Efficient Filtering of Noisy Fingerprint Images

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Abstract

Fingerprint identification is an important field in the wide domain of biometrics with many applications, in different areas such: judicial, mobile phones, access systems, airports. There are many elaborated algorithms for fingerprint identification, but none of them can guarantee that the results of identification are always 100 % accurate. A first step in a fingerprint image analysing process consists in the pre-processing or filtering. If the result after this step is not by a good quality the upcoming identification process can fail. A major difficulty can appear in case of fingerprint identification if the images that should be identified from a fingerprint image database are noisy with different type of noise. The objectives of the paper are: the successful completion of the noisy digital image filtering, a novel more robust algorithm of identifying the best filtering algorithm and the classification and ranking of the images. The choice about the best filtered images of a set of 9 algorithms is made with a dual method of fuzzy and aggregation model. We are proposing through this paper a set of 9 filters with different novelty designed for processing the digital images using the following methods: quartiles, medians, average, thresholds and histogram equalization, applied all over the image or locally on small areas. Finally the statistics reveal the classification and ranking of the best algorithms.

Keywords: fingerprint image, image noise, statistical analysis, fuzzy selection, classification

1. Introduction

The identification of individuals based on biometrics are made by different methods like: face recognition, palm recognition, voice recognition or handwriting recognition but one of the most usual approaches consists in the fingerprint based identification. Some of the most important implementations of fingerprint algorithms are the IAFIS-Integrated Automated Fingerprint Identification System used by the FBI, which will be followed by the Next Generation Identification system[1] developed by Lockheed Martin in partnership with Safran and also commercial applications implemented in: mobile phone applications, different operating systems like: Apple-iOS, Android, access systems and airports.

Automatic identification based on fingerprints can be synthesized into five distinct phases: pre-processing, feature extraction, feature measurement, classification and matching. At the step of pre-processing the challenge is to find the best methods for enhancing images, taking into consideration the accuracy and the time for execution.

In this work we refer to automation of image enhancement implemented through a number of 9 algorithms having different levels of novelty as a defining stage for improving the quality of processed images. In general, digital image processing is a subdomain of digital signal processing and has many advantages versus the analogue image processing, because the multitude of algorithms used is more extensive and does not raise questions of overlapping the signal or the noise (Bansal, Saini & Verma, 2015).

Modeling in this step is done by algorithms capable of improving image quality, known as filters.

Quick classification of spatial filters on specific aim can be defined as follows:

[1] Privacy Impact Assessment-Integrated Automated Fingerrint Identification System (IAFIS) / Next Generation Identification (NGI) Biometric Interoperability, https://www.fbi.gov

- reducing noise / parasites (Noise Reduction): Median Filter (Arias-Castro & Donoho, 2009), Filter Olympic (Drury, 2001), (Jensen, 1996), (Lillesand & Ralph, 1994), P-Median Filter (Hartman & Kincaid, 2014), Modal Filtering of Classification Results (Mendrok & Kurowski, 2012);
- optimization of the filters' quality (Filters Enhancement): CS -Comparison and Selection Filter (Kantawan & Tsai, 2014), WMMR-Med Majority Filter with Minimum Weighted Range–Median (Liu, Ma, Lee & Zang. 2007), Volter / Unsharp Filter (Suresh, Sanha Kumari, Yashwanth & Raghavendra, 2015);
- transformation of filters' texture (Texture): Range Filter, Fourier transformation.

In the frequency domain the filtering (Gonzales & Woods, 2002 refers to:

- Smoothing Frequency-Domain Filters: Ideal low pass, Butterworth low pass, Gaussian low pass;
- Sharpening Frequency-Domain Filters: Ideal High pass, Butterworth High pass, Gaussian high pass.

2. Contributions to image noise reduction

In the following we mention some of the major contributions, in the field of image noise reduction:

- Priyanka Kamboj and Versha Rani (2013) have studied various noise model and filtering techniques to improve the qualitative inspection of an image and the performance criteria of quantitative image analysis techniques;
- Raymond H. Chan, Chung-Wa Ho, and Mila Nikolova (2005) put forward a two-phase scheme for removing "salt and pepper" noise: an adaptive median filter is used which identify pixels that are likely to be affected by noise and the second the image restoration using a specialized regularization method that applies only to those selected noise candidates. The algorithm can remove "salt and pepper" noise with a noise level as high as 90%;
- M. S. Nair, K. Revathy, and Rao Tatavarti (2015) showed an improved decision-based algorithm for the restoration of gray-scale and color images that are highly corrupted by "salt and pepper" noise which is efficiently removed by preserving all details by utilizing formerly processed neighboring pixel values to get better image quality than the one using only the previously applied pixel value. The projected algorithm is faster and also produces better result than a Standard Median Filter (SMF);
- B. Singh and R. Singh (2014) propose an improved decision based unsymmetrical trimmed median filter algorithm for removing the noise from the color images that are highly corrupted by "salt and pepper" noise;
- W. Luo (206) suggested that images are often corrupted by noise known as "salt and pepper" which can corrupt the images and proposes that the corrupted pixel take either maximum or minimum gray level. Along with these standard median filters has been established as reliable method to remove the "salt and pepper" noise without harming the edge features. Though, the major problem of standard Median Filter (MF) is that the filter is effective only at low noise densities.

3. Fingerprint image analysing

In the scientific literature the noise is defined as unwanted information which deteriorates image quality and usually appears during the acquiring and transferring process from different type of media or different formats. In the literature are defined two types of noise:

- gaussian noise usually resulted from the image acquisition;
- impulsive noise ("salt and pepper") usually introduced while transmitting over an unsecured channel or by acquisition as well.

The Gaussian noise is a value added to each pixel in an image or a region taken from a zero means Gaussian distribution.

"Salt and pepper" noise is caused by sharp, sudden disturbances in the image and is characterized by white isolated spots in dark areas and black pixels in wide light areas.
On the other hand, the "salt and pepper" filter can be employed before doing a Gaussian noise reduction.

4. Image filters

Filters are algorithms by a wide range used for removal of those types of noise and they are necessary not only for improving image quality but as a preprocessing phase in almost any application involving digital images (Gulhane & Alvi, 2012): encoding, pattern recognition, image compression, target tracking and so on.

The noise reduction is a two-step process: noise detection and noise reduction. In the first step the noisy pixels are being identified and in the second they are replaced by an estimated value.

The Gaussian noise removal usually is made by some classical algorithms like: blur/median filter, Gaussian filter and weight median filter.

Some of the classical algorithms of the "salt and pepper" noise reduction are (Jasim, 2013): minimum, maximum, mean, rank order, median filters.

In this paper we have used for comparing the following classical filters like: blur filter, two derivative of Gaussian filter – Laplacian of Gaussian (Log) and (LoG2), Sobel filter, Sharp filter and Gabor filters.

The results obtained after the convolution operation applied on the original images show an overall processing without taking into consideration the "local" statistics.

5. Configuring the model

The digital fingerprint images used for tests are taken with ink, they are of various dimensions and the sources of images are the databases: FVC2000[2], FVC2002[3], and FVC2004[4]. The images were cut to different sizes between 150 to 300 pixels width and height, so they are of heterogeneous dimensions.
The proposed model is structured as following:

a) design a model for filtering that consist in a set of 9 filters for: enhancement of contrast, noise removal, obtaining the "near" binary image (0 to 255) while preserving the defining details;

b) apply a fuzzy/aggregation(sum) model for automatically choose the best filter;

c) classify and rank the filters according to those criterions.

a) The set of filter algorithms
As a general principle the filtering is made overall the image and/or "locally" on smaller surfaces, chosen according to the local statistics.
In the following we denote the proposed filter algorithms with A1 to A9, elaborated with classic theory of quartiles with different levels of novelty introduced by different types of thresholds and local processing.

The formulas (1), (2) and (3) for calculating the Q1, Q2, Q3 quartiles are:

$$Q_1 = \frac{n+1}{4} \quad (1)$$

$$Q_2 = \frac{2(n+1)}{4} \quad (2)$$

$$Q_3 = \frac{3(n+1)}{4} \quad (3)$$

[2] Fingerprint Verification Algorithms, 2000, http://bias.csr.unibo.it/fvc2000
[3] Fingerprint Verification Algorithms, 2000, http://bias.csr.unibo.it/fvc2002
[4] Fingerprint Verification Algorithms, 2000, http://bias.csr.unibo.it/fvc2004

In the image processing field, the quartiles are used also for eliminating the outliers (aberrant values) and replacing them with a median value, but in this paper we would like to avoid the median value because often introduces blurring in the resulting image. The set of algorithms uses the quartiles to transform the values under or upper the quartiles Q1, Q3 (in the overall image) and the q1, q3 (in the 10X10 vicinity) in black or white, leaving the rest of pixels in greyscale or introducing other type of processing like increasing or decreasing the values of pixels in the vicinity of the quartiles or simply by locally adjust values according to the vicinity values.

