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Realization of Experiments with Image Quality of Fingerprints

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Abstract

This article introduces briefly the theory for estimation of fingerprint image quality. This is followed by the description of experiments with fingerprint image quality, concretely image contrast, mean value and number of papillary lines in fingerprint using the scanners Suprema.

Keywords: *fingerprint, image quality, image contrast, papillary line*

1. Introduction

The exact definition of the quality of a fingerprint image [3][4][5] is difficult and nearly impossible. Different types of information are important for various cases – e.g. once it is the contrast, another time the continuality of trajectory of some papillary lines or resulting minutiae quality, etc. In general, it is impossible to formulate one definition covering all cases. But in case of fingerprints, we can find some common properties and, on the basis of such properties, we are able to define some quality requirements.

1.1 Image Contrast

The image contrast could be defined in a variety of ways. In the field of fingerprint recognition, two options for the image contrast are available. In these two options, the image contrast is defined as relative local differences in pixel intensities. The definitions are [2][1]:

- Michelson contrast: $C_{Michelson} = \frac{(L_{\max} - L_{\min})}{(L_{\max} + L_{\min})}$,
- Weber contrast: $C_{Weber} = \frac{\Delta L}{L}$,

where $L_{\max}$ and $L_{\min}$ in the Michelson contrast are the intensities of the foreground (papillary line) and background (gaps between papillary lines, called valleys), respectively; $L_{\max}$ corresponds to the region with the highest intensity. In the Weber contrast L determines the intensity of the background and ΔL is difference between foreground and background intensities. The difference of both contrasts is small when small variations of foreground and background intensities are observed, and vice versa, with increasing intensity variations of foreground and background the difference is increasing, too. The complete image contrast could be computed as the mean value of all local intensity differences.

1.2 Image Histogram

The meaning of the histogram in this context is the representation of frequencies with a special characteristic, e.g. such histogram makes possible to track the luminosities (gray grades) of image pixels on the horizontal axis.

The horizontal axis is divided into 256 channels depending on the grades of grayscale; the channel with the value 0 corresponds to the lowest luminosity (black) and the channel with the value 255 corresponds to the highest luminosity (white). Other values of the grayscale lie between these two limit values. The histogram is made in such a way that for each image pixel one is added to the sum (or probability distribution function) which corresponds to the luminosity of a given pixel. If we go through the whole image, we obtain a luminosity histogram or histogram of gray grades for a specific fingerprint.

We can define the histogram as follows:

$$Hist(r_k) = \frac{n_k}{n},\ k = 0,1,2,\ldots,L-1$$

where $Hist(r_k)$ is the discrete function of the histogram, r_k is the k^{th} gray grade value, n_k is the number of pixels in the channel r_k, L is the number of gray grades and n is the sum of pixels in the image (e.g. 261,144 image pixels for the resolution of 512×512 pixels).

1.3 Mean Value of the Histogram

If we analyze the histogram, we can identify two appreciable peaks. The left peak corresponds to the ridges (papillary lines) and the right one to the background (valleys; light background is considered). The papillary lines in fingerprint images are represented usually in dark colors and the valleys (gaps among papillary lines) in light colors; however, an inverse representation is also possible. The presented histogram is nearly an ideal case. Unfortunately, it happens very often that both peaks are not so well recognizable and separable. In general, either one peak is missing or the gray grades are so distributed that a lightly rolling curve spreads across the histogram.

In an optimal case, the mean value should be exactly in the middle of the histogram, i.e. at the value 128 (if we consider 256 gray grades). If it is so, it means that the area under the left part S_L of the curve corresponds to the area under the right part S_R of the curve.

The mean value M represents a quality measure for the distinguishing of papillary lines from the background. The mean value M can lie in the interval $<0,255>$, because the value represents a gray grade value. Consequently, the magnitudes of both areas on the left and right sides from the mean value M have to be computed. We denominate these areas as S_L and S_R and then we can write [2]:

$$S_L = \sum_{i=0}^{M-1} h_n(i) \quad \text{and} \quad S_R = \sum_{i=M}^{255} h_n(i)$$

where M is our mean value (at the beginning M = 128) and are normalized probability distribution functions for corresponding grades of gray.

