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Semi-spectrum correlation methods for fingerprints' recognition

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ABSTRACT

There are presented the results of the investigations of the fingerprints' images correlation recognition in conditions of different distortions – scale, angular orientation change, image's surface reducing, noises' influence. There are examined possibilities of the persons' identification and their verification. There are proposed and investigated the method of the fingerprints' semi-spectrums recognition and the method of the fingerprints' space-dependent recognition.

Keywords: correlation, recognition, fingerprints, semi-spectrums, space dependent, identification, verification

1. INTRODUCTION

The persons' verification and identification, on the bases of the fingerprints, represent a very important problem, the effective solution of which is necessary in different applications – in criminology, access systems etc. Between different requirements to the systems can be selected the most important – speed of fingerprints' recognition, discrimination possibility (or reliability), complexity and others.

The correlation method, being realized in optical processors, allows the images recognition with a very high speed, until 10^{14}bits/sec. At the same time, the construction of the optical processor is not very complex and it can possess small- weight and dimensions characteristics (around $13cm^2$).

Optical processors can be used successfully for the fingerprints' images recognition, invariant to displacements. Unfortunately, the standard correlation method wasn't, profoundly, investigated from the point of view of fingerprints' recognition stability in the conditions of the change of the scale, of the angular orientation, of the image's surface reducing, of the noises influence, etc. Such fingerprints' images distortions are typical in criminology.

Taking into account this fact, the experimental investigations were executed with the purpose to establish the possibility of utilization of the correlation method for the fingerprints' images recognition in conditions of influence of the indicated above distortions and resolving of the persons' identification and verification problems(Sec.2).

The carried out investigations permitted to establish the negative influence of the noise on the recognition of the fingerprints' images with a reduced surface. In criminology, it appears frequently the necessity of the analysis of such types of fingerprints - with the reduced surface and which contain a noisy background.

Taking into consideration this fact, it was proposed and investigated the method of the fingerprints' semi-spectrums recognition (Sec.3). It was shown that this method is characterized by stability to the reduction of the surface of the input fingerprints images and to the noise. At the stage of comparison with standards, this method is characterized by a reduced volume of information, which allows the decrease of the processing time and the volume of information necessary for storing of the standard images. The method is proved to be efficient for the person's verification on the base of the fingerprints and for the persons' identification in conditions of a strict observance of the requirements regarding the angular position and the scale of images.

For an effective resolving of the persons' verification and identification problems, it was proposed the method of the fingerprints' space-dependent recognition, which represents the extension of the previous method (Sec. 4). The proposed method allows the fingerprints' recognition independent from displacements, rotation and scaling.

2. FINGERPRINTS' IMAGES CORRELATION RECOGNITION

The method of the fingerprints' images correlation recognition (FICR) is based on the calculation of the correlation function between the image of the unknown fingerprint and one of its standard images. In general, the correlation function is expressed by the following formula:

$$C(\xi, \eta) = \iint_{-\infty}^{\infty} P(x,y)H^{*}(x-\xi, y-\eta)dxdy, \quad (1)$$

where P(x,y) describes the unknown image and H(x,y) is the standard one.

One of the most efficient methods of the correlation function calculation is based on the utilization of the bi-dimensional Fourier transformation. In this case, the function of correlation takes the following form:

$$C(\xi,\eta) = F^{-1}\{F\{P(x,y)\}F^{*}\{H(x,y)\}\}=F^{-1}\{P(u,v)H^{*}(u,v)\}= F^{-1}\{C(u,v)\}, \quad (2)$$

where F and F^{-1} are the operations of the bi-dimensional Fourier transformation, direct and, respectively, inverse; the sign * is that of the complex conjugation; P(u,v), H*(u,v) are the Fourier transformations of the functions P(x,y) and respectively, H(x,y); u, v - the coordinates in the frequency space.