A1 - uses quartile (figure 1.) which applies "locally" in small areas, usually 10x10 pixels or estimated using a sample representing approximately 40% of all image data (columns) and transform;

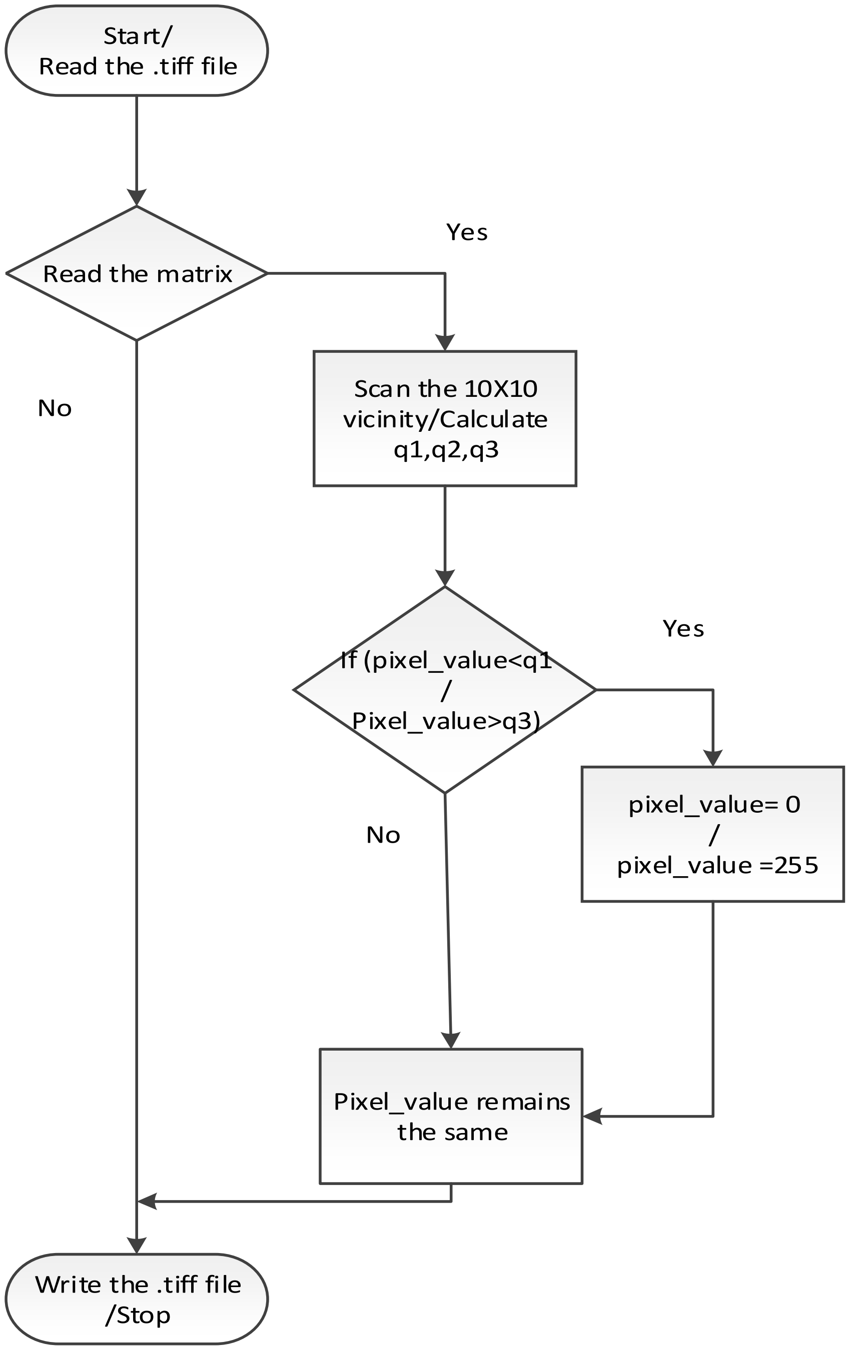


Figure 1.Algorithm A1-pseudocode

A2-uses the principle of quartiles over the entire image in conjunction with applying the quartiles calculated on small areas "locally"(Figure 2.);

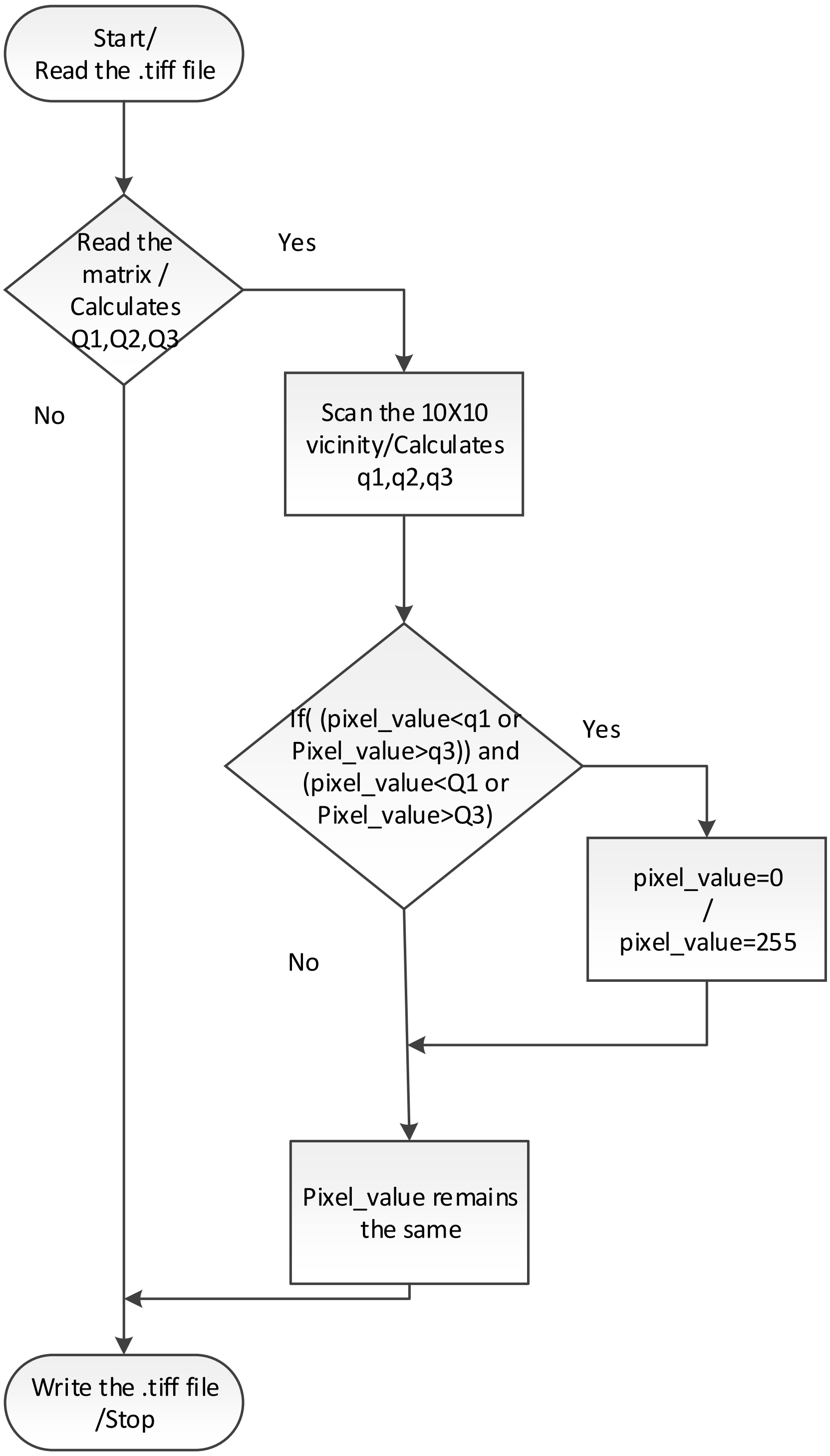


Figure 2. Algorithm A1-pseudocode

A3-is achieved by the extrapolation of the values that are "in the immediate" neighborhood of extremes (0 and 255), made in a "local" manner (Figure 3.);

