Fingerprint Image Enhancement with easy to use algorithms

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Abstract: This paper looks at measures to enhance image quality with the intention of improving recognition rates of finger recognition systems. There are thus different algorithms when compared to each other. The methods cover sharpness enhancement in general; wavelet sharpness, photocopy filters, EAW filters, DoG filters and Cartoon filters. The FVC2000 Db1a is used as reference dataset. The scores for the comparison are based on the NFIQ quality scores. The approach of the paper is to use a few single algorithms of the GIMP program and evaluate which one improves the reference database the most. GIMP is open-source software so everybody can use it to improve fingerprint images without having advanced programming skills.

1 Introduction

The most frequently used biometric systems are systems with fingerprint recognition [GAKD00]. For example police agencies use them to identify people on a crime scene. The ridge characteristics are one of the last recognisable features after person's death [TB06]. Another example is smartphones, some of which have fingerprint sensors in their default configurations. With those sensors, the user is able to unlock their phone without entering the passcode [Inc15]. Minutiae extraction is an important process for recognising fingerprints. The most frequent minutiae used are ridge ending and ridge bifurcation [HWJ98]. The ridge ending is the point where the ridge terminates, whilst the bifurcation is the point where the ridge splits (forks) into two ridges. A good-quality fingerprint has between 40 and 100 minutiae [HWJ98]. Poor image quality might result if the finger is too dry, wet, worn-out or dirty at the scanning process [Kri06]. Another influence can be to high or low pressure or scratches. The problem is that many incorrect minutiae are extracted and a large percentage of correct minutiae may be ignored [HWJ98]. The goal of enhancement algorithm is to improve the ridge structure of the input fingerprint images and remove the unrecoverable regions [HWJ98].

The paper is organised as follows. The next section introduces the related work to give an overview of the already published papers. Section 3 introduces the reference dataset. In Section 4 the method sharpness (general), wavelet sharpness, photocopy filter, EAW filter, DoG filter and Cartoon filter will be described. In Section 5 the results of the methods will be shown. Finally, in the last section some conclusions are drawn.

2 Related work

In the article [DPP13] GIMP is used as one part of the pre-processing chain to alter the colours of fingerprint images. In [FAF07] they use various quality measures to compare fingerprint images. The article [KAY14] is about the comparison of fingerprint enhancement algorithms for poor-quality fingerprint images. They also use NFIQ as a comparison score. The article [KN14] also discusses the enhancement used for low-quality images, using the FVC2000 database as a reference. This paper gives a closer look at the algorithms which are available in the image manipulation program GIMP and where these can improve fingerprint images with FVC2000 as the reference database.

3 Dataset

The experimental results have been evaluated on the public fingerprint database FVC2000 Db1a[1]. The database is 100 fingers wide and 8 impressions per finger deep. The resolution of each fingerprint image is 300 x 300 pixels. In the modified framework (see section 4) there is a resolution of 500 x 500 pixels needed as a minimum. For this requirement the terminal program *composite*[2] with an empty image (blanko.tif) of resolution 500 x 500 pixels is used. Subsequently, you can find an example command:

Example command: composite -gravity center 1_1.tif blanko.tif 1_1.tif

For scoring the fingerprint image quality of the reference dataset, the NFIQ scores are used. The score is standardised in NIST IR 7151. In the standard are five quality measures: *EXCELLENT*, *VERY_GOOD*, *GOOD*, *FAIR*, *POOR*. In total the database Db1a has 800 images of a quality 94.375 % good (EXCELLENT, VERY_GOOD, GOOD), 0.875 % fair (FAIR) and 4.750 % poor (POOR). The quality is measured by the fingerprint feature extractor and comparator Verifinger SDK[3] and used as baseline.

4 Fingerprint enhancement (experiment)

4.1 Minutiae extraction

The process of fingerprint image enhancement involves getting a fingerprint image as an input, applying a set of intermediate steps to the image, and outputting the enhanced image for further feature extraction [HWJ98].

For the first analysis the VeriFinger 7.1/MegaMatcher 5.1 Identification Technology Algorithm Demo from Neurotechnology were used. With this software it is possible to *enrol* a set of fingerprints and *identify* whether a given fingerprint image is in the enrolled set. For the experiment we enrol all images from database *Db1a*. With an improvement of the input images there will be more and better minutiae extracted. Thus with an improvement of the NFIQ score there will be better input images.