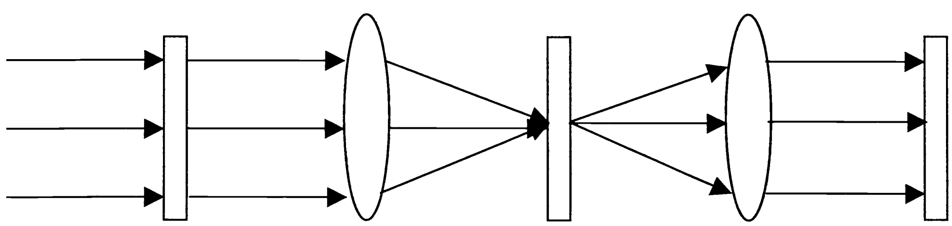

Fig. 1. The structure of the optical processor

For an efficient calculation of the correlation function, described by the formula (2), can be used the optical processor, the structure of which is presented in the figure 1. The image P(x,y) is placed in the P1 focus plane of the Fourier lens LF1. When the image is illuminated by a laser, in the P2 focus plane of the lens LF1 it is formed the Fourier transformation of the image P(x,y):

$$F\{P(x,y)\}= P(u,v)=\iint_{-\infty}^{\infty} P(x,y)\exp[-j2\pi(xu+yv)]dxdy. \quad (3)$$

Also, in the P2 plane is placed the holographic filter H*(u,v). As a result, in the P2 plane appears the formula C(u,v)=F(u,v)H*(u,v). After the realization of the Fourier transformation of the function C(u,v) by the help of the lens LF2, in the P3 plane the correlation function C(ξ, n) will be formed.

If the initial image contains, for example, 10^6 pixels, and the time of performing the correlation operation is determined by the light beam time passing in the processor and is equal to 10^{-8} sec, the productivity of the processor will be very high, equal to 10^{14} bits/sec. At the same time, the construction of the optical processor is not very complex and it can possess small weight and dimensions characteristics (around $13cm^2$).

Optical processors can be used successfully for the fingerprints' images recognition, invariant to displacements. Unfortunately, the standard correlation method wasn't, profoundly, investigated from the point of view of fingerprints recognition stability in the conditions of change of the scale, of the angular orientation, of the image's surface reducing, of the noises influence, etc. Such fingerprints' images distortions are typical in criminology.

Taking into account this fact, a lot of experimental investigations were executed with the aim to establish the possibility of utilization of the correlation method to the resolving of the invariant fingerprints' recognition, for resolving of the persons' identification and verification problems. These investigations were carried out using the special software "IPS-1"[1]. Some fingerprints images are presented in the figure 2.

AD1 AD2 AD3

Fig.2. Fingeprints images

There were been made investigations related to the influence of the change of the fingerprints' image angular orientation, of the scale, of the image's surface reduction and the influence of the noise on the C_M - the maximal value of the correlation function: $C_M = \max\{[C(\xi\eta)]^2\}$. The parameter K was used in investigations, calculated as the relation of the C_M values of the cross-correlation function (this in the case of the image distortions) and of the auto-correlation function.

Investigation of the influence of the fingerprints' image angular orientation on the C_M value

In the figure 3 are presented the K_U relations of the C_{MU} values of the correlation function in the $\Theta \neq 0$ angular positions of the fingerprints' images, to the C_M value of the correlation function at $\Theta=0$, $K_U=C_{MU}/C_M$, for different values of the images resolution R. From the presented data, it is possible to conclude, that in the case of the fingerprints, the correlation function is very sensitive to the angular position of the image. For the threshold value $K_U=0.7$ (which corresponds to that given in practical problems), the accepted differences in the angular orientation of the input and standard fingerprints' images are those of $\Theta_A=1°$ for $R=128^2$ and $\Theta_A=0.8°$ for $R=64^2$.

Investigation of the influence of the scale change of the fingerprints' images on the C_M value

In the figure 4 are presented the K_S relations of the C_{MS} maximal values of the fingerprints images cross-correlation functions at the scale $S \neq 1$ to the C_M maximal value of the auto-correlation function (at $S=1$), $K_S=C_{MS}/C_M$ for different values of the images' resolution R. The analysis of the presented data shows that the correlation function is very sensitive to the change of the scale of the fingerprints. For the $K_S=0.7$ threshold value, the accepted difference in the scale change of the input and standard fingerprints' images is of $S_A=5\%$ for $R=128^2$ and $S_A=3\%$ for $R=64^2$.