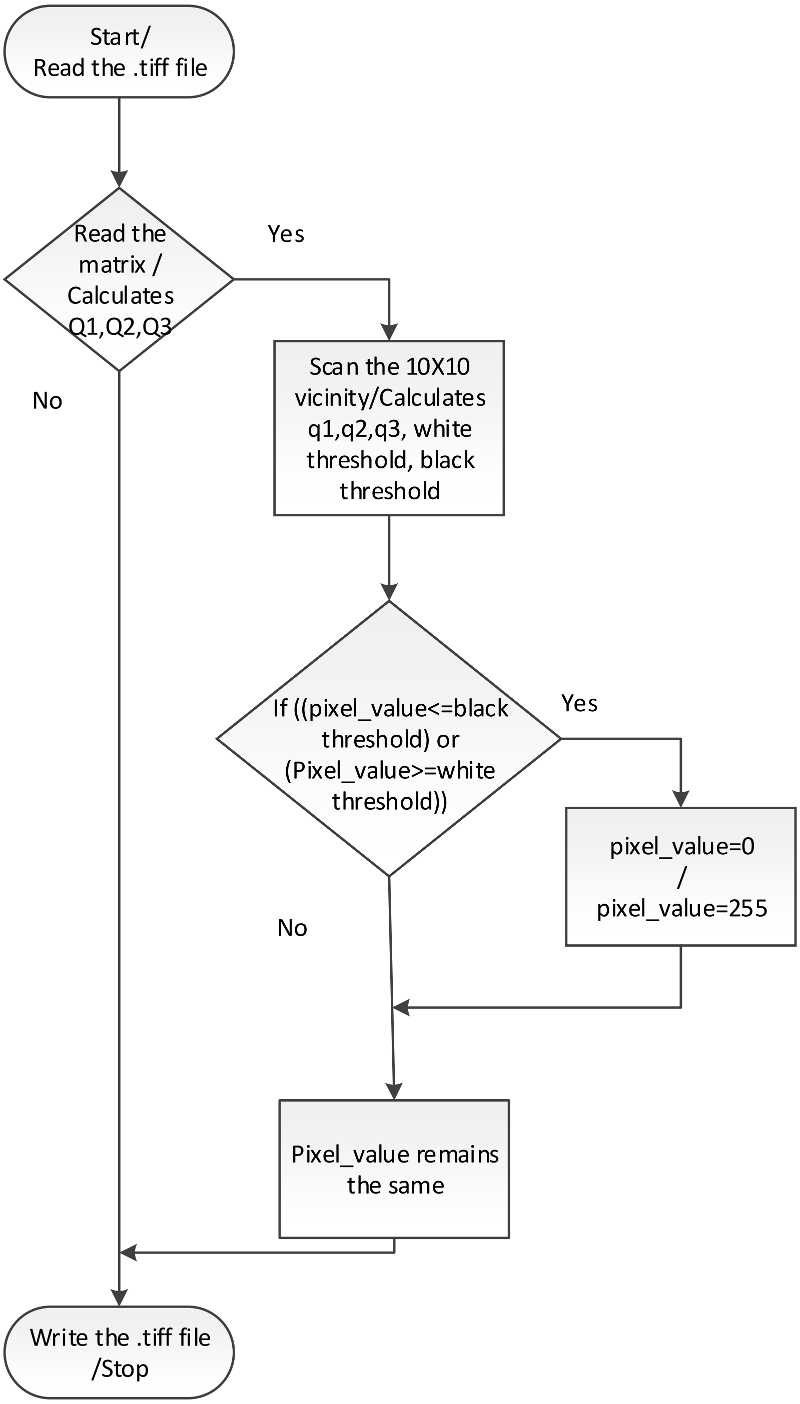


Figure 3. Algorithm A3-pseudocode

A4- uses quartiles principle applied globally, in conjunction with the thresholds referred to A3 (Figure 4.);

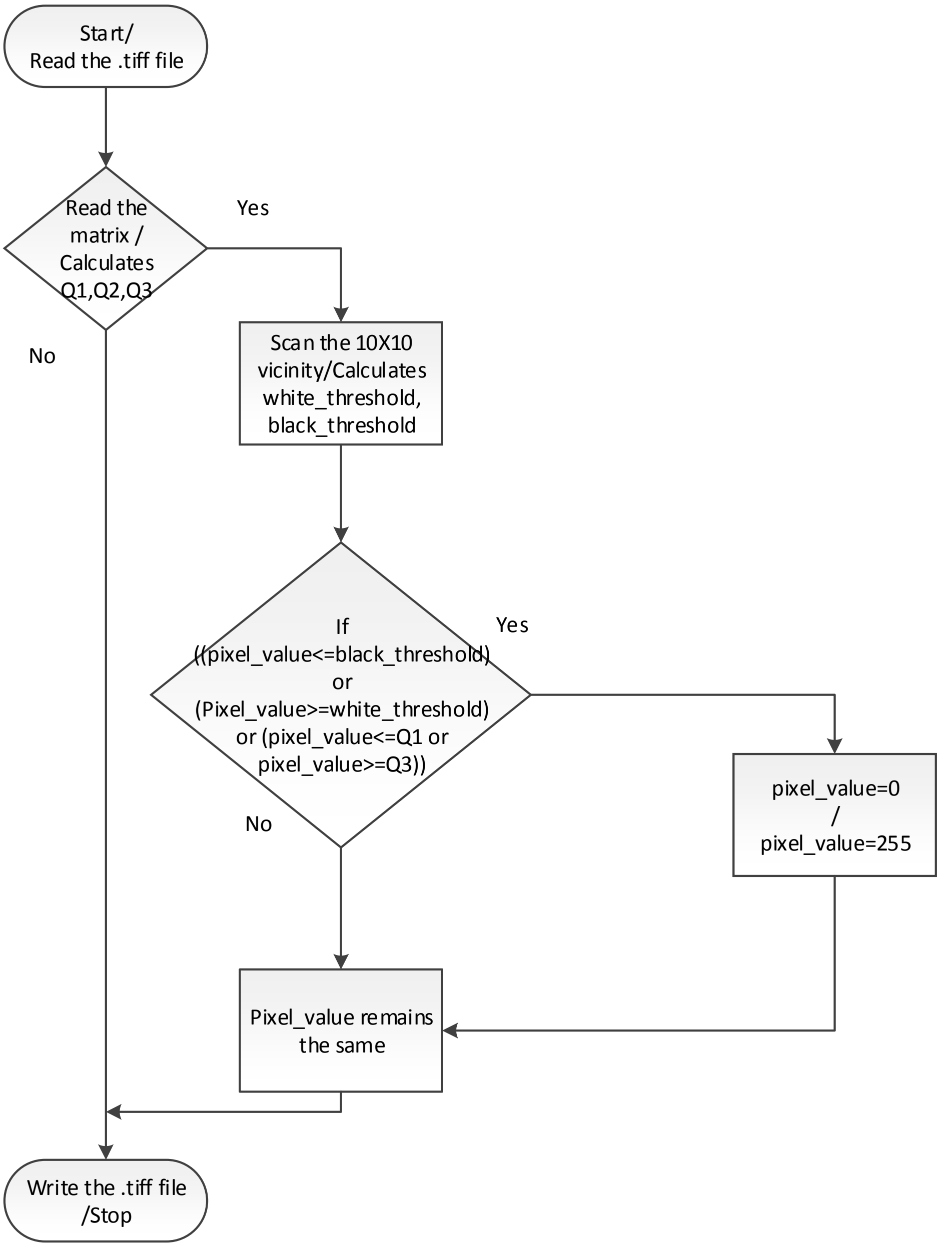


Figure 4. Algorithm A4-pseudocode

A5-apply thresholds globally across the image (Figure 5.);