We should also take notice of the limits of the histogram. Let us denote the beginning of the histogram B_{Dark} and the end B_{Light}. The mean value should obviously lie between B_{Dark} and B_{Light}. We can compute the theoretical mean value M_T as follows [2]:

$$M_T = \frac{B_{Dark} + B_{Light}}{2}$$

Using the real mean value M, we are able to compute the deviation D from the theoretical value M_T as follows [2]:

$$D = \left| 1 - \frac{M_T}{M} \right| \cdot 100\%$$

1.4 Number of Papillary Lines

In the literature, the number of papillary lines is used for the computation of the number of papillary lines lying between the fingerprint core and a delta point [2]. This number could be determined in the so called dactyloscopic fingerprints nearly without any problem, because they cover bigger area, including the delta point. The “tip” fingerprints, which are scanned only by putting the finger on the scanner platen (access control), cover smaller area, i.e. the delta point in the fingerprint is often missing. Obviously, it is then impossible to determine the number of papillary lines in such fingerprints as defined in the literature.

If we cross the fingerprint image in vertical and horizontal directions, we are able to count the number of papillary lines in each row or column, i.e. how many papillary lines are cut through by the abscissa running from one edge to the other in the given row or column of the fingerprint image. From the mathematical point of view, the maximal number of papillary lines should be found near the core (center) or similarly in homocentric circles where the highest number of such crossings lies near the center of all of them. We are able to determine quite precisely not only the center of the fingerprint [2] but also the quality rate of the sensor.

A larger fingerprint area contains more unique information which can be then exploited for the comparison of fingerprints. The larger the area, the higher number of papillary lines is contained in the fingerprint. It leads to the conclusion that the more papillary lines (in horizontal and vertical directions) we are able to detect, the better results offers the sensor.

One outstanding influence which can affect the count of papillary lines in both directions is either strong blurring (due to a small contrast ratio between papillary lines and background or finger movements during scanning) or merging of two papillary lines together (due to strong pressure or moisture on the finger during scanning). Despite of such influences, the data on the amount of papillary lines are in general stable and reliable.

2. Experiments with Quality Estimation

This chapter contains the introduction of experimental results from the tested devices – the evaluation kit Suprema SFM3000 EVK which was used for the image quality testing – it is a development kit base board which can cooperate with other sensor units listed in the following overview (Fig. 1). The evaluation kit including all four sensor units has been lent by the company Digitus and all components have been placed in the biometric laboratory at the Department of Intelligent Systems, FIT BUT.

Figure1. Suprema scanners (from left: SFM3000, SFM3010, SFM3020, SFM3050)

The results of fingerprint acquirement have been saved into a database of fingerprints. This database includes the fingerprints from 30 users; each person has provided the fingerprints from both hands and all fingers except of little fingers (these are generally not used in the access system – it often happens that these fingers are placed wrongly on the scanner platen due to their size; a small finger contains a smaller amount of significant information). Each user put all four fingers on both hands 5 times on each sensor. Thus each user provided 160 fingerprints which have been stored in the database. The size of the full database is 4,800 fingerprints (its volume is approximately 650 MB).

All fingerprint images have been visually checked one by one; the criterion for rejection was the fingerprint area smaller than one half of the image (images containing fingerprint on three quarters of the area were preferred). The second factor for rejection was associated with smudged or blurred papillary lines (due to the high perspiration of hands).

2.1 Determinations of Contrast Ratios

The Michelson contrast was used for the computation of contrast in the images for this metrics. The values of local intensity differences have been computed according to the definition. After averaging them we obtained the global image contrast.

The local intensity differences were determined on specific parts (regions) of the image in a predefined range. What concerns various input sizes, it has been decided to determine the local differences in corresponding sizes of partial regions; their size was set in accordance to the size of the whole image. The exact values are shown in Tab. 1.

Table 1. Region sizes [2]

Module	Output resolution	Region size
SFM3000	128 × 128	8 × 4
SFM3010	360 × 500	15 × 12
SFM3020	272 × 320	15 × 12
SFM3050	256 × 360	15 × 12

Generally, it is very difficult to determine the exact contrast values which should be contained in the images. It depends strongly on the quality of the recognition algorithm, which should be able to recognize the images correctly with low contrast ratios. Thus the more contrast the sensor provides, the better is the separation of papillary lines from background and therefore the higher quality is achieved at the input of the recognition algorithm. The maximal value for the contrast is 1.0. The more these sensors can approach this value, the better image output is achieved. The fingerprint quality is closely related to this metric. The bigger finger area is scanned, the higher contrast is reached and therefore the image quality is also better. The distribution of global contrast ratios for all sensors is shown in Fig. 2.

