Journal of Information Hiding and Multimedia Signal Processing ©2015 ISSN 2073-4212
Ubiquitous International Volume **6**, Number **5**, September **2015**

Use of Mean Square Error Measure in Biometric Analysis of Fingerprint Tests

Janusz Kowalski
Faculty of Medicine, Biotechnology and Laboratory Medicine
Pomeranian Medical University
Rybacka St. 1, Szczecin, 70-204, Poland
janus@sci.pum.edu.pl

Jakub Peksinski and Grzegorz Mikolajczak
Department of Electrical Engineering
West Pomeranian University in Szczecin
26 Kwietnia St. 10, Szczecin, 71-126, Poland
jpeksinski@zut.edu.pl; gregorm@zut.edu.pl

Received March, 2014; revised May, 2015

Abstract. *The article presents the possibility of using digital image processing methods for the identification of fingerprints. The presented method uses an objective criterion for evaluating the quality of the processed digital images, which is the Mean Square Error MSE. The value of this ratio significantly depends on the image content allowing you to use it for comparison with the reference image contained in the database. This indicator may be susceptible to various disturbances occurring in the process of obtaining a fingerprint - shift and rotation. For this reason, it proposed the modified method of use of the indicator. The modification consists of adjusting the image obtained by the image within the database, using an algorithm based on finding shifting and angle of rotation. In order to improve of certainty testing used to identify the MSE, in the image is divided into segments. The results indicate the great effectiveness of the proposed method.*
Keywords: Adjustment of data, Biometry, Mean Square Error

---

1. **Introduction.** From time immemorial, people have sought to discover methods that will clearly allow, without raising any doubt, to identify a person on the basis of certain characteristics. Such identification can be done using a variety of methods. Among current methods of identification we can distinguish the following groups:

- methods of using knowledge about a given person;
- methods of comparing unique features that each person has.

The first group includes all methods that use of alpha-numeric string, such as passwords, PIN codes, etc., where these strings are known to only one person. The second group includes methods that use techniques of analysing biological characteristics of the individual, so-called biometric parameters. Biometric techniques base their action on the analysis of the unique characteristics possessed by each person.

The basic methods of identification using biometric techniques include [5] the tests of: fingerprints, hand geometry, face geometry, retina, iris, DNA.

Nowadays, a popular and frequently used method for biometric analysis is to compare fingerprints. Each person has a unique pattern of the ridge. This pattern consists of the distinctive elements such as [5, 8]:

Minutiae, Set of friction ridges, Pore distribution, Pore shape, Friction ridge shape.

In the article, the authors main objective is to find a simple and effective method for fingerprint identification. To do so, they apply methods and algorithms commonly used in digital image analysis and processing. The digital image processing as a scientific discipline covers a range of issues starting from digital image registration, through its processing, analysis and archiving, ending with displaying it on the screen, phone, etc. [1].

The wide range of issues referring to digital image processing mentioned above includes:

- digital image quality assessment;
- issues related to geometric transformations in the image included in the category of dot transformations.

The authors pay attention to these two types of issues as in the article, in order to achieve the desired objective of identifying the person on the basis of fingerprint, the following measures have been used:

(1) Popular and commonly used digital image quality measure called Mean Square Error MSE [2, 3, 4] which is formulated in Equation (1).

$$MSE = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}\left[f_{in}(x,y) - f_{out}(x,y)\right]^2}{M \cdot N} \tag{1}$$

where: $f_{in}(x,y)$ - original image, $f_{out}(x,y)$ - processed image, $M \cdot N$ - resolution

The above quality measure is only one of many existing comparison criteria for evaluating the quality of digital images using the reference image. However, after its analysis it can be easily seen that the numerical value of this measure significantly depends on the content of the image. Therefore, it is very important as it can be used to compare images using the reference image.

The reference image, in our case, is a picture of a persons fingerprint, obtained in the process of scanning, which will be put in the database.