[1] http://bias.csr.unibo.it/fvc2000/default.asp
[2] http://www.imagemagick.org/script/composite.php
[3] http://www.neurotechnology.com/download.html#verifinger_sdk_trial

4.2 Image improvements with PILLOW

As we have heard in the sections above, for a good comparison score the quality of the minutiae extraction is important. The main point of this extraction is that the image has a high quality. For this purpose, we use an easy sharpening algorithm which was implemented in the Python Imaging Library *pillow*[4]. The algorithm is based on an article of P. Haeberli and D. Voorhies [HV94]. In the algorithm the image is manipulated with linear interpolation and extrapolation and a factor α, which acts as a kernel scale factor. For degenerate images a blurred image may be used; interpolation reduces the high frequencies and extrapolation increases them. The image is sharpened by the unsharpening mask. Independent of the size of the kernel, a series of convolutions can be easily done [HV94].

4.3 Image improvements with GIMP

GIMP[5], the GNU Image Manipulation Program is a widespread image manipulation program. In our experiment we have used the Mac OS X version GIMP 2.8. Some of the image manipulation algorithms looked very useful for improving the quality of the fingerprint images. A selection of some of the algorithms is shown in the following subsections. These algorithms looked very promising in the algorithm preview (GIMP).

4.3.1 Wavelet sharpness

The wavelet-sharpening filter[6] enhances the original image by increasing the contrast in high frequency space. By adjusting the sharpening radius, the amount of unsharpness can be taken into account. You can also adjust the amount of sharpening separately. The algorithm was designed by Marco Rossini in the year 2008.

4.3.2 Photocopy filter

The idea of the filter is to give the image the look of a photocopy, such as that made by a copier, with the relative darkness of the values of the neighbouring particular regions. This is done by darkening areas of the image which are darker than the neighbourhood average and setting other pixels to white. In this manner, enough large shifts are darkened to black. The degree of darkening is set by the *pct_black* value. The *mask_radius* parameter manages the size of the pixel neighbourhood whose average is computed. Large values for *mask_radius* result in very thick black areas and less detail. Smaller values result in less toner overall and more details. Small *pct_black* values make the mixture of white regions to black border lines smoother and the toner regions themselves thinner and less perceptible. The algorithm was designed by Spencer Kimball and Peter Mattis in the year 1995. In Figure 1 you can see the original Image 27_3 and the image with the photocopy manipulation.

[4] http://python-pillow.github.io
[5] http://www.gimp.org
[6] https://github.com/gimp-plugins-justice/wavelet-sharpen

Figure 1: Original image 27_3 (left) and photocopy filtered image (right)

4.3.3 EAW filter

The filter *edge avoiding wavelets* (EAW) is based on an algorithm from Rannan Fattal from the year 2009 [Fat09]. The algorithm sharpens an image without halos and can be used for local contrast boosting. The algorithm uses a robust data-prediction lifting process. The scheme works on the edge content and avoids taking pixels from both sides of an edge. The multi-resolution analysis shows a better decorrelation compared to common linear translations-invariants. The wavelets encode - in shape and smoothness - information at every scale. That can be used to derive a new edge-aware interpolation scheme. The effectiveness of the wavelet can be used for various computational photography applications such as multi-scale dynamic range compression, edge-preserving smoothing and detail enhancement and image colorisation.

4.3.4 DoG filter

The DoG filter is used as edge detection the *Difference of Gaussians* (DoG) method. This method is based on a 2004 algorithm from William Skaggs. The edges are found by doing two Gaussian blurs with different radii and subtracting the results. There are efficient methods for Gaussian blurs so the algorithm is very fast. The important parameter is the blurring radius for the Gaussian blurs. Decreasing the radius leads to an increase in the *threshold* for recognising edges.

4.3.5 Cartoon

The Cartoon filter is based on a 1995 algorithm from Spencer Kimball and Peter Mattis. The filter spreads dark values in an image based on each pixel's darkness relative to a neighbouring average. The filter also modifies the active layer so that it looks like a cartoon draft. The draft is comparable with a black felt pen drawing which is then shaded with colour. This effect is created by darkening areas that are already noticeably darker than those of their neighbourhood. The parameters in the implementation are *mask_radius* and *percent_black*. The first parameter controls the size of the working area, with large values yielding very thick black areas and less detail. Small values yield subtle pen strokes. The parameter *percent_black* determines the amount of black colour added to the image. Larger values create thicker, sharper and darker lines.