Investigation of the influence of the surface change of the of the fingerprints images on the C_M value

In the figure 5 are presented the K_{SP} relations of the C_{MSP} values of the cross-correlation functions for the input fingerprints with the surface coefficient $SP \leq 1$, to the C_M value of the auto-correlation function (at SP=1), $K_{SP}=C_{MP}/C_M$ for different values of the image resolution R. The presented data show, that the correlation function is stable to the reduction of the surface of the fingerprints' images. The C_M value decreases to 30% for the parameter SP=0.5 ($R=64^2$).

Investigation of the noise's influence in the fingerprints' input image on the C_M value

In the figures 6-9 are presented the results of investigations of the noise's influence in the fingerprints' input image on the C_M maximal value of the correlation function, for different values of the resolution R of the images (fig.6), angular orientation (fig.7), scale (fig.8) and the fingerprints' surface (fig.9). The N parameter represents the probability of the additive noise introduction in to image.

The results of the investigations demonstrated the followings: in the case of the rotation or of the scale changes of the fingerprints' images, the introduction of the noise, in fact, doesn't influence on the C_M maximal value of the correlation function (fig. 7,8).The noise influences on the C_M in case of change of the fingerprints' surface or resolution. At N=0.02, the accepted value of the fingerprints' surface reduction is until 15% for R=256.

Investigation of the discrimination possibility

Pursuing the purpose of investigating the discrimination possibility of the correlation recognition method, there were been calculated correlation functions between different fingerprints' images and calculated the relations: $K_{Di}= C_{Mii}/C_{Mij}$, where C_{Mii}, C_{Mij} are functions of auto-correlation and, respectively, of cross-correlation. The data presented in the figures 10 and 11 show that the K_D values depend on the images' resolution R. At the reduction of R until $R=64^2$, the value of K_D reduces, but it remains sufficient for the correct fingerprints recognition.

The results of the investigations of the method of correlation recognition of the fingerprints' image (CRFI) demonstrated the followings.

1. This method is very sensitive to the non-correspondence of the angular orientation, of the scale of the fingerprints' input image to the standard one. A difference only of 0.8° in the angular position or of 3% in the scale causes the reduction, until the critic value, of the maximum of the correlation function;

2. The method FICR isn't so influenced by the surface reduction of the fingerprints' images submitted to recognition; the fingerprints' surface could be decreased until 50%;

In case of rotation or scaling change of the fingerprints' image, the noise, in fact, doesn't influence on the maximal value of the correlation function, but influences it in case of change of the fingerprints' surface and of the image's resolution. The accepted value for the fingerprints' surface reducing is till 30% (at N=0.02).

3. The method is characterized by a high discrimination possibility (DP) regarding the fingerprints' recognition. Concomitantly, the DP of this method depends on the images' resolution;
4. The method FICR is considered to be efficient both to the resolving of the verification and identification of the persons on the base of the fingerprints, in conditions of a strict observance of the requirements to the angular position, scale, surface of the fingerprints' images and absence of the noise in images.

3. FINGERPRINTS' SEMI-SPECTRUMS RECOGNITION

3.1 Method of the fingerprints' semi-spectrums recognition

The results of the investigations, presented in Sec.2, indicate the negative influence of the noise in the recognition of fingerprints' images with a reduced surface. In criminology, it appears frequently the necessity of the analysis of such types of fingerprints - with the reduced surface and which contain a noisy background.

For an efficient recognition of the fingerprints' images we propose a new method - the fingerprints' semi-spectrums recognition (FSR). At the basis of this method, it is used the property of concordance between the objects' images and their Fourier spectrums. As it is described in [2.3], the Fourier spectrum of the image is symmetrical and repeats to 180°. At the image rotation, the Fourier spectrum rotates with an equal angle. To the image scaling, the Fourier spectrum's dimensions change in an inverse proportion. So, the Fourier spectrum represents the object's initial image. Moreover, the proposed method bases on the fact that the noise of additive type, present in image, is characterized by low frequencies in the Fourier space.

The elaborated method consists in the followings.

1. In the first stage, there is formed the Fourier spectrum of the input image $P(x,y)$:

$$P(x,y) \rightarrow P_S(u,v) = |F\{P(x,y)\}|^2.$$

2. The image $P_S(u,v)$ is segmented on the base of brightness criterion, which allows to avoid the influence of the noise's frequencies: $P_S(u,v) \rightarrow P_{SB}(u,v)$.