The above measure belongs to a group called objective measures of quality, i.e. it generates a number whose value reflects the effectiveness of the tested algorithm or matching images. Using the objective measures is possible due to the ease to combine the optimized image processing with the quality of the results.

(2) Operations of geometric transformations performed on digital images include:

- Image shifts (translation) described by the Equation (2).

$$x_n = x_0 + 1 \quad y_n = y_0 + 1 \tag{2}$$

  where: x_0, y_0 - old coordinate of image; x_n, y_n - new coordinate of image.
- Image rotation at a given angle described by the Equation (3).

$$\begin{cases} x_n = A + (x_1 - A)\cdot\cos(\alpha) - (y_1 - B)\cdot\sin(\alpha) \\ y_n = B + (x_1 - A)\cdot\sin(\alpha) - (y_1 - B)\cdot\cos(\alpha) \end{cases} \tag{3}$$

  where: x_0, y_0 - old coordinate of image; x_n, y_n - new coordinate of image; A, B - rotation point; α - rotation angle.

2. **The possibility of using MSE measure to identify a person on the basis of a fingerprint.** In order to demonstrate the efficiency of the MSE measure and its possible use in the process of identifying a person basing on a digital photo of fingerprint, the authors provide the following example.

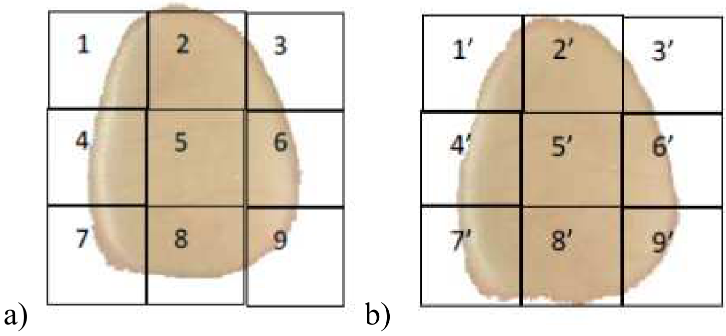

FIGURE 1. Fingerprint a) pattern stored in the database, b) obtained from a scanner

Example 2.1. *The figure 1 below shows the digital image of the fingerprint obtained from a scanner. The image is scanned at a resolution of 200 dpi. The images have been divided into segments from 1 to 9. Each of the segments of image "a" has its counterpart in the image "b". They form pairs 1-1 ', 2-2', etc.. Each segment has the same size and is located exactly at the same spot on the plane of X and Y.*

In order to determine the efficiency of the MSE measure, fingerprints from images A and B have been compared using the MSE criterion. The comparison has been made in two ways:

2.1. **Method 1.** The first method consisted in an overall comparison of the images using MSE measure. Sample measurement results are shown in Table 1.

TABLE 1. Results of MSE measure for the example 1 method 1

Pairs of fingerprints A and B	Fingerprints of the same person	MSE measure
Pair 1	No	127.3
Pair 2	Yes	12.3
Pair 3	Yes	3.1
Pair 4	Yes	5.2
Pair 5	No	117.9
Pair 6	No	198.1
Pair 7	Yes	7.8
Pair 8	Yes	2.8
Pair 9	No	79.1
Pair 10	No	278.12

Analyzing the results of MSE measure shown in the Table 1, it can be concluded that the applied measure confirmed its effectiveness. While comparing ingerprint images belonging to one and the same person the values of the measure were small and ranged from 0.5 to 12.3, whereas in case of comparing images representing he fingerprints belonging to different people the values of the measure were clearly much bigger and ranged from a few dozen to several hundred.

2.2. **Method 2.** The second method consisted in making a comparison by applying MSE measure to individual segments 1-1 ', 2-2' and so on. The measurement results for a pair of images 1, 2, 3, 5 of the Table 1 have been shown in Table 2.