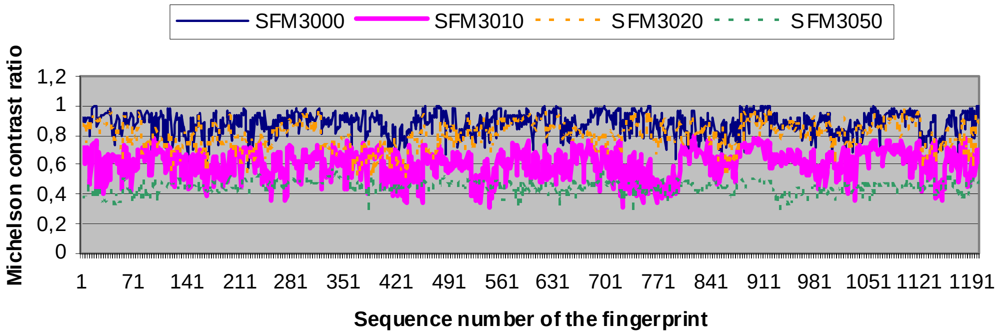

Figure 2. Michelson contrast ratios for all sensors [2]

2.2 Mean Value of Grayscale Levels

This method expresses the ability of the sensor to distinguish background and papillary lines from each other. Two clearly recognizable peaks can be found normally in the image histogram, which represent the background and papillary lines.

The graphs presenting the complete deviation values in all measured samples are shown in Fig. 3 through 6 (the blue color corresponds to the mean value of gray grades for each image from respective sensor; the violet color corresponds to the average value).

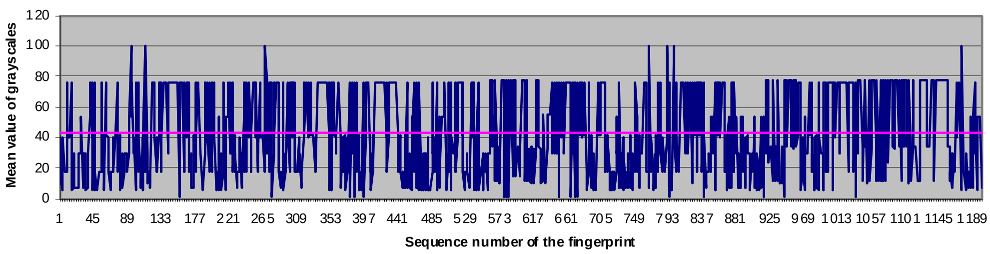

Figure 3. The mean value of grayscale values for the sensor Suprema SFM3000 (average ≅ 43) [2]

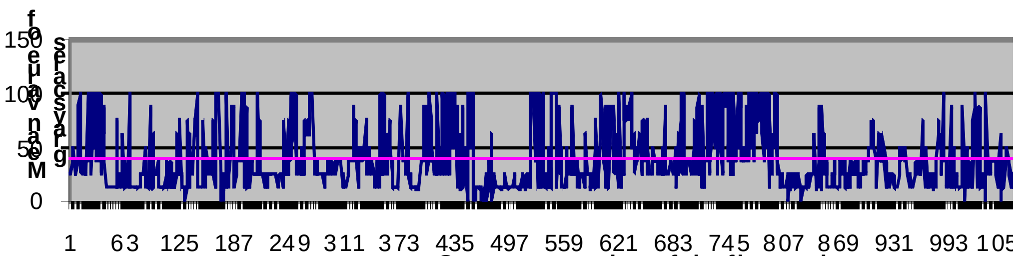

Figure 4. The mean value of grayscale values for the sensor Suprema SFM3010 (average ≅ 40) [2]

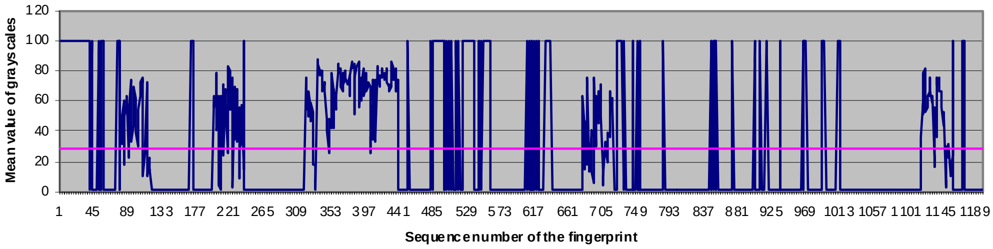

Figure 5. The mean value of grayscale values for the sensor Suprema SFM3020 (average ≅ 28) [2]