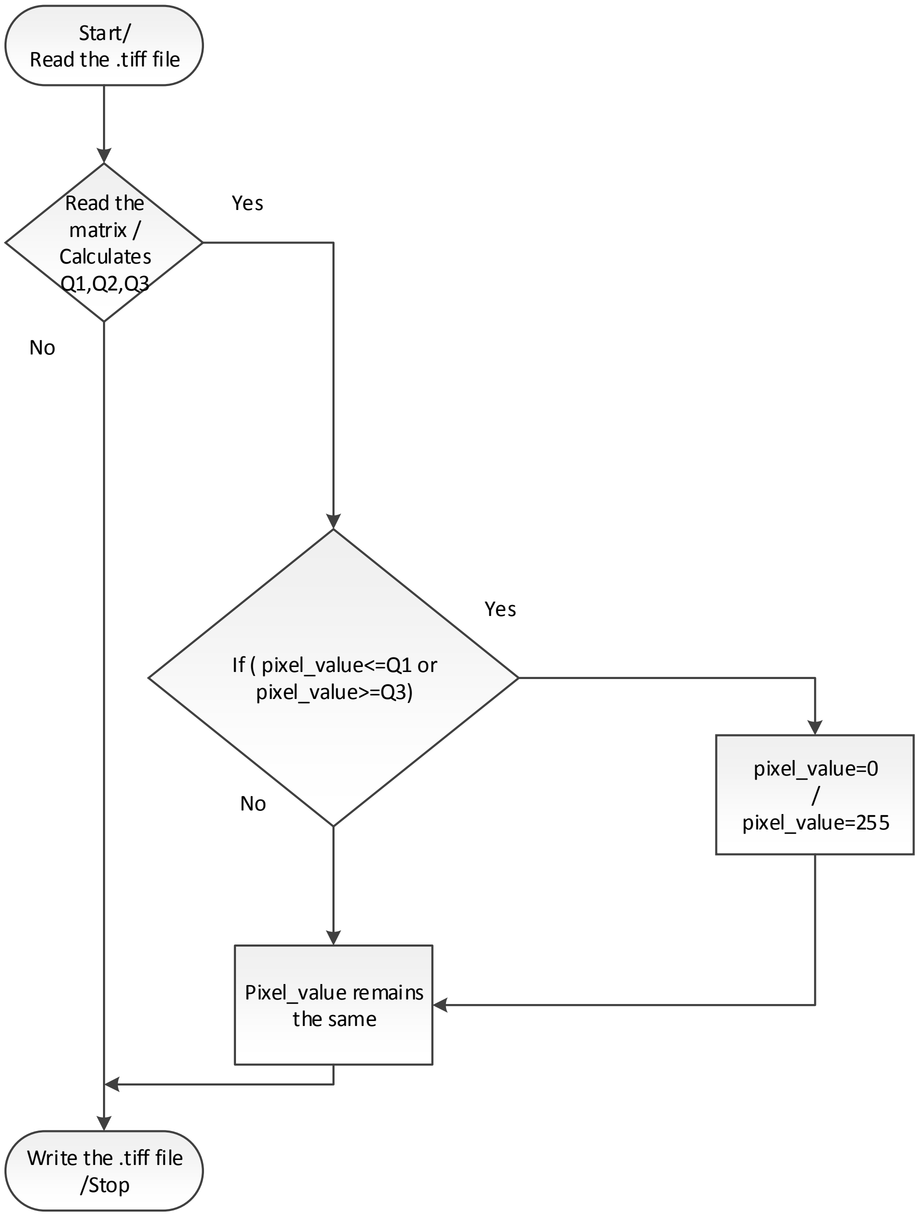


Figure 5. Algorithm A5-pseudocode

A6-the principle of quartiles applied to the entire image, using the quartiles q1 and q3 as thresholds, but the update refers only for the pixel values only if Q1 < q1 or Q3 > q3, where q_1 and q_3 are the quartiles calculated in the 10x10 pixels area (Figure 6.);

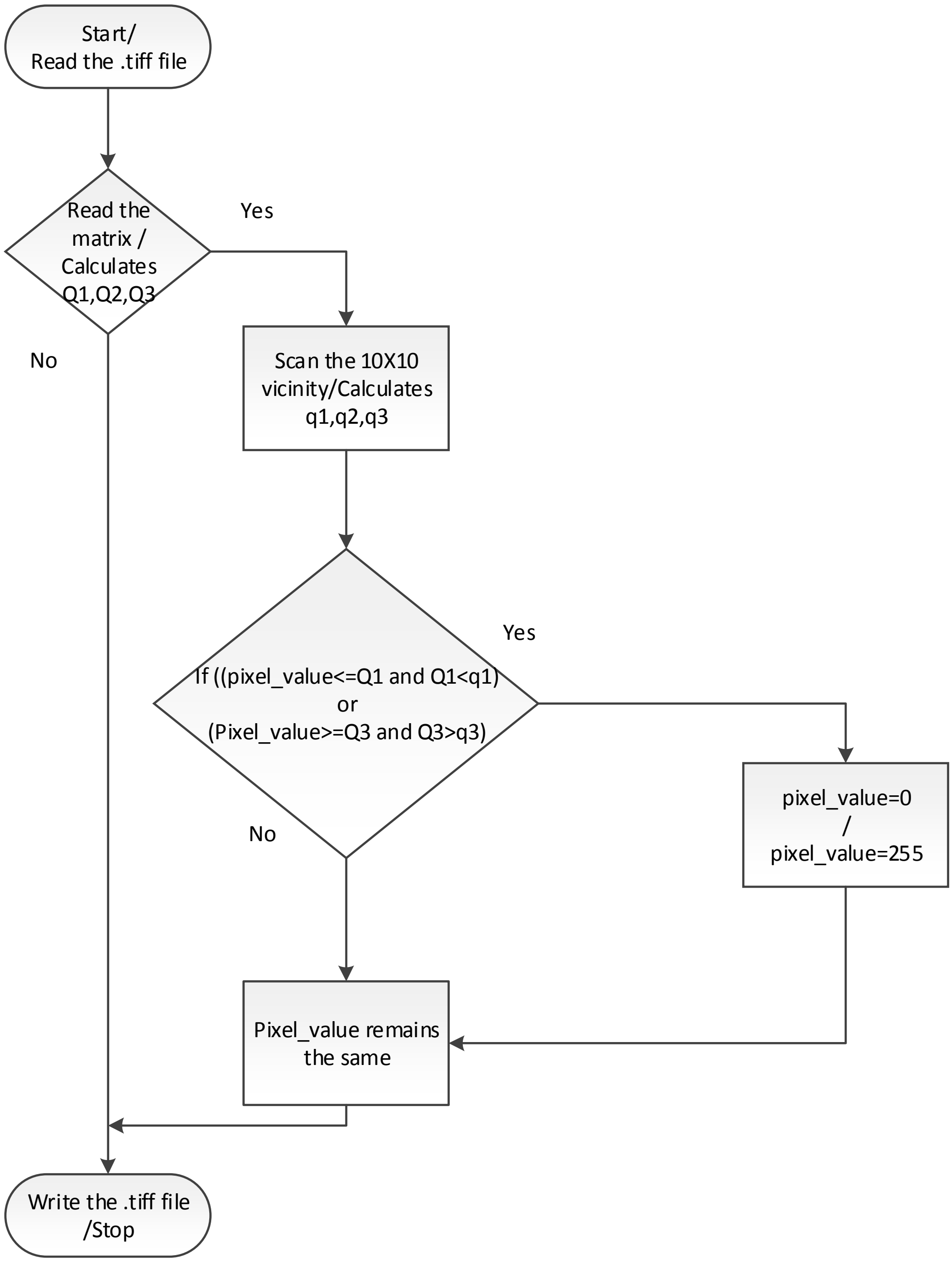


Figure 6. Algorithm A6-pseudocode

A7-applied to the entire surface using quartiles(Q1 and Q3) in conjunction with an algorithm for the processing of gray tones between Q1 and Q3 is as follows: if in addition is full field the condition that (q2 >Q2), when the initial value of the pixel is adjusted at (initial_value*(1-(q2/q1))), and on the other hand if (q2<Q2) then the value is adjusted to (initial_value*(1+q3/q2)), please see Figure 7.;