Analyzing the sample results presented in Table 2 we can see that the method 2 is as effective as the method 1, and the results obtained correlate with the results shown in

Table 2. Results of MSE measure for the example 1 method 2 for pairs 1, 2, 3 and 5 where fingerprints belonging to different people

Number of segment	MSE measure result for pair 1	MSE measure result for pair 2	MSE measure result for pair 3	MSE measure result for pair 5
1-1’	27.1	27.9	2.3	123.9
2-2’	12.9	17.3	1.9	97.8
3-3’	376.3	16.4	3.1	111.4
4-4’	273.4	6.5	2.1	78.3
5-5’	56.2	1.2	1.2	67.4
6-6’	231.4	4.3	1.4	87.3
7-7’	245.5	9.9	3.1	94.0
8-8’	97.0	9.7	2.0	72.1
9-9’	453.4	11.0	1.9	119.9

Table 1. If the results are the same, why do the authors divide the image into segments which significantly lengthens the time needed to compare the tested images representing a fingerprint of a person? The reason for this is that, compared to the first method, the second method has as important advantage, namely it gives more control measurements on the basis of which we can make an analysis of the fingerprint.

This is particularly important, for example, when a person has a scar or blemish on the analyzed finger, and the scar appeared only after the registration of the fingerprint in the database. The scar has a significant influence on the value of MSE measure. The problem has been illustrated in the example 2.

Example 2.2. *The figure 2 below shows the fingerprint of the same person. However, the figure 2b shows a flaw which does not appear in the reference image in the Figure 2a.*

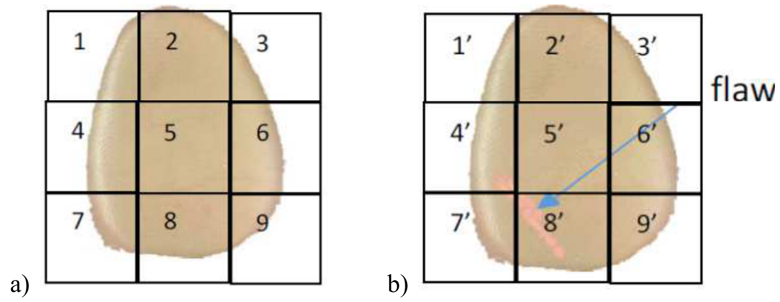

Figure 2. Fingerprint a) original image, b) image with flaw

Using a comparing method 1 (overall) the result of MSE measure is as follows:

$$MSE = 458.1$$

Such a result proves that examined the fingerprints belong to different people. Using a comparing method 2 (partial), we obtain the following results os the MSE measure for the individual segments as shown in Table 3.

Analyzing the results from the Table 3, it is clear that in the segments where there is a flaw (segments 4’, 7’, 8 ’) the measure result is clearly high, and in the segments where there is a flaw it is low.

Therefore, in order to identify fingerprints using the MSE measure the authors recommend the use of the method No. 2 (partial) as it gives you a lot more points of

TABLE 3. Results of MSE measure for the example 2, where compared pairs a and b in figure 2

Number of segment	MSE measure result
1-1'	2.3
2-2'	1.9
3-3'	3.1
4-4'	67.9
5-5'	1.2
6-6'	1.4
7-7'	78.9
8-8'	46.8
9-9'	1.9

measurement so that the results are more reliable in comparison to the overall measurement. Dividing the image into a large number of segments by using the method 2 allows to better identify a person regardless of any scars on the tested finger. The example above confirmed the effectiveness of the MSE measure whose comparative properties can be successfully used in the identification of people on the basis of fingerprint analysis.

However, in order to successfully apply the MSE measure to identify people, it is necessary to eliminate its major drawback which has a significant impact on the value of its results namely, the MSE measure result is strongly dependent on the shift of the tested images in relation to each other. The situation has been illustrated in the example 3.

