Fingerprint Quality: a Lifetime Story

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Abstract: Currently, it is a largely accepted fact that biometric sample quality is the most determinant factor to achieve high recognition accuracy in biometric systems. However, even in extensively researched characteristics such as fingerprints, there is still a lack of evidence on how quality evolves throughout the life of an individual. For instance, how does the quality of children fingerprints compare to that of adults or elders? Do these changes imply any age limits for the use of fingerprints with current technology? The present paper addresses this key problem based on a database of over 400K fingerprints coming from more than 250K different fingers. The database was acquired under real operational conditions and contains fingerprints from subjects aged between 0 and 98 years. Such a unique set of data has allowed us to analyse for the first time how fingerprint quality changes through life.

Keywords: Fingerprint quality, age, children, adults, elderly.

1 Introduction

Quality assessment of biometric samples is nowadays one of the most researched topics within the field of biometrics, as a consequence of the concern arisen after the poor performance observed in different biometric systems on certain samples [AFFOG12]. Different studies have shown that biometric systems performance is heavily affected by the quality of the input signals, and that even the best systems worldwide struggle in the presence of noisy samples [GT07].

Although existing standards consider biometric sample quality from different points of view [IS06], currently the most extended one is the *utility* interpretation. Under this perspective, quality is understood as a metric that estimates how suitable a biometric sample is for automatic recognition purposes, or, in other words, of its discriminative potential. As such, biometric sampl quality is a way to predict the accuracy of automatic recognition systems on a given set of data. Biometric samples showing good quality should translate into high recognition accuracy, while poor quality should entail higher error rates.

The study of biometric sample quality has been particularly intense in the field of fingerprint recognition where multiple works have proposed different methods to measure it [Al08, Ya16]. Based on the findings and knowledge built by these research studies, an initiative led by the US NIST (National Institute for Standards and Technology) produced in 2005 a *de facto* standard metric integrated in the open source tool NFIQ1 (NIST Fingerprint Image Quality), which has recently been superseded by its successor NFIQ2. The evidence generated by all these scientific efforts has led to the certainty that fingerprint

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quality is one of the key factors, if not *the* key factor, that determines the recognition accuracy.

As shown above, fingerprint quality is considered an essential aspect for the development of the technology and, consequently, different tools are available to measure it. However, few works have studied how it is affected by time. How does fingerprint quality evolve through a lifetime? How does the quality of children fingerprints compare to that of adults or elders? Do these changes imply any age limits for the use of fingerprints with current technology? While some valuable efforts have been conducted to address these and other similar issues (see Sect. 2 for a review of the state of the art), there is still not enough consistent evidence to provide reliable answers to the questions raised above.

The lack of large comprehensive studies addressing the effect of time on fingerprint quality is mostly explained by the lack of large-scale long-term databases acquired under operational conditions. The data scarcity has forced researchers to conduct their time-related studies on limited sets of fingerprints, in many cases acquired under controlled laboratory-like conditions for the purpose of the experiments [UW09, DG13, Ja17]. Although the results of these works are certainly valid to point out general trends and to formulate hypotheses, further analysis is required on larger, more comprehensive and realistic sets of data in order to confirm those results and to provide more consistent evidence that supports the findings.

With the aforementioned issues as motivation, the present research study is an attempt to shed some further light into the evolution of fingerprint quality through life. To that end, the study has been conducted on a database of almost half a million fingerprints of ages between 0 and 98, captured under real operational conditions for the issuing of passports. We believe that this constitutes the first comprehensive study of fingerprint quality for the whole age range of human life.

The rest of the paper is structured as follows. Related works are presented in Sect. 2. The dataset and the experimental protocol are described in Sects. 3 and 4 respectively. Results are given in Sect. 5, while conclusions are finally drawn in Sect. 6.

2 Related works

The effect of time on biometric technology has been lately the focus of books [Fa13], surveys [La10] and specific publications in biometric characteristics such as fingerprint [Ja17], face [Pa16], iris [Gr13], or signature [GMDF13].

From a general perspective, such time-related biometric studies analyze two different effects. 1) Age effect: which refers to the variations in performance between different user groups due to their age, such as, for example, children, adults and elderly. In this case, a short time difference between the reference and probe samples is assumed. 2) Ageing effect: which accounts for the variations in performance due to the increase of the time difference between the reference sample and the probe sample.