3. Considering the symmetry property of the Fourier spectrum, from the image $P_{SB}(u,v)$ is forming another one, which represents only a half of this image and which is called "semi-spectrum": $P_{SB}(u,v) \rightarrow P_{SBN}(u,v)$.

This allows to reduce the volume of the information necessary for the storing of the standard image and of the volume of calculations necessary for the fingerprints' recognition.

4. It is realized the operation of recognition of the $P_{SBN}(u, v)$ image by the calculation of the correlation function with different standards:

$$C_j(\xi, \eta)=\max_{\Omega} \max_{j} \{\iint_{-\infty}^{\infty} P_{SBN}(u,v) \sum_{j=1}^{L} H^*_{SBN}(u-\xi, v-\eta) du dv, \quad (4)$$

where Ω- the correlation field, L-the number of standard images.

The proposed method permits the recognition of the fingerprints with the reduced surface in comparison with the standard image, if even the first one could be distorted by noise. At the same extent, this method is characterized by the reduced volume of information in the phase of comparison with the standards which permit to reduce the processing time and the volume of information necessary for the storing of the standard images.

3.2. Investigation of the fingerprints' semi-spectrums recognition method

For proposed in Sec. 3.1. method, it was investigated the influence on the C_M-maximal value of the correlation function, of the noise in the input fingerprints' image, of a different surface of the fingerprints (fig.12), of the resolution (fig. 13), of the angular orientation (fig.14), of the scale (fig 15), of the discrimination possibilities (figs. 16, 17).

On the bases of the obtained results of the investigations it is possible to conclude the following.

1. The noise in the input image doesn't, practically, influence the value C_M;

2. This method is very sensitive to the non correspondence of the fingerprints' image to the standard one, from point of view of angular position and scale. The difference only of 0.5° in the angular position or of 4% in scale causes a critic reduction of the maxim of the correlation function;

3. The method is stable to the reducing of the surface of the fingerprints' image. The fingerprints' surface could be reduced until 40%;

4. The method is characterized by a high discriminatory possibility in what regards the recognition of the fingerprints' images;

5. The method is efficient in the persons identification and verification on the bases of the fingerprints in conditions of a strict observance of the requirements in what concerns the angular position and the scale.

4. FINGERPRINTS' SPACE-DEPENDENT RECOGNITION

4.1 The method of fingerprints' space-dependent recognition

The disadvantage of the methods FICR and FSR consists in the necessity of a strict observance of the requirements regarding the angular position and the scale of the fingerprints' images. In connection with this, it was elaborated another method which could offer the possibility of recognizing the fingerprints indifferent of the indicated distortions. The proposed method is based on the formation of the fingerprints' images semi-spectrums and their presentation in the polar-logarithm system of coordinates.

The method of the fingerprints space-dependent recognition (FSDR) includes the following stages.

1. There forms the Fourier spectrum of the input image P(x, y), that allows the centering of the fingerprints:

$$P(x,y) \rightarrow P_S(u,v) = |F\{P(x,y)\}|^2.$$

2. The operation of $P_S(u, v)$ image segmentation brightness is realized with the aim of noise removing:

$$P_S(u,v) \rightarrow P_{SB}(u,v).$$

3. There forms the spectrum of the image $P_{SB}(u,v)$:

$$P_{SB}(u,v) \rightarrow P_{SBN}(u,v).$$

4. There takes place the operation of image $P_{SBN}(u, v)$ transformation in the coordinate system (u_1,v_1):

$$P_{SBN}(u,v) \rightarrow P_{SBN}(u_1,v_1),$$

where $u_1 = \mathrm{arctg}(v/u)$, $v_1=\ln\{(u^2+v^2)^{1/2}\}$.

This transformation allows to reduce the influence of rotation and scaling in the image $P_{SBN}(u,v)$ to displacements on the u_1 and v_1 axes, and, respectively, to utilize the property of the correlation algorithms concerning the shifts.