Example 2.3. *The following figure shows a digital image of the fingerprint of the same person. The fingerprint of the Figure 3b was artificially moved at a few pixels (-3 in the X direction and -2 in the Y direction) with respect to the image 2a. The shift can be barely noticed. You can see it by making the subtraction of two images one from another. The shift difference between the Figure 3a and 3b has been presented in the Figure 3.*

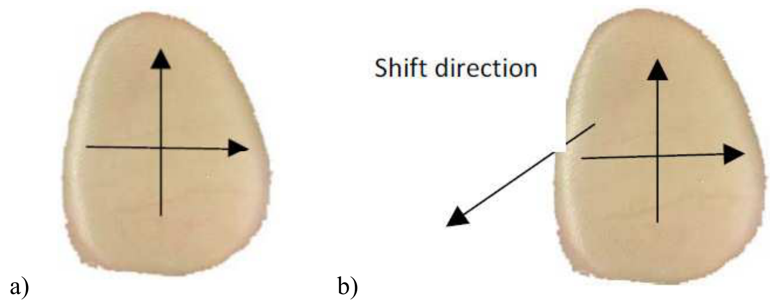

FIGURE 3. Fingerprint a) original image b) image shifted at a few pixels

This small difference in the position of the tested images representing a fingerprint has a significant impact on the MSE measure result. As the measured data listed in Table 1 show, in case of the same images the measure result should oscillate within a few possible ones, but the MSE measure result for images shown in Figure 3 is as follows:

$$\text{MSE} = 111.6$$

which would mean that the two fingerprints are different and belong to two different people and which is not true because they belong to the same person but their positions have been shifted in relation one to another at a few pixels.

Figure 4. Shift difference between the image 3a and 3b

The impact of the shift on the MSE measure result has been presented in sample results of experimental studies in the Table 4. All the shifts have been made artificially for experimental purposes.

Table 4. The impact of the shift on the MSE measure result

Pairs of fingerprints A and B	Shift X	Shift Y	MSE measure result before shift	MSE measure result after shift
Pair 1	-1	0	6.1	25.6
Pair 2	-2	0	4.6	37.8
Pair 3	-3	0	3.0	65.7
Pair 4	1	1	1.9	26.1
Pair 5	1	2	7.4	37.8
Pair 6	3	-1	12.3	68.9
Pair 7	-3	-2	4.6	111.6
Pair 8	0	4	10.0	124.2
Pair 9	2	2	2.4	59.9
Pair 10	-1	-3	0.0	78.4

Analyzing the results shown in the Table 4, it is clear that the problem of shift between the compared images representing fingerprints is serious and has a significant impact on the final outcome of the evaluation. Therefore, for the MSE measure result to be real, not subject to errors caused by the shift and so that it be used in identification systems, an effective method of eliminating the problem of the lack of synchronization between the analyzed images should be applied. Thus, there is a need to develop an effective method to find the shift occurring between the studied images representing the footprints. This shift can result from the movement of the fingers in the X and Y scanned plane, but it can also be due to the rotation between the fingers.

For this purpose, the authors of the article applied typical operations used in digital images as described formulas 2 and 3 to indicate the relation between the negative MSE measure and the shift mentioned in the example 2, which here is used to find the value of the shift.

3. **The method of finding the shift between the images based on the analysis of the MSE measure.** For the method of finding the shifts between the studied images to be effective, it is necessary to adopt the following assumptions:

- Fingerprints are taken on the same scanning device with the same resolution;
- Fingerprints are always taken in the same well-defined area in the scanning plane;
- Fingerprints are always taken in the same position, which means that, for example,

there will not occur a situation of applying thumb rotated at 90 degrees in relation to the scanning plane.

Taking into account the points mentioned above we can assume that:

- the images representing the fingerprint will have the same size and resolution;
- the shift between the images will be of more than a few pixels;
- the angle of rotation will be only a few degrees,

First of all it is necessary to check whether the compared images representing the fingerprint require synchronization. For this purpose, we should subtract one image from another. If the difference between the two is 0, this will mean that the images are synchronized, otherwise it is necessary to proceed with the synchronization between them. However, for the synchronization process to be effective, it is necessary to find the shift which occurs between the images representing the fingerprints.