5 Results

When the quality of the input fingerprint image is poor, the performance of the extraction methods degrades rapidly. Therefore, fingerprint image enhancement is one of the key steps in an automated fingerprint identification system (AFIS). In the following subsections the results of the different methods will be described in detail.

5.1 Sharpness

We can see in Figure 2 that the total quality increases from sharpness 10 to sharpness 25. When the sharpness is over 25 the quality falls again. The best quality value is at sharpness 25, with 85.25 % of images *excellent*.

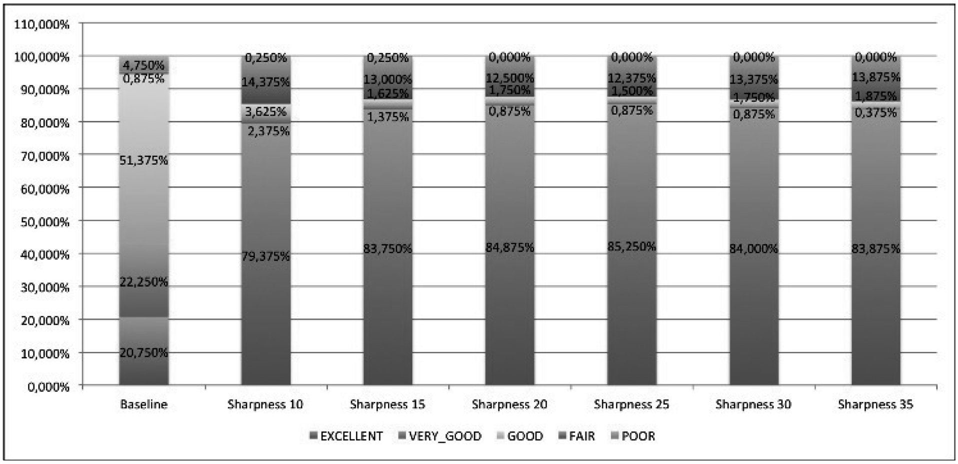

Figure 2: Different sharpness configurations

5.2 Wavelet sharpening

In Figure 3 the results of the wavelet sharpening are given in comparison to the baseline (data without enhancement). In Figure 3 you can see that the score of the *excellent* value has increased to 86.625 %. The parameters for this experiment are radius=10.0, amount=0.5 and luminance=0, these being the standard parameters.

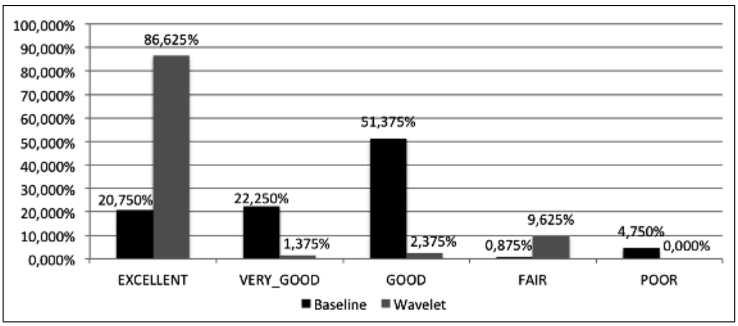

Figure 3: Wavelet sharpening

5.3 Photocopy filter

The parameters for the experiment are *mask-radius*=8.0, *sharpness*=0.8, *pct-black*=0.2 and *pct-white*=0.2 (standard values). The *excellent* value has increased to 73.875 %, but the *poor* value has also increased to 10.750 %. This suggests that some images overfitted with these values. It is obvious that nearly 3 % of the *excellent* values have decreased.

5.4 EAW filter

The *poor* value has also increased to 10.750 %. This is a clue that some images overfitted with these values. In this experiment the EAW filter is used with the standard parameter alpha=1.5, maxband=10, inband=5 and mode=0. The result is a minimal total increase (see Figure 4). It is clear that this filter with these parameters is not well suited to the application of fingerprint image enhancement. The highest loss is in *VERY_GOOD* and *EXCELLENT*. This can also be a sign of overfitting.