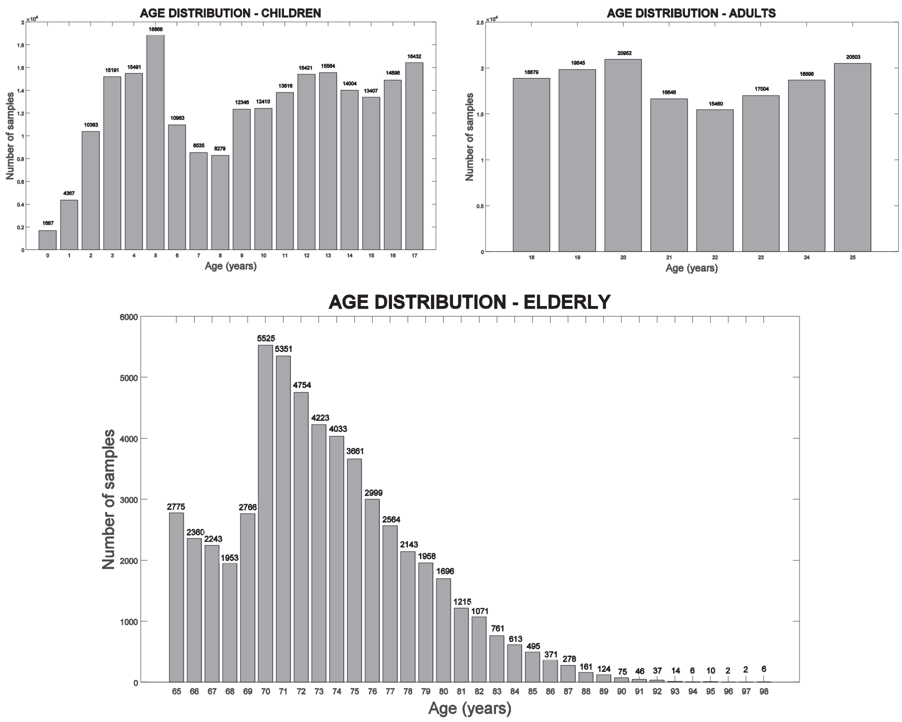

Fig. 1: Fingerprint distributions in the database according to the age.

The present work analyses the evolution of fingerprint quality through human life and is therefore related to the age effect. Consequently, only relevant articles addressing this issue will be considered here.

As mentioned in the introduction, the specialised literature studying the changes in fingerprints through a long period of time is quite limited [Du05, SE05, Mo07, UW09, DG13, Ja17]. Although some not very important variations may be found among the results presented in these works, it is safe to summarize their findings as: the fingerprint quality of children below 12 years of age and of elders above 62 years of age is lower than that of adults and, as a consequence, fingerprint recognition systems may fail to perform adequately for these age groups.

The main limitation of all these works is the significantly small-scale datasets used, which did not exceed 5,000 samples. This way, while the general methodology followed is correct and some interesting trends can be observed regarding the differences between age-groups, further tests are required on more comprehensive sets of data to confirm the conclusions drawn in those studies and to model in a more accurate way the fingerprint quality variations for different ages.

Furthermore, the literature on the age effect focuses almost completely on the differences between adults and children fingerprints. However, barely any research has been carried

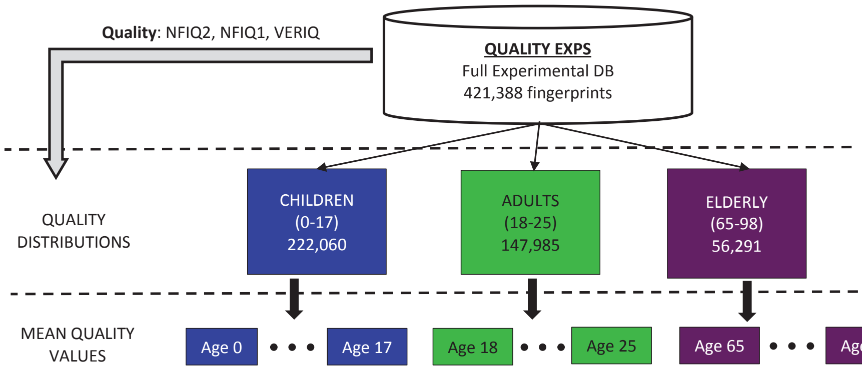

Fig. 2: Diagram depicting the protocol followed to analyse the evolution of fingerprint quality over age.

out on such an important demographic group as the elderly [SE05, Mo07]. Solving the lack of reliable information regarding the possible deterioration of elderly fingerprints is at the moment one of the priorities of entities issuing travel documents.