The first step is to find the axis and angle of rotation between the two images representing the fingerprint. Taking into account the assumptions presented above, we know that the rotation will be small and the axis of rotation should be near the centre of the images. To find the axis of rotation we should proceed in accordance with the following algorithm: First, select the image segment with the lowest MSE measure result (almost always they will be the middle segments). Then, move the segments in relation one to another in the X and Y plane every pixel. In each position, check the MSE measure result. The axis of rotation will be found at the point where the MSE measure has the lowest result. The process has been illustrated in the Figure 5.

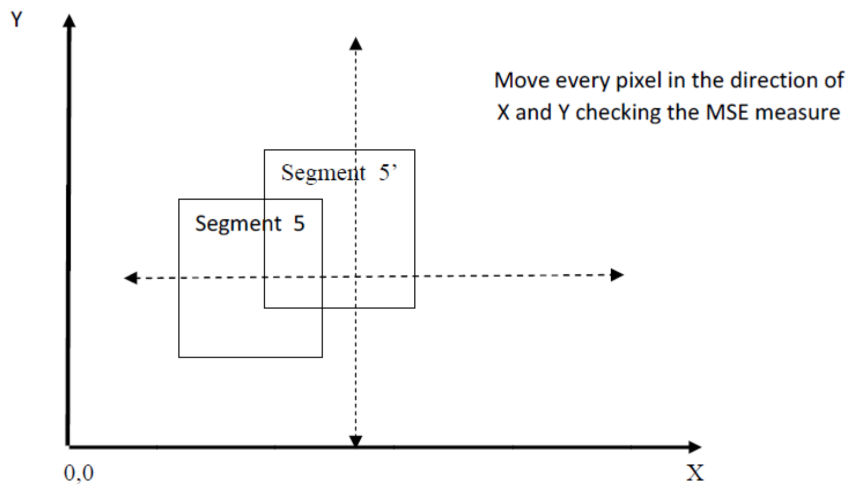

Figure 5. Process of finding the axis of rotation

After having determined the axis of rotation, the next step is to find the angle of rotation between the studied images. To do so, take the edge of the tested segment that is furthest away from the found axis of rotation (O) to get the section of with the length of (a), which has its origin in the axis of rotation and its end at the point X. Then select the mask with the size of, for example, 15 x 15 (selected experimentally for a given type scanner). Move the mask along the horizontal edge pixel by pixel starting from the point X. Check the value of the MSE measure in each position. Mark the point Y in the position where the MSE measure has the minimum value. In this way we will get a section with the length (b) having its origin at the point X and the end at the point Y. The whole process has been shown graphically in the Figure 6.

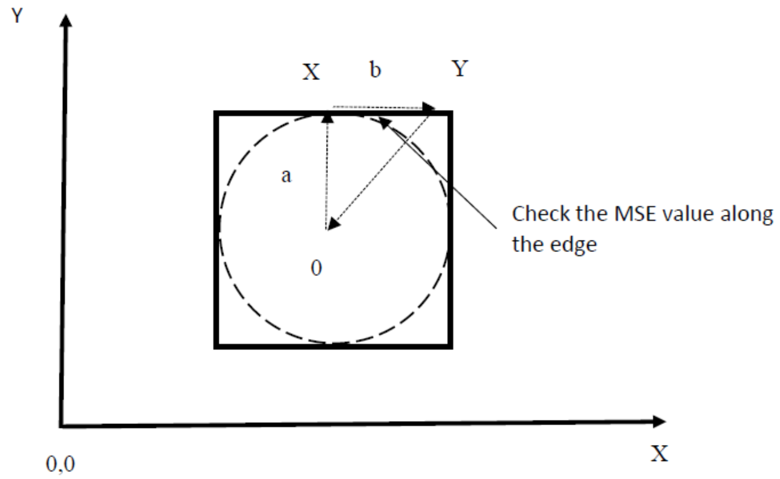

Figure 6. Finding the angle of rotation between the images

In this way we obtain a rectangular triangle with the edge lengths equal to the length of the matching segments a and b. Using trigonometric relationship the angle can be calculated according to the Equation (4).