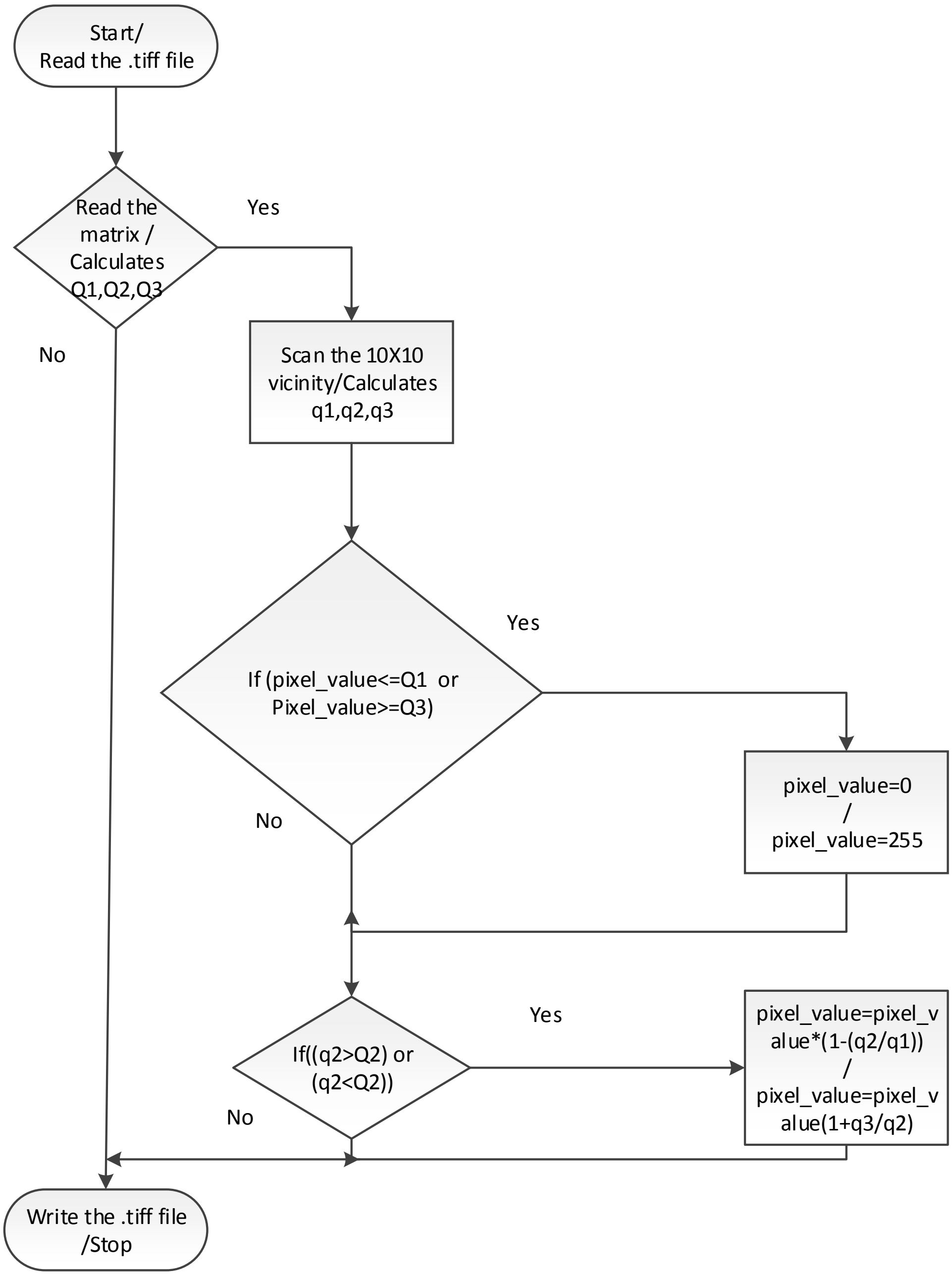


Figure 7. Algorithm A7-pseudocode

A8 - uses the principles of quartiles per global and additionally adjusts the gray tones between Q1 and Q3 as follows:

-if (q2<Q2), the pixel shall be updated with the following value (initial_value *(1.1));
-if (q2 >Q2) when the pixel value is updated with (initial_value *(0.9)), and the purpose is to bring q2(local quartile or median) as much closer as possible to Q2(2 quartile or median overall global), please see Figure 8.;

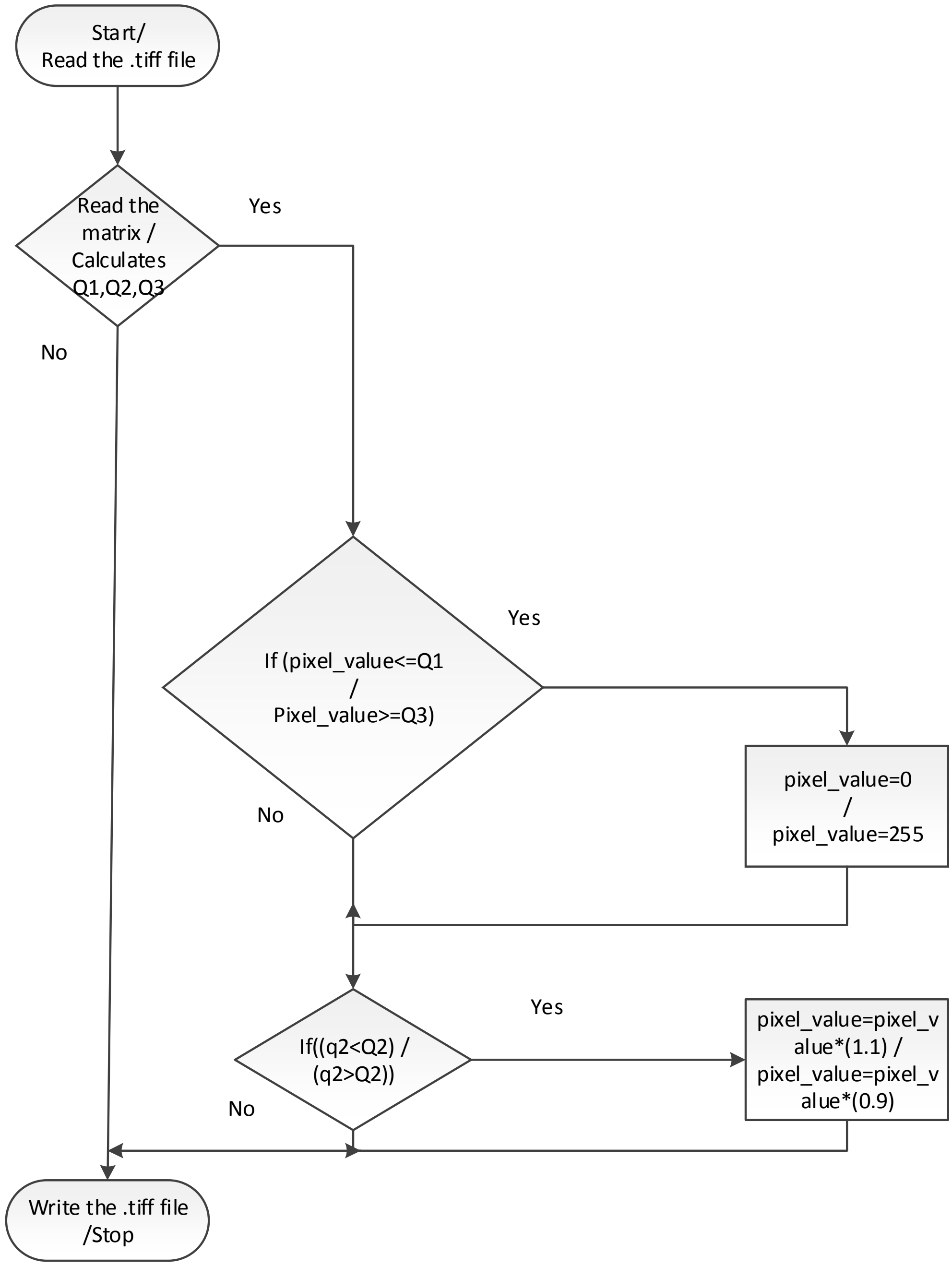


Figure 8. Algorithm A8-pseudocode

A9-the most developed algorithm provides more processing at punctual situations(Figure 19.), uses global quartiles (Q1, Q2, Q3) in conjunction with the following rules:

-if (initial_value<Q1), the initial_value=0;

-if (initial_value>Q3), then initial_value=255, and the gray values between Q1 and Q3 are using other algorithms in order to eliminate the effect of "salt and pepper" and to deal with alleged membership of a pixel to details.

This subset includes the following following situations:

-if (initial_value) is black and in its neighborhood (3x3 pixels) is only gray, then the whole neighborhood will be black;

-if (initial_value) is white and its neighborhood (3x3 pixels) is in grayscale, the whole neighborhood turns into grayscale;

-if (initial_value) is white, and the neighborhood of (3x3 pixels) are all black, then the entire neighborhood turns black;

-if (initial_value) is gray and in the neighborhood(3x3 pixels) everything is white, then turns white initial_value;

-if in the vicinity of (3x3 pixels) there are three gray neighbors and the rest white, then the middle one is white;

-if the neighborhood (3x3 pixels) three neighbors are gray and the rest white, then the middle one is white;

-if the vicinity of (5x5 pixels) is composed entirely of gray, the whole vicinity of (3x3 pixels) of the same pixel turns black;

-if in the vicinity like in the Figure 9.

m-2 255	m-1 Gre y	m Grey	m+1 Grey	m+2 Grey	m+3 255

Figure 9.Vicinity of 6 pixels for local adjustment

where m is the column the matrix corresponding to the digital image, and "Grey" is any tone between 0 and 255(exclusive),then if gray value of m is less than the value of the(m+1) column, where m is 0 and the corresponding pixel values (m-1) and (m+1) become 255 (white), as shown in figure 10.

m-2 255	m-1 255	m 0	m+1 Grey	m+2 255	m+3 255

Figure 10.Result of the local adjustment applied on figure 9.