3 The Dataset

The dataset used in the experiments was provided under strict security and data protection measures by the Portuguese authorities, approved by the Portuguese data protection authority and following a prior notification to the European Data Protection Supervisor. It contains real operational fingerprint data acquired for the issuing of passports. In total, the database contains fingerprint impressions from 265,341 different fingers which have produced a total 421,388 images.

These data can be divided in three main groups according to the age of the fingers: children, comprising ages 0-17 (222,060 samples), adults, comprising ages 18-25 (147,985 samples) and elderly, comprising ages 65-98 (56,291). The dataset contains no fingerprints in the age range 26-64. The fingerprints distribution per age is shown in Fig. 1.

4 Experimental Protocol

The objective of the experiments is to determine if the age of the individual plays a role in the fingerprint image quality and to quantify such potential variations in order to determine: 1) age groups exhibiting low fingerprint image quality and 2) possible age limits for the use of fingerprints in certain applications. To reach these goals, three different quality metrics have been used:

- **Quality metric: NFIQ1**. The first version of the NFIQ tool was published in 2004 as part of the NIST Biometric Image Software (NBIS). It was developed by NIST as a response to the increasing need of providing a vendor-independent application capable of giving reliable feedback on fingerprint quality for different scanners and matchers. This metric has been extensively used in the literature and has become a *de facto* standard. It returns values between 1 (excellent quality) and 5 (very poor quality). The software is supplied as an open-source tool through the NIST portal[3].

- **Quality metric: NFIQ2**. The development of NFIQ2 was driven by the advances in fingerprint quality estimation since the original version of NFIQ was made public. NFIQ2 was released in 2017, being the major differences with respect to the original application: 1) modular design; 2) possibility to be retrained to adapt to specific contexts (e.g., latent fingerprints); 3) increased accuracy in the estimation of fingerprint quality; 4) increased sensitivity range from 0 (very low quality) to 100 (excellent quality). NFIQ2 is being formally standardized as part of "ISO/IEC 29794-4 Biometric Sample Quality". Alike the original NFIQ1, NFIQ2 is also supplied as an open-source platform through the NIST portal[4].
- **Quality metric: VERIQ**. This is a proprietary fingerprint quality evaluation metric supplied under different licensing options with the VeriFinger feature extraction and matching algorithms developed by Neurotechnology [5]. The algorithm returns values between 0 (very poor quality) and 255 (excellent quality). As per feedback from the Neurotechnology support team, the values between 200-255 should correspond to the NFIQ1 values of 1 (excellent) and 2 (very Good).

It should be noted that, from all three tools, it is probably NFIQ2 the most relevant and reliable one, given all the investment experience and research that has been put into its development. Nevertheless, since biometric sample quality is not an exact and deterministic feature, the other two metrics can be valuable assets to confirm, complement or even put in doubt, the results obtained with NFIQ2.

The three quality metrics were used to extract the quality scores from all the 421,388 samples present in the experimental dataset. The quality distributions for each of the three main groups (i.e., children, adults and elderly) are computed. Finally, the mean quality value per age of acquisition is also computed (i.e, mean quality value for ages 1-25 and 65-98). The full experimental protocol is depicted in Fig. 2.

5 Results

One general observation valid for all the results presented in this section is the very high consistency shown by the three quality metrics (NFIQ2, NFIQ1 and VERIQ) in all the experiments.

[3] `https://www.nist.gov/services-resources/software/nist-biometric-image-software-nbis`
[4] `https://www.nist.gov/services-resources/software/development-nfiq-20`
[5] `http://www.neurotechnology.com/verifinger.html`

