 3.43
	Face + Fingerprints (10 Fingers)	79.36 ± 1.77
	Face + Fingerprints (10) + Iris (2)	100 ± 0

after score fusion can be observed in Experiment 2 as well.

• Amongst all the modalities, face shows the lowest GAR of 18.96% and 24.46% at 0.1% FAR in Experiment 1 and Experiment 2 respectively. This shows that for children of this age, face may not be robust, and may be subject to different kinds of variations, depending on the acquisition conditions. However, due to the unobtrusive nature of data capture and a significant number of applications related to law enforcement, face samples of subjects can be utilized for recognition whenever iris or fingerprint samples are not available. This implies a requirement of a large research impetus to boost the performance of face recognition in young children and approaches which utilize domain knowledge [4] should be explored.

• Though iris yields the best results, as mentioned earlier, it requires a lot of cooperation from children and assistance from adults. Among three modalities, in our experience, face is the easiest to capture; however, the performance is not as good as in case of regular (adult) face recognition.

4.2. Results of Inter-Modality Fusion Experiments

Table 4 shows the results of Experiment 3. This experiment evaluates the performance of inter-modality score fusion on CMDB. In the following subsections, we present the inferences obtained by performing fusion with all three modalities. Two different algorithms are used for score level fusion: sum rule [10] and SVM fusion [12]. Match scores are first normalized using tan-h normalization followed by applying the fusion algorithm.

• The first fusion experiment combines scores from the face, left index finger, and right index finger. From Table 4, we observe that individually these three do not yield over 60% verification accuracy; however, from Table 5, score fusion using sum rule yields GAR of 87.71% at 0.1% FAR and SVM fusion yields 76.42% GAR at 0.1% FAR.

• We next combine match scores from all ten fingers with face and obtain the GAR of 89.96% at 0.1% FAR. From Table 4, when scores from all ten fingerprints are fused, a much higher verification accuracy is observed. This shows that fusion of all ten fingerprints is sufficient and there is no need to combine it with face modality.

• We next analyze the effect of combining iris with ten fingerprints and face. With SVM fusion, 100% GAR at 0.1% FAR is obtained. This performance can be mainly attributed to the high accuracy of iris-matching. This also suggests that when iris matching fails, fingerprint and face scores may be able to match correctly. It is very rare (and absent in our database) that all three collected independently are unable to identify the subject correctly. Furthermore, fusion of face and fingerprint is only necessary when iris data is not available.

5. Conclusion and Future Directions

With the increase in applications and problems where biometrics can be used to establish identity, we are also interested in increasing the inclusivity of a biometric system for all ages. Generally, current biometric systems do not enroll and authenticate toddlers and pre-school children, whereas the potential of biometric systems for young children is immense. In this research, we propose the first-ever prepared multimodal biometric database of young children. The proposed CMDB database comprises face, fingerprint and iris images from more than 100 children in two different sessions. This research also demonstrates that iris biometric modality can provide the highest genuine accept rate, particularly when both left and right irises are combined. However, data collection from young children requires special care and patience. Further, depending on application scenarios, fusion of face and fingerprints can also be performed and the proposed database provides baseline results for the same.

There are several challenges associated with biometrics for young children, particularly when capturing fingerprints and irises. While adult supervision helps in boosting the motivation and attention of young users of biometrics systems, we believe that face as a non-invasive choice can provide better user experience. However, it requires significant research efforts for enhancing the recognition capabilities. It is our assertion that the availability of this database will promote research on this important topic.

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References

[1] Verilook. http://www.neurotechnology.com/verilook.html.

[2] Verieye. www.neurotechnology.com/verieye.html, (accessed 2017-20-04).

[3] S. Bharadwaj, H. S. Bhatt, R. Singh, M. Vatsa, and S. K. Singh. Face recognition for newborns: A preliminary study. In *IEEE International Conference on Biometrics: Theory Applications and Systems*, pages 1–6. IEEE, 2010.

[4] S. Bharadwaj, H. S. Bhatt, M. Vatsa, and R. Singh. Domain specific learning for newborn face recognition. *IEEE Transactions on Information Forensics and Security*, 11(7):1630–1641, 2016.

[5] P. Flanagan. NIST biometric image software (NBIS). https://www.nist.gov/services-resources/software/nist-biometric-image-software-nbis, 2010.

[6] F. Galton. Finger prints of young children. *British Association for the Advancement of Science*, 69:868–869, 1899.

[7] A. K. Jain, S. S. Arora, K. Cao, L. Best-Rowden, and A. Bhatnagar. Fingerprint recognition of young children. *IEEE Transactions on Information Forensics and Security*, 12(7):1501–1514, 2017.

[8] W. Jia, H.-Y. Cai, J. Gui, R.-X. Hu, Y.-K. Lei, and X.-F. Wang. Newborn Footprint Recognition using Orientation Feature. *Neural Computing and Applications*, 21(8):1855–1863, 2012.

[9] L. E. Morgan and F. Pauls. Palm prints for infant identification. *The American Journal of Nursing*, 39(8):866–868, 1939.

[10] A. Ross and A. Jain. Information fusion in biometrics. *Pattern Recognition Letters*, 24(13):2115–2125, 2003.

[11] S. Tiwari, A. Singh, and S. K. Singh. Multimodal database of newborns for biometric recognition. *International Journal of Bio-Science and Bio-Technology*, 5(2):89–100, 2013.

[12] M. Vatsa, R. Singh, and A. Noore. Integrating image quality in 2v-svm biometric match score fusion,. *International Journal of Neural Systems*, 17(05):343–351, 2007.

[13] D. Weingaertner, O. R. P. Bellon, L. Silva, and M. N. Cat. Newborn's biometric identification: Can it be done? In *International Conference on Computer Vision Theory and Applications*, pages 200–205, 2008.