-if in the vicinity like in the Figure 11.,

m-1 255	m Grey	m+1 Grey	m+2 255

Figure 11.Vicinity of 4 pixels

we have the gray value of m less than that of column (m+1), then the value of m is 0 and the value of (m+1) becomes 255, like in Figure 12:

m-1 255	m 0	m+1 255	m+2 255

Figure 12.Result of local adjustment applied on figure 3.

and vice versa, otherwise ;

-if in the vicinity like in the Figure 13,

m-2 255	m-1 Grey	m Grey	m+1 Grey	m+2 255

Figure 13.Vicinity of 5 pixels

tier m pixel's value is the minimum of (m-1), m and (m+1), then the value at the position m is 0 and (m-1) and (m+1) are 255, as in Figure 14;

m-2	**m-1**	**m**	**m+1**	**m+2**
255	**255**	**0**	**255**	**255**

Figure 14.Result of local adjustment applied on figure 13.

or, if the minimum value is at tier(m-1), respectively(m+1), it results like shown in Figures 15. and Figure 16.:

m-2	**m-1**	**m**	**m+1**	**m+2**
255	**0**	**255**	**255**	**255**

Figure 15.Result of local adjustment applied on figure 13. where minimum value is at tier m-1

m-2	**m-1**	**m**	**m+1**	**m+2**
255	**255**	**255**	**0**	**255**

Figure 16. Result of local adjustment applied on figure 13. where minimum value is at tier m+1

The proposed algorithms refer to two directions: suppressing the noise resulted from acquisition of the fingerprints, the Gaussian noise in filters: A1 to A8 and to "salt and pepper" reduction noise in A9.

The set of 9 filters make use of some methods like:

-thresholds for segmentation of the digital images and adapted for filters A4, A5 and A6;

-quartiles that dive ranked data set in four equal groups and they are applied on the filters: A1, A2, A4, A6, A7, A8, A9;

-selections of parameters, like in: A7, A8 and the dimension of the local neighborhood (in our case 10x10 pixels);

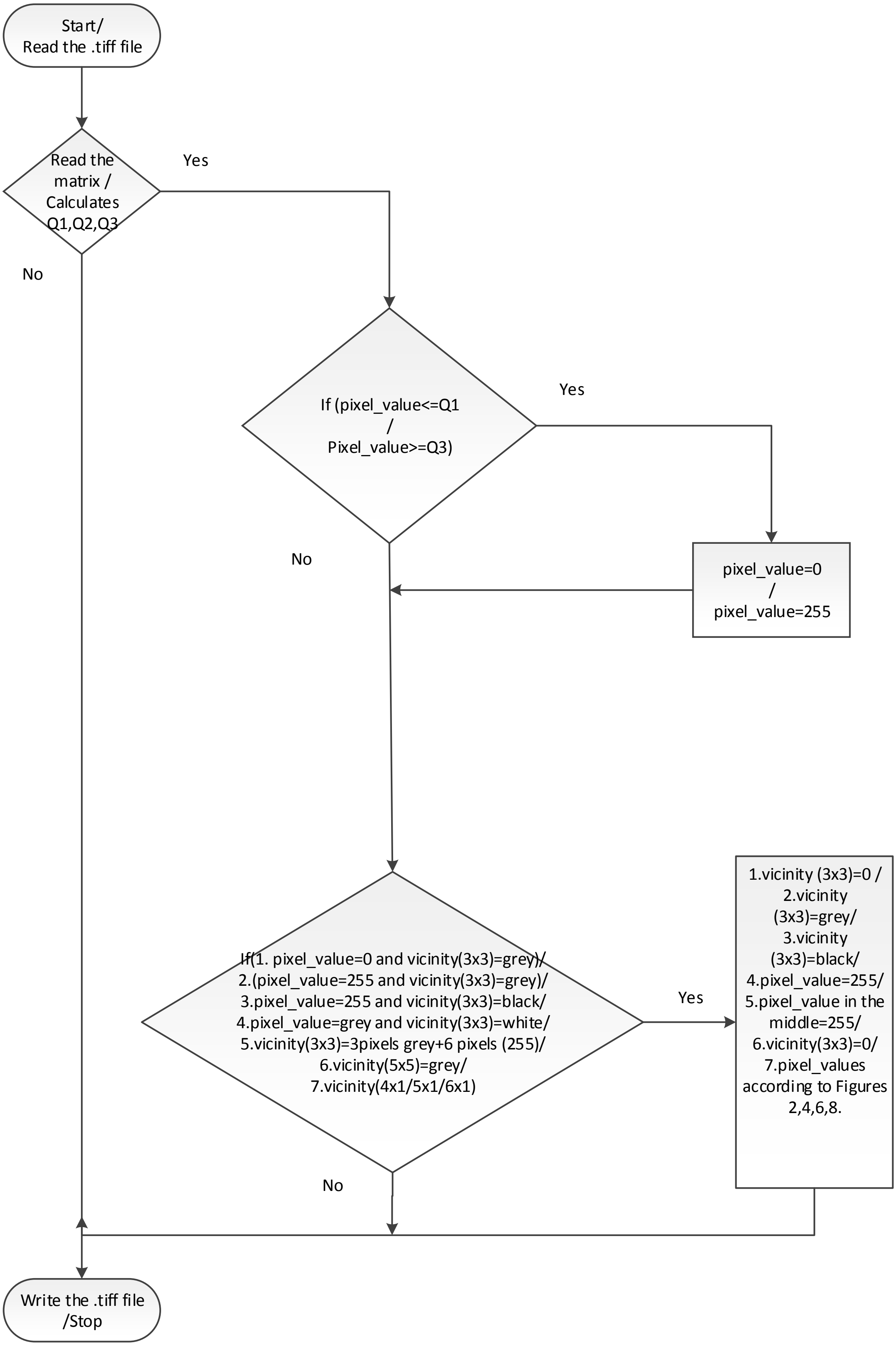


Figure 17. Algorithm A9-pseudocode

The noise and/or image quality in terms of luminosity/contrast can be realized by classical indicators like: correlation coefficient (r)[5], PSNR-Pick Signal to Noise Ratio (Huynh-Thu & Ghanbari, 2008) and RMS-Root mean square (RMS) (Sangwine & Horne, 1998), or by custom indicators and in our case they would be our custom indicators: black/white ratio (or white/black) and grey/BW ratio.

The correlation coefficient r is denoted in the equation (4) and has values in the interval [0,1] and takes into consideration two matrices: A corresponding to the original image and B correponding to the filtered images(A1 to A9), where Amn and Bmn are the elements mn from the matrix A and B and $\overline{A}$, $\overline{B}$ are the mean values of matrix A and B.

$$r = \frac{\sum_m \sum_n (A_{mn} - \overline{A})(B_{mn} - \overline{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \overline{A})^2\right)\left(\sum_m \sum_n (B_{mn} - \overline{B})^2\right)}} \quad (4)$$

MSE- Mean Square Error in formula 5, is the dominant quantitative performance metric in the field of signal processing. It remains the standard criterion for the assessment of signal quality and fidelity; it is the method of choice for comparing competing signal processing methods.

$$MSE = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}[A(i,j)-B(i,j)]^2}{M*N} \quad (5)$$

where M, N, i, j, are the width, height of the image, i, j are the pixel positioning coordinates, and A, B are the original and processed matrix.

PSNR - Pick Signal to Noise represents the maximum possible power of a signal and the power of corrupting noise that affects the quality of the images. PSNR is expressed in terms of the logarithmic decibel scale and is computed after the formula 6:

$$PSNR = 10 * \log 10\left(255^2 \middle| \sqrt{MSE}\right) \quad (6)$$

In our case PSNR will be used as an indicator of the useful/noise ratio in the fingerprint images and our optimization process seeks for the higher scores relatively to this indicator.

Root mean square (RMS) contrast does not depend on the spatial frequency content or the spatial distribution of contrast in the image. RMS contrast is defined as the standard deviation of the pixel intensities, like in the formula 7:

$$RMS = \sqrt{\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}(I_{ij} - \bar{I})^2}{MN}} \quad (7)$$

where intensities I_{ij} are the i-th j-th element of the two-dimensional image of size M by N, $\bar{I}$ is the average intensity of all pixel values in the image and the image I is normalized in the range of [0,1].