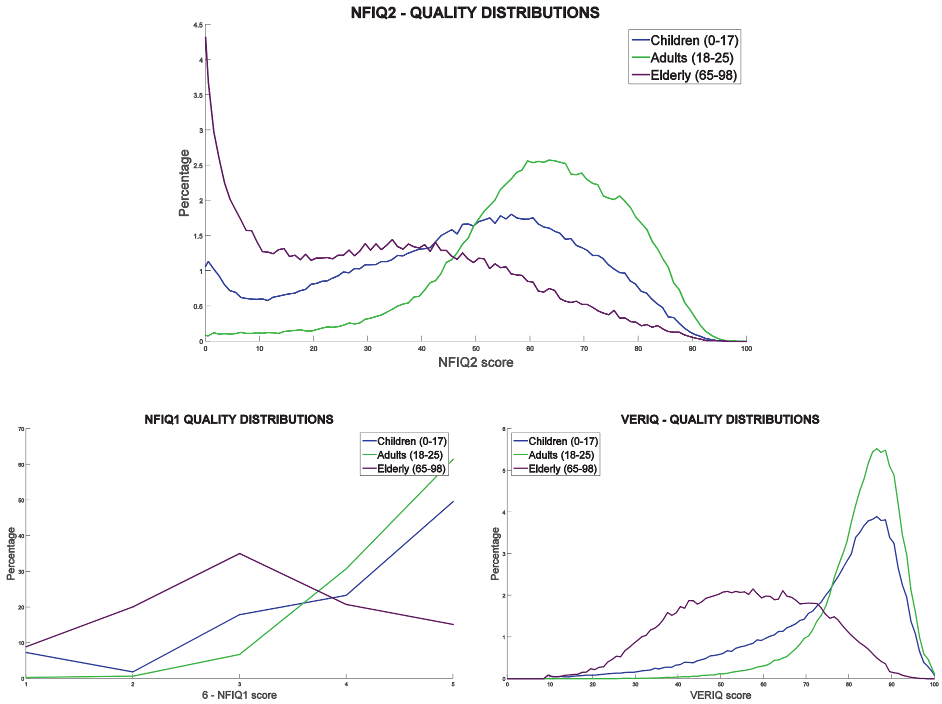

Fig. 3: Quality distributions of the fingerprints belonging to each of the three main age-groups represented in the experimental dataset: children (0-17), adults (18-25) and elderly (65-98). Distributions have been computed with NFIQ2 (top), NFIQ1 (bottom left) and VERIQ (bottom right).

Fig. 3 shows the comparison of the fingerprint quality distributions corresponding to the three overall age groups in the experimental dataset: children, adults and elderly. From this plot we believe it is safe to extract the next conclusion:

- ***FINDING 1***. In terms of fingerprint quality, the most challenging age-group is the elderly (65 years of age and above), which presents an overall quality significantly lower than that of children (0-17 years of age). As could be expected, adults clearly present the highest fingerprint quality.

Fig. 4 shows the year-by-year evolution of the mean fingerprint image quality in the experimental dataset. The 90% confidence intervals for each of the mean values are shown as vertical red lines.

For those ages not present in the dataset, i.e., ages between 26 and 64 (plotted in light grey in Fig. 4), the mean fingerprint image quality has been estimated using values for ages 18-25 and 65-90 as described in the following, where *N* represents the estimated age at which fingerprint quality starts decreasing. 1) *Mean quality estimation for ages 26-N*: Given the reduced number mean quality scores for adults (eight ages available, 18-25), this mean value has been estimated as the average of the mean quality values for ages 18-25