5. The realization of the operation of image $P_{SBN}(u_1v_1)$ recognition:

$$C_j(\xi, \eta) = \max_{\Omega} \max_{j} \{\iint_{-\infty}^{\infty} P_{SBN}(u_1,v_1)\sum_{j=1}^{L} H^*_{SBNj}(u_1-\xi,v_1-\eta)du_1dv_1. \quad (5)$$

So, the described method contains a supplementary stage in comparison with the precedent one, which allows to recognize the fingerprints' independent from displacements, rotation and scaling.

5.2. Investigation of the method of fingerprints' space-dependent recognition

The elaborated method of the fingerprints' recognition was studied from the point of view of the influence of the angular position (fig.18), of the scale (fig.19), of the noise in the input image on the C_M value of the correlation function. Also, was investigated the discrimination possibility (figs. 20, 21).

The results of the investigations show the followings.

1. The method is stable to the change of the angular position and scale of the fingerprints. At the change of indicated parameters, the maximums of the correlation function decrease insufficiently. The discrimination possibilities are high.

2. The FSDR method could be used for resolving of the problems of identification and verification of the persons on the base of the fingerprints.

CONCLUSION

1. The carried out investigations of the fingerprints' images correlation recognition method permitted to establish the fact this method is very sensitive to the non-correspondence in the angular orientation and in the scale of the input and standard fingerprints' images. The discussed method is stable to the surface fingerprints reduction; the noise doesn't, practically, influence on the maximal value of the correlation function in case of rotation or of scaling of the fingerprints' images, but, this happens when the fingerprints' surface and the image's resolution are changing; the recognition discrimination possibility depends on the images' resolution.

The FICR method could be efficiently used especially for verification of the persons on the base of the fingerprints. The persons' identification can be made in conditions of a strict observance of the requirements concerning the angular position, the scale, the surface of the fingerprints' images and the absence of the noise in image.

2. It was elaborated the method of fingerprints' semi-spectrums recognition, characterized by stability to the reduction of the surface of the input fingerprints images and to the noise. At the stage of comparison with standards, this method is characterized by a reduced volume of information, which allows the decrease of the processing time and of the volume of information necessary for the storing of the standard images. This method is proved to be efficient for the person's verification on the base of the fingerprints and for the persons' identification in conditions of a strict observance of the requirements regarding the angular position and the scale of images.

3. There was presented the method of the fingerprints' space-dependent recognition. It allows the fingerprints' recognition independent from displacements, rotation and scaling. This method could be successfully used to the resolving of the problems of the persons' verification and identification.

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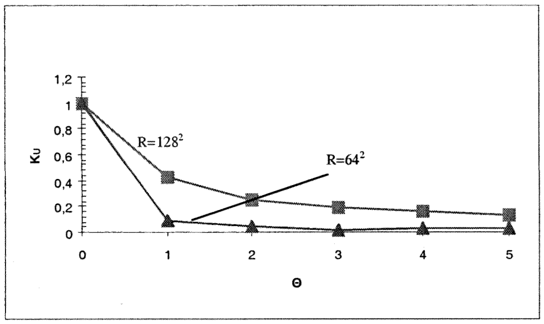


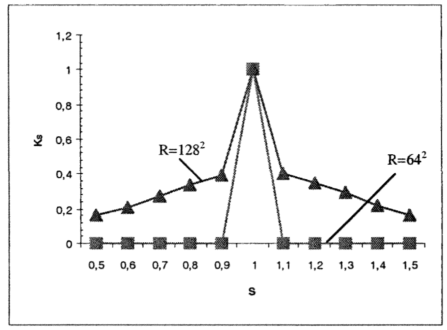
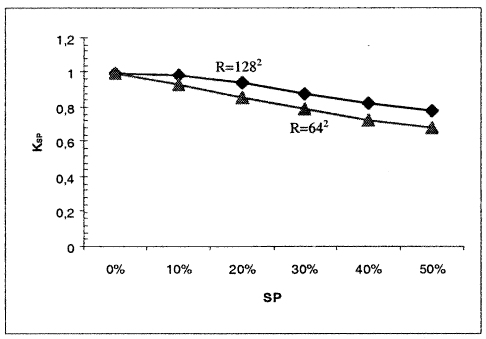


Fig.3.Influența poziției unghiulare Θ a AD asupra parametrului K_U Fig.4. Influența scării S a imaginii AD asupra parametrului K_S