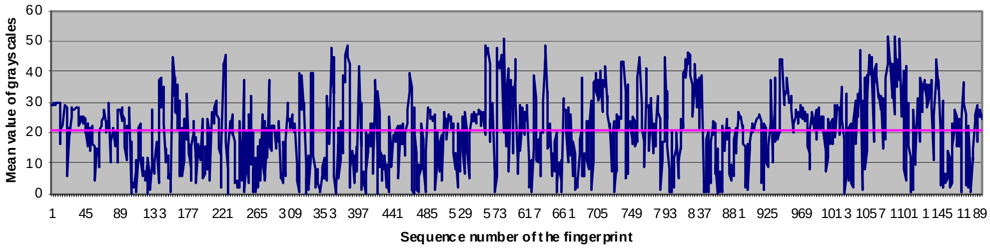

Figure 6. The mean value of grayscale values for the sensor Suprema SFM3050 (average ≅ 21) [2]

The real evaluation rank of each sensor may not be clearly visible from the above results. Although some sensors have shown great deviations and therefore would not pass through the tolerance limit of 20%, their histograms show insufficient resolution. The results come out from a precise histogram analysis where the method does not offer suitable resolution in sparse histograms. These histograms have strong non-uniform distribution but both peaks which determine papillary lines and background are nevertheless visible, whereas other smaller peaks are nearly insignificant. It is therefore very important to interpret the histograms correctly. The fully relevant results have been achieved only with the sensor SFM3050 which provides the outputs with a histogram using full range of values.

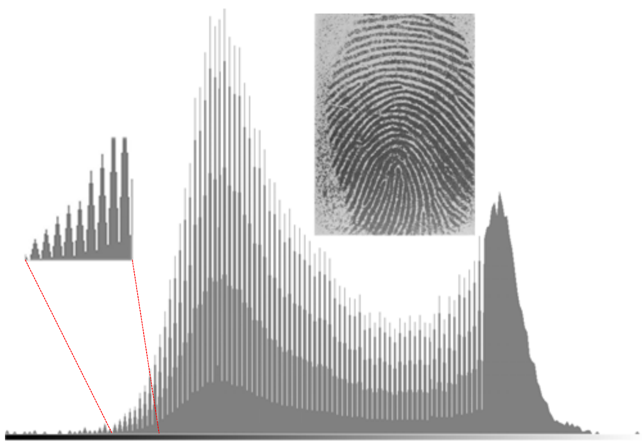

Figure 7. Histogram of the sensor SFM3050 (only a half of the x-axis is used) [2]

Some interesting aspects could be seen in the test data from the sensor SFM3050 – the incompleteness of histogram from acquired images – see Fig. 7. The basic line imitates the expected curve but when subjected to a detailed analysis, it can be seen that each second value is zero. The effectiveness of the sensor is evidently not influenced by this fact, but the question is why the sensor performs such a strict filtering.

2.3 Number of Papillary Lines

In general, it can be stated that the higher the density of papillary lines in the image is, the more accurate is the process of recognition – this reflects the relationship to the amount of information in the image. The density depends directly on the scanning area of the sensor.

Some external values may not correspond to the real state. Due to a lower quality of certain images, it was not possible to exploit the fully automatic detection of papillary lines. It is necessary to say that the application of a suitable filter would improve this situation but this exceeds the scope and purpose of this test. In addition, the application of such filter would distort the information about real quality of images supplied by the sensor. The measured values of the number of papillary lines in horizontal and vertical directions are summarized in the Tab. 2.

Table 2. Average, maximal and minimal numbers of papillary lines [2]

Sensor	**SFM3000**	**SFM3010**	**SFM3020**	**SFM3050**
Horizontal minimum	6.00	6.00	9.00	10.00
Horizontal average	12.86	19.30	19.93	21.25
Horizontal maximum	23.00	27.00	30.00	31.00
Vertical minimum	5.00	3.00	11.00	11.00
Vertical average	13.26	33.18	22.79	25.67
Vertical maximum	24.00	51.00	31.00	37.00

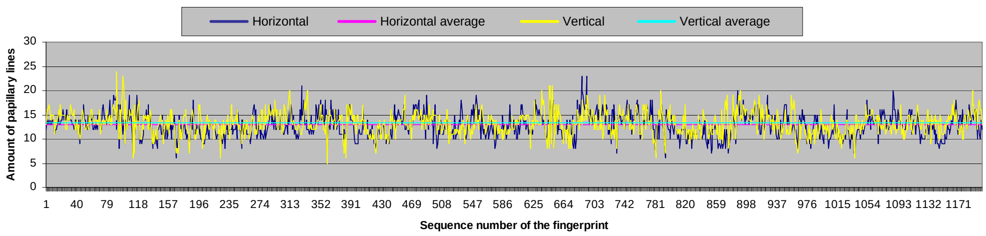

Figure 8. Numbers of papillary lines for the sensor SFM3000 [2]