$$\alpha = \arctan\left(\frac{b}{a}\right) \tag{4}$$

Having found the axis of rotation and the angle of rotation, proceed with fitting the two images using the formula described in Equation (3). The table 5 presents the sample results of the experimental studies which can serve as a proof of the effectiveness of the methods.

Table 5. The sample results of the experimental studies in finding the axis and the angle of rotation

Pairs of fingerprints fingerprings	Axis of rotation		Axis foung		Angle of rotation	Angle of rotation found
	X	Y	X	Y		
Pair 1	128	320	128	320	3	3
Pair 2	147	380	147	380	2	2
Pair 3	221	457	221	457	4	4
Pair 4	339	567	339	567	3	3
Pair 5	400	500	400	500	4	4
Pair 6	297	398	297	398	3	3
Pair 7	511	623	511	623	4	4
Pair 8	234	329	234	329	2	2
Pair 9	455	567	455	567	1	1
Pair 10	385	447	385	447	2	2

After completing the operations presented above, proceed to compare the fingerprints in accordance with the method 2 described in Example 2. The block diagram of the identification algorithm has been shown in the Figure 7.

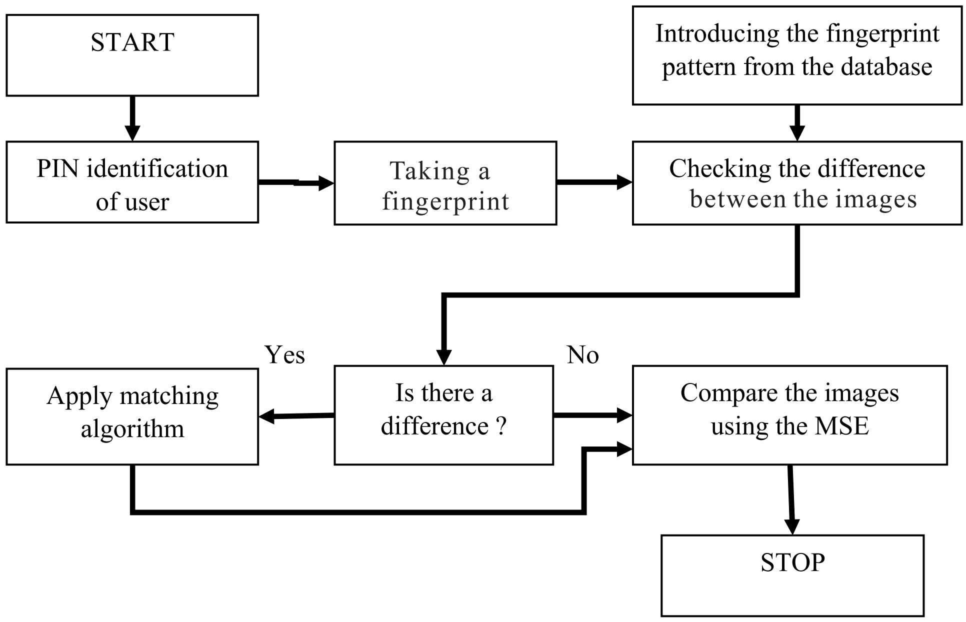

Figure 7. The block diagram of the identification algorithm

Table 6. Results of experimental research related to fingerprint identification

	Synchro-nization required	Number of segments with the MSE<10	Specialist ebaluation	Evaluation according to the criteria	Number of segments in the repeated measurement where MSE<10	Evaluation according to the criteria
Pair 1	Yes	6	Match	Match		
Pair 2	Yes	7	Match	Match		
Pair 3	Yes	7	Match	Match		
Pair 4	Yes	6	Match	Match		
Pair 5	Yes	8	Match	Match		
Pair 6	Yes	9	Match	Match		
Pair 7	Yes	8	Match	Match		
Pair 8	Yes	7	Match	Match		
Pair 9	Yes	8	Match	Match		
Pair 10	Yes	5	Match	Different	7	Match
Pair 11	Yes	4	Match	Different	6	Match
Pair 12	Yes	6	Match	Match		