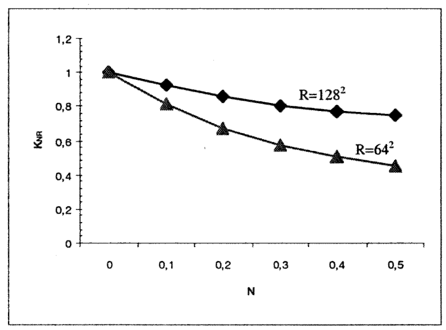
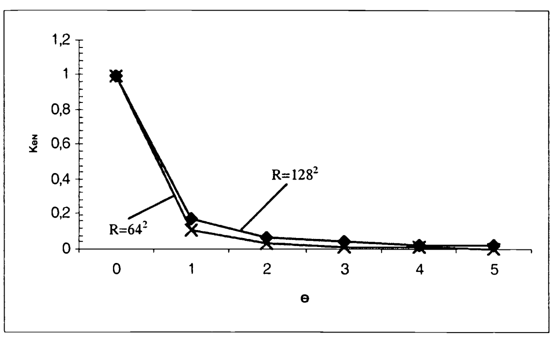


Fig.5. Influența suprafeței SP a AD, asupra parametrului K_{SP}

Fig.6. Influența zgomotului N în imagine asupra parametrului K_{NR}



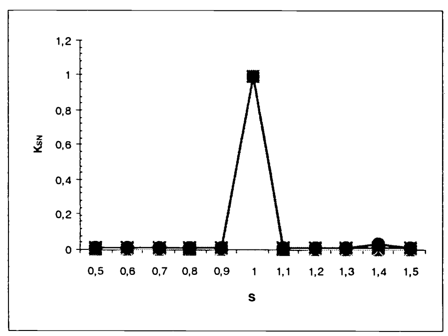


Fig.7. Influența poziției unghiulare Θ a AD asupra parametrului $K_{\Theta N}$ Fig.8. Influența schimbării scării S a AD asupra parametrului K_{SN}

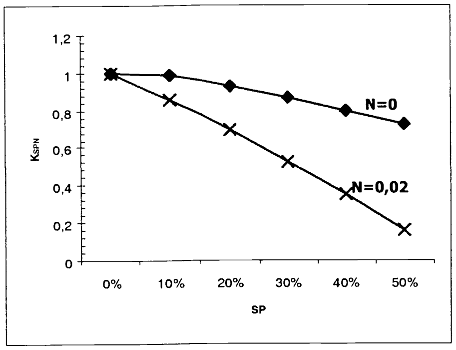


Fig.9. Infleuence of the fingerprints' SP surface on K_{SPN}

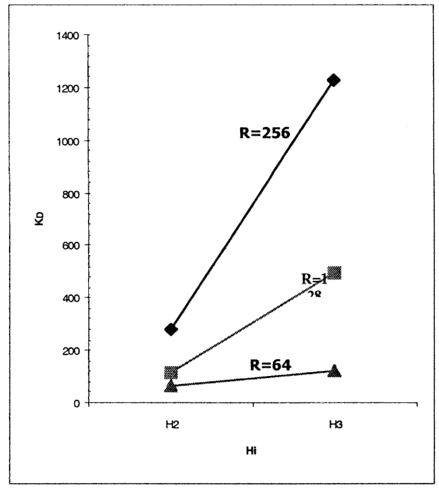


Fig.10. K_D descrimination possibility of the fingerprints' method of recognition