The two custom indicators we propose derive from our specific objectives: a balanced black and white image (BW ratio) and on the same time a small grey quantity of pixels(grey/BW):

-BW ratio is defined an a sub unitary ratio of the total number of black pixels and total number of white pixels and as closer is to 1 the filtered image is nearly “binarized” in black and white;

-grey/BW ratio is a fraction between total number of grey pixels to total number of black plus white pixels and is preferably to be as small as possible to serve the same scope like the BW ratio.

b) The fuzzy/aggregation (sum) model for automatically selection of the best filter

Based on a single indicator it is impossible to make clear delimitation in terms of low correlation or high luminosity (RMS) or a clear level of noise. Even there are used more indicators a

[5] Mathworks documentation, http://www.mathworks.com/help/images/ref/corr2.html

direct comparison does not gave an appropriate result, more indicators for all the algorithms are provided in the Table1, as follows:

Table 1. Classical and custom indicators of noise for some of the filtered images

Image/ Filter	Black/White Ratio(BW)	RMS	PSNR	Grey/ BW	Distance Grey/BW	Distance PSNR	Distance RMS	Sum	Best Sum	Distance Manhattan	Best Fuzzy
1/1	0.8965	0.8990	0.9109	0.5608	1.4000	0.1000	0.5000	3.8665	0	3.7800	1
1/2	0.4273	0.9232	1.0000	1.0000	1.4000	0.1000	0.5000	3.6360	0	3.7800	1
1/3	0.2048	0.3986	0.7792	0.0225	1.4000	2.0000	0.5000	2.3889	0	6.6800	0
1/4	0.5405	0.9183	0.9802	0.9007	1.4000	0.1000	0.5000	3.6962	0	3.7800	1
1/5	0.6481	0.8942	0.9087	0.4077	1.4000	0.1000	0.5000	3.5674	0	3.7800	1
1/6	0.4273	0.9232	1.0000	1.0000	1.4000	0.1000	0.5000	3.6360	0	3.7800	1
1/7	0.8682	1.0000	0.8888	0.5454	1.4000	0.8000	0.5000	3.9127	1	4.4800	0
1/8	0.6481	0.9100	0.9062	0.4077	1.4000	0.1000	0.5000	3.5807	0	3.7700	0
1/9	0.6117	1.0000	0.8888	0.3813	1.4000	0.8000	0.5000	3.6093	0	4.4800	0
2/1	0.9750	0.8834	0.9212	0.2845	1.4000	0.1000	0.5000	3.8608	1	3.6800	1
2/2	0.5565	0.9117	1.0000	0.4551	1.4000	0.1000	0.5000	3.5981	0	3.7800	0
2/3	0.3694	0.5796	0.8182	0.0119	1.4000	0.8000	0.5000	2.7705	0	5.4800	0
2/4	0.6035	0.9080	0.9885	0.4315	1.4000	0.1000	0.5000	3.6232	0	3.7800	0
2/5	0.9154	0.8797	0.9361	0.2489	1.4000	0.1000	0.5000	3.8022	0	3.6800	1
2/6	0.5565	0.9117	1.0000	0.4551	1.4000	0.1000	0.5000	3.5981	0	3.7800	0
2/7	0.8559	1.0000	0.9030	0.3252	1.4000	0.1000	0.5000	3.8517	0	3.7800	0
2/8	0.9154	0.8660	0.9322	0.2489	1.4000	0.1000	0.5000	3.7846	0	3.6800	1
2/9	0.8340	1.0000	0.9030	0.2198	1.4000	0.1000	0.5000	3.7997	0	3.7800	0
3/1	0.0685	0.7115	0.8882	0.1419	1.4000	0.8000	1.7000	2.8083	0	6.6800	0
3/2	0.4081	0.6080	0.9994	0.9978	1.4000	0.1000	0.5000	4.0009	0	3.7800	1
3/3	0.0282	0.2722	0.8596	0.0028	1.4000	0.8000	0.5000	2.1627	0	5.4800	0
3/4	0.1678	0.6029	0.9873	0.4435	1.4000	0.1000	0.5000	3.1960	0	4.7800	0
3/5	0.0742	0.6734	0.9399	0.1606	1.4000	0.1000	0.5000	2.8461	0	4.7800	0
3/6	0.4093	0.6081	0.9996	1.0000	1.4000	0.1000	0.5000	4.0045	1	3.7800	1
3/7	0.1569	0.6612	0.9438	0.4131	1.4000	0.1000	0.5000	3.1698	0	4.7800	0
3/8	0.0742	0.5299	1.0000	0.1606	1.4000	0.1000	0.5000	2.7627	0	4.7800	0
3/9	0.0588	0.6612	0.9438	0.1096	1.4000	0.1000	0.5000	2.7720	0	4.7800	0
4/1	0.4280	0.7518	0.7881	0.1034	1.4000	2.0000	1.7000	3.0699	0	6.8800	0
4/2	0.8121	0.6992	0.9914	0.2755	1.4000	0.1000	0.5000	3.7747	0	3.7800	0
4/3	0.1707	0.4260	0.7323	0.0016	1.4000	2.0000	0.5000	2.3305	0	6.6800	0
4/4	0.9332	0.6903	0.9041	0.2283	1.4000	0.1000	0.5000	3.7530	0	3.6800	1
4/5	0.5894	0.7124	0.9456	0.1519	1.4000	0.1000	0.5000	3.3974	0	3.7800	0
4/6	0.8090	0.6996	1.0000	0.2762	1.4000	0.1000	0.5000	3.7813	1	3.7800	0
4/7	0.8814	0.9241	0.7528	0.2186	1.4000	2.0000	0.5000	3.7741	0	5.6800	0
4/8	0.5894	0.6900	0.9405	0.1519	1.4000	0.1000	0.5000	3.3699	0	3.7800	0
4/9	0.3759	0.9241	0.7528	0.0853	1.4000	2.0000	0.5000	3.1370	0	6.6800	0

As a consequence the indicators of fuzzy logic (Oussalah, Alakhras & Hussein, 2015) and the statistical considerations, like weighted sum are very suitable for solving the decision problems:

"How to automatically choose the best filter?" or "How to classify these resulting images according to different criterions?".

The implementation stages of a fuzzy selection can be defined as following:

- Identifying the inputs and outputs;
- Define the universe of discussion, variables, linguistic values, affiliation function;
- Inference methods;
- Implementing the model;
- Testing, performance evaluation;
- Return to previous stages if necessary.

Our fuzzy decision would be: determining the preferred/best filter in terms of "good quality".
Stages of the selection process:

- Elaborate the set of factors used for selection;
- Define the ideal profile of the filter;
- Construct each filter profile;
- Determine a matrix of distances to the ideal filter;
- Select the filter

Evaluation factors are: correlation, BW ratio, grey/BW ratio, PSNR, RMS.
The linguistique values of the utilized factors are for each of them: S-small(low), M-medium(medium) and H-high(high).
The ideal filter profile compared to the requirements is defined as follows:

1. Correlation >0.90 and the values of factors corresponding would be: S=(0;0.90), M=(0.9;0.98), H=(0.98;1);
2. BW ratio =1 and the values of factors for this criteria are: S=(0;0.40), M=(0.4;0.80), H=(0.80;1);
3. Grey/BW =0 and the values for the factors would be: S>0.9, M =(0.4;0.90) and H=(0, 0.4);
4. PSNR as high as possible but it is transformed in the range of [0,1] and the best value will be PSNR=1 and as a consequence the factors would be like: S=(0;0.90), M=(0.9;0.98), H=(0.98;1);
5. RMS like the previous factor it desirable to be as high as possible (=1) because it is transformed in the [0,1] range and the values of factors occupy the same range: S=(0;0.10), M=(0.1;0.90), H=(0.90;1).

The fuzzy set of requirements for qualifying as a candidate for the best filter are defined as follows:

1. Correlation={0.1/S;0.9/M;1/H};
2. BW={0.1/S;0.9/M;1/H};
3. Grey/BW={1/S;0.3/M;0/H};
4. PSNR={0/S;0.8/M;1/H};
5. RMS={0/S;0.9/M;1/H}.