4. **Results of experimental research.** In order to confirm the effectiveness of the method of comparison of the fingerprints using the MSE measure and the synchronization algorithm described in Section II of the paper, the authors have made a series of experimental research, the results of which have been compared with the evaluation of the specialist in the field of dactyloscopy. The authors assume that in order to determine if the image representing the fingerprint of the analyzed person fits the pattern introduced in the database, 6 of 9 segments must have the MSE measure result below 10. Otherwise, it is necessary to repeat the procedure and, if there is no positive outcome, the fingerprints do not match.

Analyzing the experimental research results presented in the Table 6, we can draw a conclusion that the method proposed in the article is effective. Of course, in order to accelerate and facilitate the process of identification we can apply a technique called two-level identification method [5] in which the user first provides the specified identifier, e.g. PIN code, and only then proceeds with the fingerprint analysis. This method is widely used in many systems based on biometric identification and gives much faster and better possibilities of identification, as it is not necessary to search the whole database containing fingerprint patterns and a preliminary identification takes place at the moment of entering a PIN code.

5. **Conclusions.** The method of person identification proposed by the authors on the basis of the analysis of the MSE measure can be easily implemented at home with the use of the digital scanner. This method, despite its simplicity, is very effective. The proposed algorithm for finding the axis and angle of rotation between the tudied images can be successfully applied to other issues related to digital image processing, such as creating panoramic images [5], or in learning neural network that generates FIR filter which requires proper synchronization of the input data [7].

REFERENCES

[1] E. Kornatowski, J. Kowalski, G. Mikolajczak, J. Peksinski, Linear and non-linear filtration of discrete images, *Hogben Editor, Szczecin, Poland*, 2006 in polish.

[2] W. Zhou, A. C. Bovik, Mean squared error: Love it or leave it? A new look at Signal Fidelity Measures, *Signal Processing Magazine*, vol. 26, no. 1, pp. 98-117, 2009.

[3] J. Peksinski, G. Mikolajczak, Generation of FIR Filters by Using Neural Networks to Improve Digital Images, *34th Int'l Conference on Telecommunications and Signal Processing (TSP), Budapest, Hungary*, pp.527-529, 2011.

[4] J. Peksinski, G. Mikolajczak, Using a Neural Network to Generate a FIR Filter to Improves Digital Images Using a Discrete Convolution Operation, *Intelligent information and database systems (ACIIDS 2012), Springer-Verlag,* LNAI 7197, pp.294-300, 2012.

[5] J. Swiatek, Two-stage Identification and its technical and biomedical applications, *Politechnics Warsaw Editors, Warsaw, Poland,* 1997 in polish.

[6] J. Peksinski, G. Mikolajczak, J. Kowalski, The preparation of input data in digital image processing, *Electrical Review*, vol. 89, no. 3b, pp.282-284, 2013.

[7] J. Peksinski, G. Mikola jczak, Generation of a FIR filter by means of a neural network for improvement of the digital images obtained using the acquisition equipment based on the on the Low Quality CCD Structure, *Intelligent information and database systems : Second International Conference,* (ACIIDS 2010) : Springer, LNCS 5990, pp.191-199, 2010.

[8] D. Maltoni, D. Maio, A. K. Jain, S. Prabhakar, Handbook of fingerprint recognition Originally published in the series: *Springer Professional Computing 2nd ed.,* 2009.