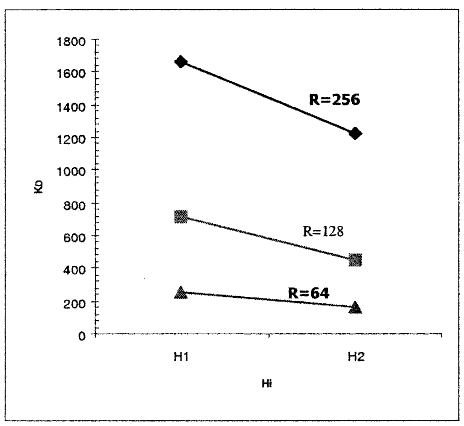


Fig.11. The descrimination possibility

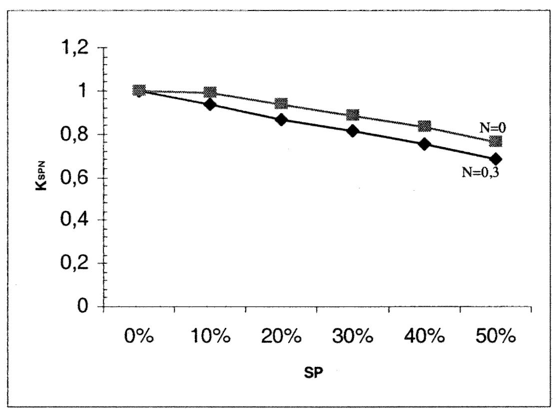


Fig.12. Influence of the SP of the fingerprints on K_{SPN} to different levels of N noises in image

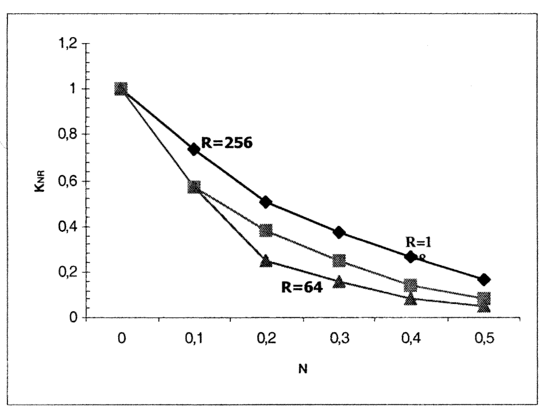


Fig.13. Influence of the N noise in image on the K_{NR} parameter

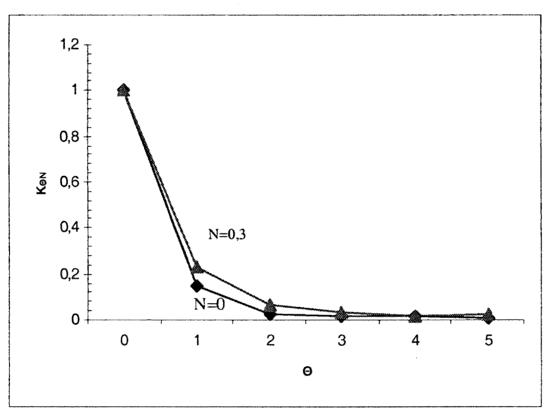


Fig.14. Influence of the Θ angular position of the fingerprints on the $K_{\Theta N}$ parameter

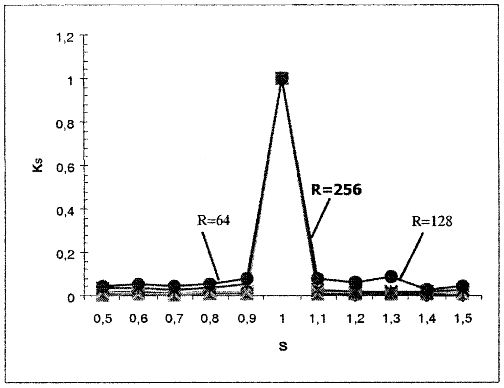


Fig.15. Influence of the change of the S scale of the fingerprints' image on the K_S parameter

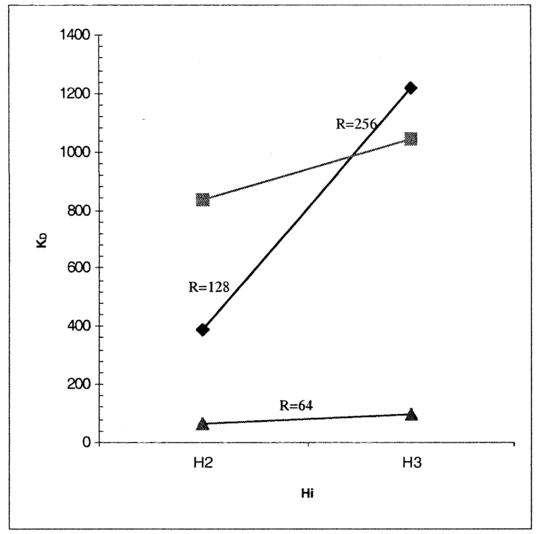


Fig.16. K_D descrimination possibility of the fingerprints' method of recognition