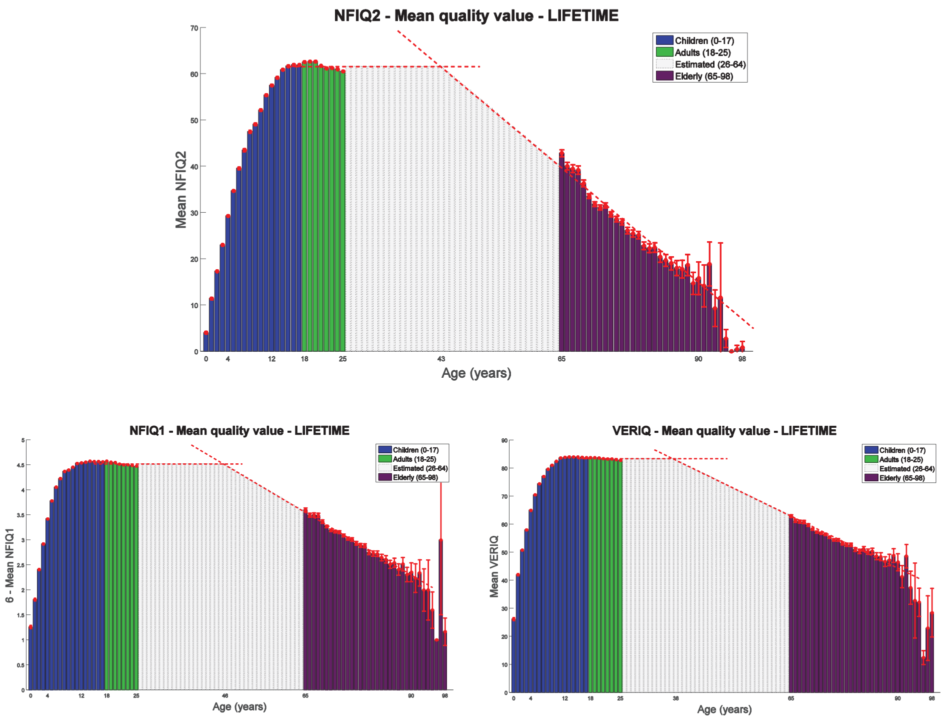

Fig. 4: Lifetime evolution of the mean quality value computed with NFIQ2 (top), NFIQ1 (bottom left) and VERIQ (bottom right). The 90% confidence intervals are shown in vertical red lines. Values for ages 26-64 have been estimated using two linear fits (shown with dashed red lines).

(horizontal red dashed line). Such an estimation follows the hypothesis that in adult life, fingerprint image quality does not vary significantly. 2) *Mean quality estimation for ages N-64*: the mean quality values have been estimated with a linear Least Squares fit using the mean quality scores from ages 65-90 (diagonal red dashed line). Mean quality scores corresponding to ages 91-98 have not been considered due to the low amount of fingerprint impressions available in the database.

The age-wise evolution of fingerprint image quality shown in Fig. 4 for all three quality metrics allows us to conclude that:

- ***FINDING 2***. Quality of children fingerprint impressions increases between 0 and 12 years of age. This increase is very fast between 0 and 4 years of age, where it improves by a factor of 3-4. Then it reduces its rate between 5 and 12, where it is basically doubled. From 12 years old until 17, fingerprint quality stabilizes and can be considered equal to that of adults (18-25).
- ***FINDING 3***. For adults, fingerprint image quality is quite stable, with an almost negligible decreasing slope between 18 and 25 years. Following the estimation made in the study, this almost constant quality is present until $N\varepsilon[40,45]$ years of

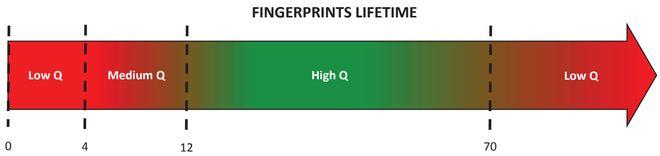

Fig. 5: Diagram showing the four age zones in which the fingerprints lifetime can be divided according to their quality. Numbers indicate age in years. The high quality between 26 and 64 years of age has been estimated as explained in Sect. 5.

age (point at which the two red dashed lines in Fig. 4 intersect). Given the limited amount of data available for adults from an age-wise perspective, covering ages 18-25, this invariable behaviour of fingerprint image quality and the actual value of N should still be confirmed over a database comprising fingerprints belonging to the 26-64 age range.

- ***FINDING 4***. For elders in the range 65-90, fingerprint image quality decreases linearly with age, at a rate of around 0.8-1% quality loss per year. This linear decrease starts at around $N\varepsilon[40,45]$ years of age (as in FINDING 3, the N value should still be confirmed on real data). It is interesting to underline that for subjects 70 years old, fingerprint image quality is similar to that of 4 year old children.

6 Conclusions

The present article has analysed the evolution of fingerprint image quality through the complete age range of a human lifetime. To reach this objective, a unique database of over 400K fingerprints has been used, which contains fingers ranging between 0 and 98 years of age captured in real operational conditions for the issuing of passports.

The conclusions reached in the work can be used to identify four different age zones for fingerprints according to their quality, as depicted in Fig. 5. One of the findings of the study that may have bigger practical implications is the fact that the elderly can pose an even bigger challenge to fingerprint recognition systems than young children. Given the nature of the data used in the experiments (passport issuing), this result is particularly relevant in border management and travel control since elders are, unlike children, fully autonomous to cross borders and, in general, have the economic resources to do so.

From a general point of view, the results presented in the article can help to define important policies such as: 1) Setting different validity periods for travel documents depending on the age of the holder; 2) Setting the minimum and maximum age limits for the reliable use of current automatic fingerprint recognition technology in the context of large-scale IT systems (e.g., border management or law-enforcement).

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