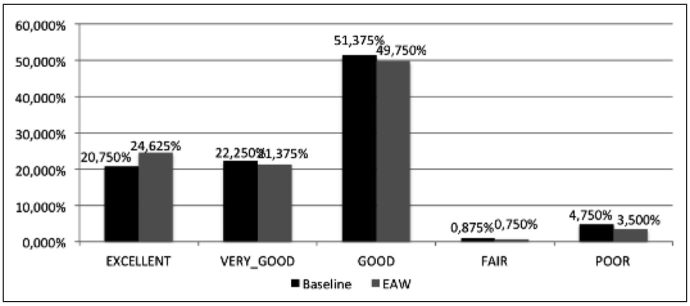

Figure 4: EAW filter

5.5 Difference to the normal distribution (DoG)

In this experiment the standard parameters *inner*=3.0, *outer*=1.0, *normalize*=True and *invert*=True are used. Figure 5 shows that the *EXCELLENT* value has a very high increase (90.625 %). The values in general are very good. None of the *EXCELLENT* values are decreasing. In this case the overfitting is very much limited.

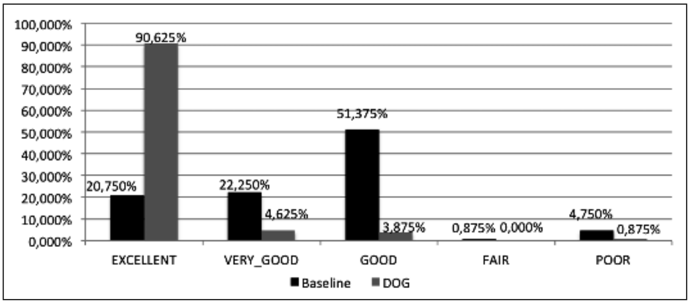

Figure 5: Difference to the normal distribution (find edges)

5.6 Cartoon filter

The last method has the standard parameters set at *mask-radius*=7.0 and *pct-black*=0.2. This method also shows good improvement when compared to the baseline (*EXCELLENT* 80.5 %). The *FAIR* value sees a drastic increase from 0.875 % to 12.875 %. This is a sign of overfitting. The *poor* values of *FAIR* come mainly from the decreasing of the *GOOD* values.

6 Conclusion

Finally, Figure 6 shows the comparison of all methods. In this figure you can see that the highest impact on the *EXCELLENT* level is with the DoG filter (90.625 %).

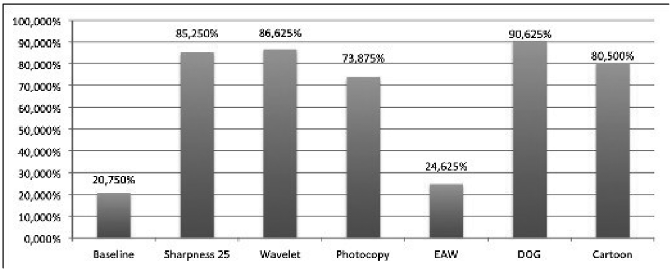

Figure 6: Comparison of the different quality scores (EXCELLENT)

Most of the filters are in the range of 80 % $\pm$ 7. The smallest impact is with the EAW filter. In general every presented method has a positive impact on the basic dataset (baseline).

Figure 7 shows the relationship between the FMR and the FNMR values. In Figure 6 we have seen that the quality score of the image shows a large increase, but if you look at Figure 7 there is only a significant improvement with the DoG algorithm. The photocopy and the cartoon filter are both on the lower side and EAW is closer to the baseline. Wavelet is also under the baseline and Photocopy is above the DoG filter in the last segment.

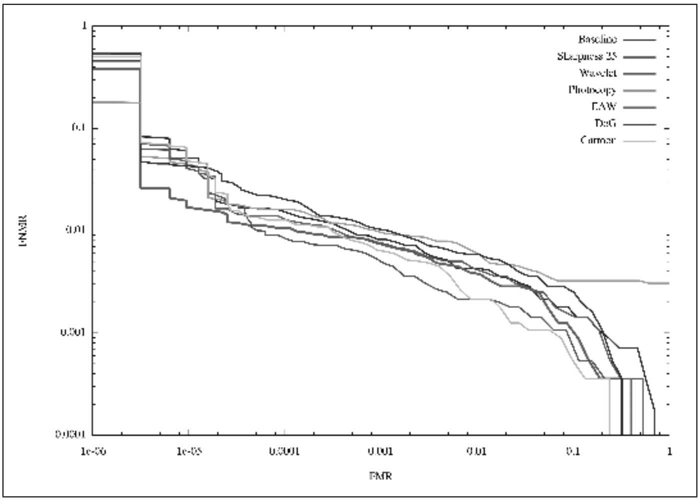

Figure 7: DET-Curve

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