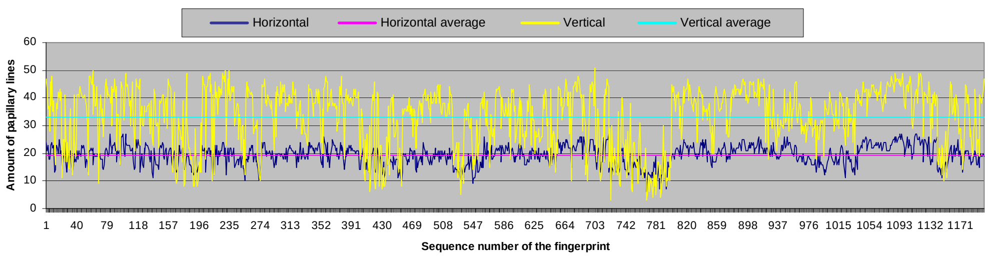

Figure 9. Numbers of papillary lines for the sensor SFM3010 [2]

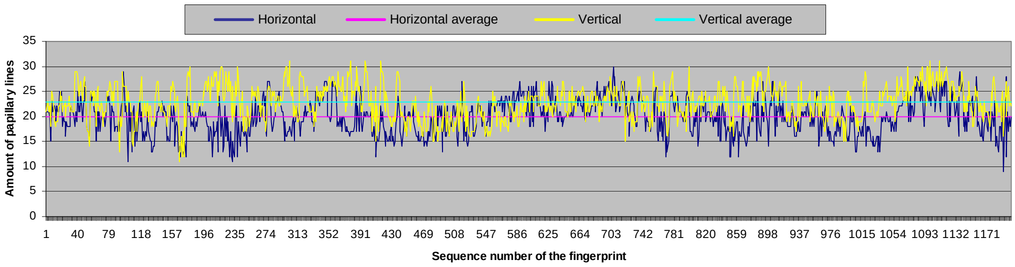

Figure 10. Numbers of papillary lines for the sensor SFM3020 [2]

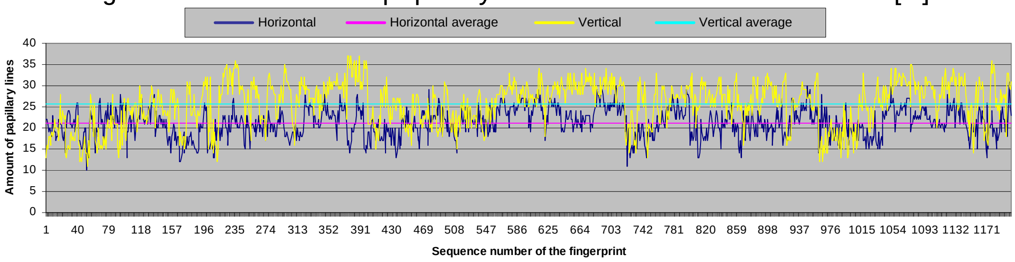

Figure 11. Numbers of papillary lines for the sensor SFM3050 [2].

The determination of one concrete value of the number of papillary lines in the defined direction is very specific and this value is sometimes impossible to determine. However, it is possible to compute a long-term average for each sensor. If the actual value from the presented finger differs from such average, it could mean that the provided fingerprint does not have a sufficient quality and therefore a new fingerprint should be acquired once again.

2.4 FTA Rate

The satisfaction of users is closely associated with the FTA rate, but it depends also on the algorithms for fingerprint processing which follow after the phase of acquirement.

The users, who participated on the creation of the database of fingerprints, recorded the events when the sensor had not responded to scanning and/or had not acquired any image or the image had not contained a fingerprint although the user applied a finger on the scanning area of the sensor. Some of these users recorded strongly biased or damaged fingerprints without feeling any responsibility for such results. All these results have been put together in Tab. 3.

Table 3. The FTA rates and percentages of fingerprints with a poor quality [2]

Sensor / Rate	FTA [%]	Fingerprints with a poor quality [%]
SFM3000	0.595	7.500
SFM3010	2.140	15.120
SFM3020	0.000	5.710
SFM3050	0.120	5.600

3. Conclusion and Future Work

In this article, there has been presented some approaches for estimation of fingerprint image quality. We can count the following possibilities among the methods: e.g. image contrast, mean value of the image histogram, number of papillary lines or the FTA rate.

The theoretical basics have been introduced in the first chapter, followed by practical experiments with the Suprema sensors. The usability of them and relevance in fingerprint recognition is different in various tasks, i.e. appropriate method has to be selected correctly for concrete task.

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