The fuzzy set for each factor can be described like:

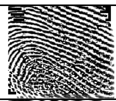
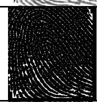
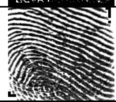
1. Correlation: S={1/S;0.9/M;0/H},
M={0.5/S;1/M;0.5/H}; H={0.1/S;0.9/M;1/H};
2. BW ratio: S={1/S;0.7/M;0.3/H}; M={0.2/S;1/M;0.7/H};H={0.1/S;0.8/M;1/H};
3. Grey/BW: S={0/S;0.3/M;1/H}; M={0/S;0.1/M;0.9/H}; H={1/S;0.2/M;0.1/H};
4. PSNR: S={1/S;0.9/M;0/H}; M={0.5/S;1/M;0.5/H}; H={0.1/S;0.9/M;1/H};
5. RMS: S={1/S;0.9/M;0/H}; M={0.5;S;1/M;0.5/H}; H={0.1/S;0.9/M;1/H};

Evaluation through natural language of the filter A1: correlation=H; BW=S; grey/BW=S; PSNR=H; RMS=H. Starting from those values we further construct the affiliation degree of each linguistic value according to the universe of discussion defined relatively to the ideal profile of filters. The distance between each indicator and the ideal value are summed and the smaller gives the best filter.

For determining the final decision we can use a variety of distances: Euclidian, Minkowski, Pearson, Mahalanobis but for our case we used the Manhattan distance and the results are shown in the Table1.

On the aggregation model the indicators are summed as a simple or weighted operation of some normalized indicators: correlation (not very relevant in this case because is very similar), black/white ratio, grey to black/white ratio, PSNR, RMS and the highest represents the best choice. Some results corresponding to 32 images and 9 filters are depicted in the Table 1 and in the Table 2. is shown a selection of filtered images.

Table 2. Selection of filtered images with the 9 algorithms and the 2 methods of classification

Algorith	Image 1	Fuzzy	Sum	Image 2	Fuzzy	Sum	Image 3	Fuzzy	Sum	Image 4	Fu	Sum
A1		✓				✓		✓				
A2		✓			✓							
A3												
A4		✓									✓	
A5		✓			✓			✓				
A6		✓							✓			✓
A7			✓									
A8					✓			✓				
A9												

c) The classification stage

The classification (Malik, Gautam, Sahai, Jha & Singh, 2013) and ranking stage can be visualized in the Figure 19, the summary of the filtered images is shown in Table 3 and the pseudocode of the current step can be visualized in Figure 18. The overall results show that the two selection criterion: fuzzy and aggregation indicate that the most efficient algorithm is A6 and according to each criterion there can be made certain decisions to choose the best filters for each situation. Also, the results are influenced by the parameters set to calibrate the filtering, the fuzzy profiles, the weighted sum or the vicinity approach.

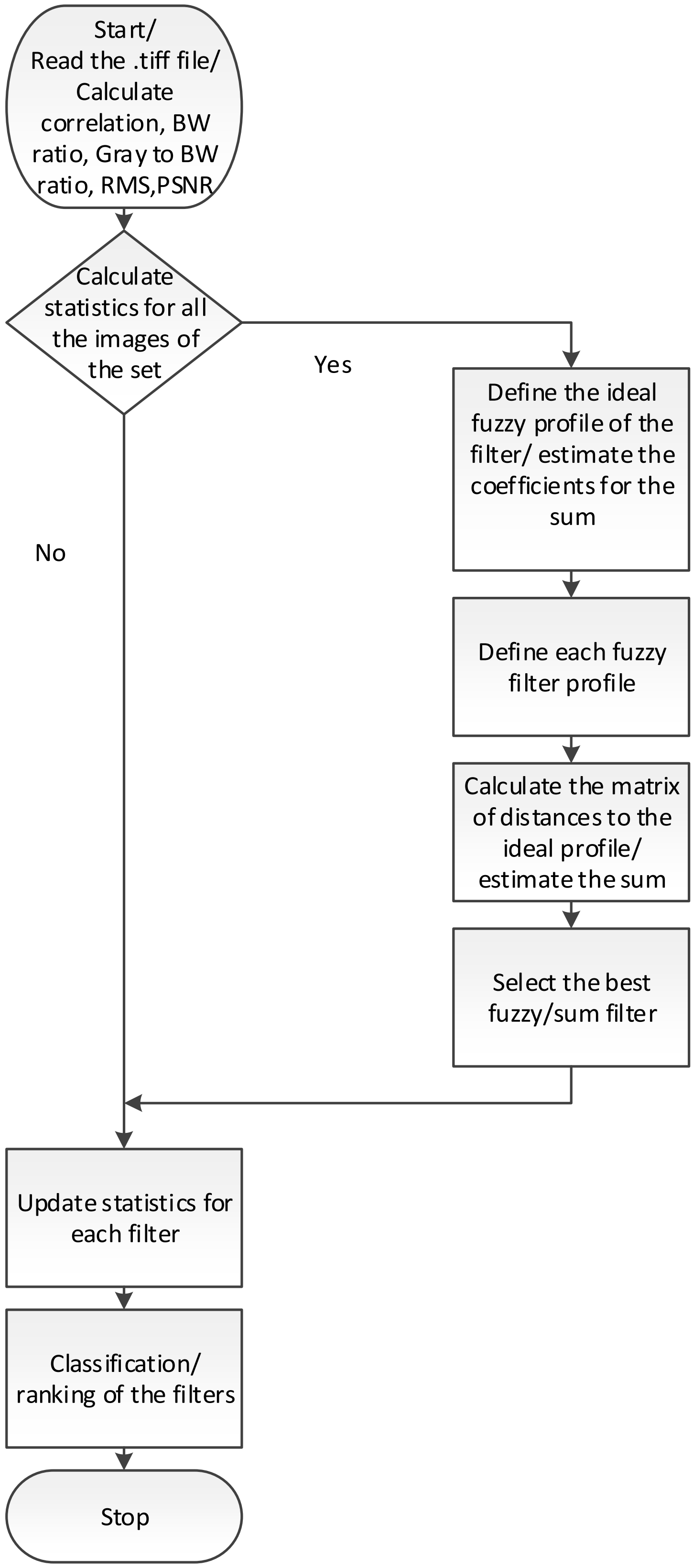


Figure 18. Classification/ranking algorithm-pseudocode

Table 3. Sumary of the filtered images with the 9 algorithms and the 2 methods of classification

Filters/Algorithms	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
Fuzzy	5	20	1	14	20	20	5	20	7
Sum	1	4	2	3	2	11	5	1	6

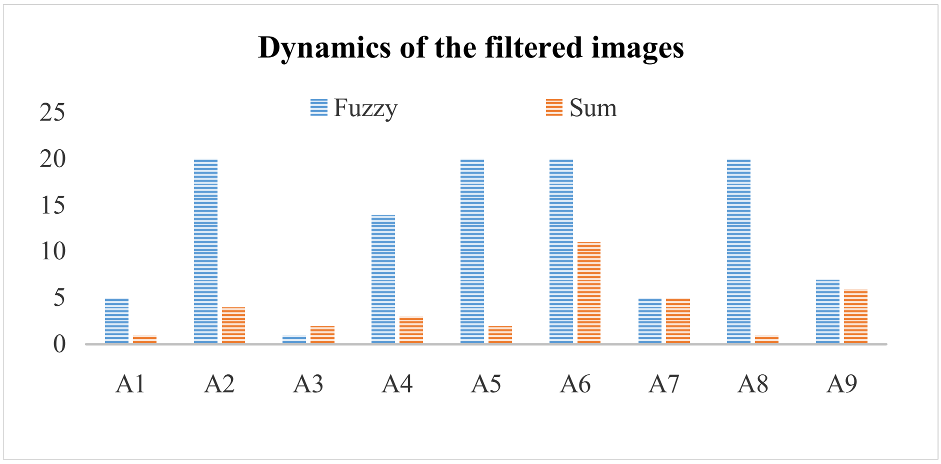


Figure 19. Dynamics of the filtered images with the 9 algorithms and the 2 methods of classification

Conclusions

Designing the model involved three major steps: defining the set of filters customized for our set of fingerprint images, defining the tools for the automatic selection of the best filter in each case and finally the classification after processing a set of images. In the annex were revealed in part the result of each filter and there evaluation and choosing the image that will be used in subsequent stages of research within the meaning of automating the entire process of identification based on fingerprints. As a continuation of the automation process there is intended to estimate the fuzzy and statistical parameters with more sophisticated methods like neural networks.

Acknowledgements

This work was possible with the financial support of the sectorial operational program for human resources development 2007-2013, co-financed by the European social fund, under the project number POSDRU/**159/1.5/S/132400** with the title „Young researchers of success – professional development in the interdisciplinary and international context".

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