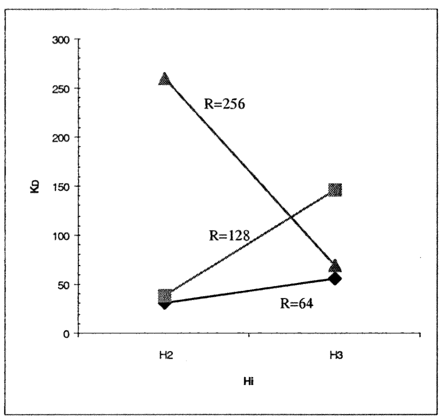


Fig.17. K_D descrimination possibility of the fingerprints' method of recognition

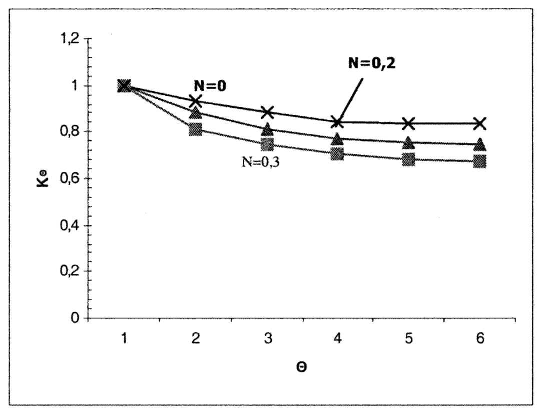


Fig.18. Influence of the Θ angular position of the fingerprints on K_Θ

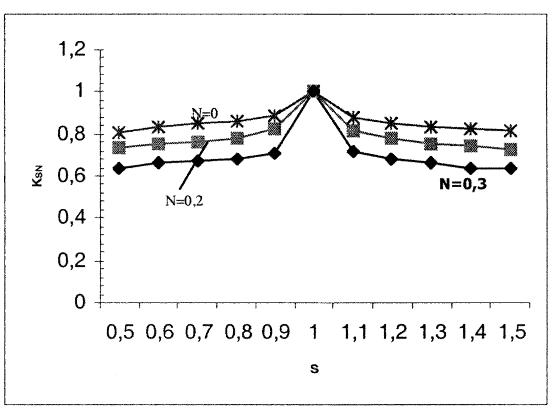


Fig.19. Influence of the S scale of the fingerprints on K_{SN}

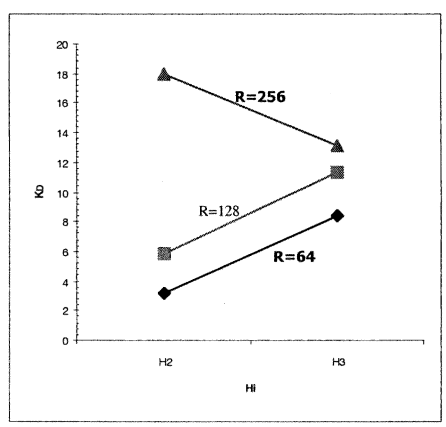


Fig.20. K_D descrimination possibility of the method of recognition

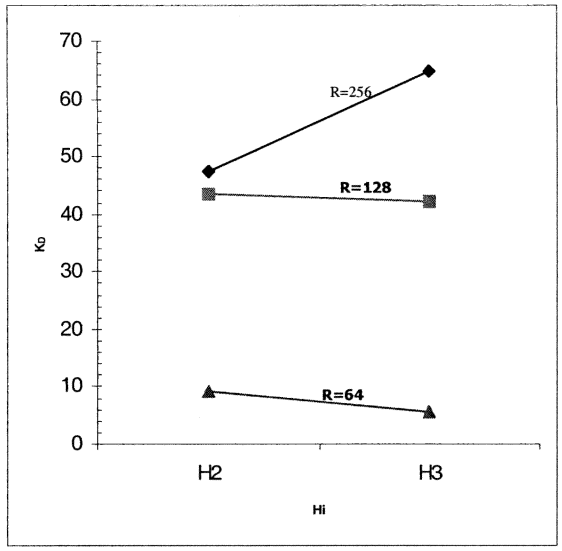


Fig.21. K_D descrimination possibility of the method of recognition