[illegible]

안전 검증을 위한 회전 불변 지문인식 시스템

Rotation-Invariant Fingerprint Identification System for Security Verification

이승현* · 류대현** · 박민순*** · 류충상****
S.H. Lee · D.H. Ryu · M.S. Park · C.S. Ryu
(1998년 2월 24일 접수, 1998년 12월 1일 채택)

ABSTRACT

We propose a rotation invariant fingerprint identification system based on the circular harmonic filter(CHF) and binary phase extraction joint transform correlator(BPEJTC) for validation and security verification. It is shown that this system has the shift and rotation robust properties and can recognize the fingerprint in real-time. The complex circular harmonic filter, which is used to obtain the rotation invariance, is converted into the real-valued filter for real-time implementation. Experimental results show that this system has a good performance in the rotated fingerprints.

국 문 요 약

본 논문에서는 안전검증 분야로의 응용을 위하여 circular harmonic filter(CHF)와 binary phase extraction joint transform correlator(BPEJTC)에 근거한 회전불변 지문인식 시스템을 제안하였다. 본 시스템은 이동 및 회전 변화에 강건하며 실시간으로 지문을 인식할 수 있는 특징을 지닌다. 실시간 구현을 위하여 회전불변 특성을 얻기 위한 복소 CHF는 실수로 구성된다. 시뮬레이션을 통해 본 시스템이 회전된 지문에 대해 강건한 특성이 있음을 보였다.

* 광운대학교 전자공학부
** 한세대학교 정보통신과
*** 광운대학교 컴퓨터과학과
**** 정보통신부 전파연구소 공업연구관

1. Introduction

Citing an instance of informations that are used for identification of an individual on personal verification system, there are innate body informations, the accuracy increased informations of reproducibility like an signature out of habit, and artificially formed individual informations.

In case of using artificially formed individual informations, we can raise the accuracy but have problems of difficult management according to damage, being the victim of robbery, fabrication etc. and can be a primary factor of offenses. These problems can be conquered by using innate body information fingerprints but the database construction or discrimination is very difficult for the reason of these informations existed with various forms in the nature[1].

The special feature of fingerprint image are lots of informations concentrated in limited field, on the otherwise, clear image difference is existing individually and it's hard to discriminate the fingerprints with naked eyes on account of the complex shape externally, and also the pattern is not standardized. But in frequency point of view, since every fingerprint image has a proper frequency, we can obtain successful fingerprint recognition results by using the proper frequency of a fingerprint image and trying the pattern coordination. Precisely, on a division of each different fingerprint image, the similarity of two fingerprints can be easily inferred when we abstract and coordinate the frequency signal from the input fingerprint images and recorded fingerprint images on the data base[2,3].

But fingerprint images have many extremely distorted cases caused by a rotation according to the position of fingers, part damage by dirts or quantization noise according to the system condition and the addition of measurement noise. Among those distortions, the problems of size alteration can be solved by maintaining the fixed measurement distance, and we do not consider the quantized noise and the measurement noise with a problem of the system forming in this paper. Consequently, it requires shift, rotation invariance and strong algorithm on partial input.

The circular harmonic filter shows the rotational invariant characteristic which has no relations with the location of the identical image when the center of conversion is found [4~6]. Through repeating the error correction of the process about part of standard fingerprint images, we detect the center of circular harmonic and record it with the original image. And we decide the similarity after the readout process by readout images and matching with the input image.

Accordingly, in this paper, we compose the circular harmonic filter of standard fingerprint images to allow rotational invariant function on fingerprint identification system and we used the similarity measurement method among fingerprints correlating with external input images.

The recognition system is implemented in the hybrid form in which the 2-D spatial frequencies of the fingerprint image are generated by the optical unit and its phase signals are extracted by the digital unit. The optical unit composed of a couple of lenses, LCDs and CCD detectors was mainly used to take the Fourier transform operation. And the digital unit control system played a part in modifying and binarizing the JTPS(joint transform power spectrum), which makes this system perform better than the conventional JTC or BJTC-based system[7,8]. In the BPEJTC system, the fingerprint identification is performed by phase matching between the reference and input image[9,10]. For the performance evaluation of the proposed system, some experiments are conducted and the results are proved to be highly acceptable.

2. Circular Harmonic Filter

If the given fingerprint image $f(r, \theta)$ in polar coordinate is continuous at $(0, 2\pi)$ and is possible to integration, Fourier series expansion is possible as Eq.(1), and can represent this as the circular harmonic components as follows:

$$f(r, \theta) = \sum_{M=-\infty}^{\infty} F_M(r) e^{jM\theta} \quad \cdots\cdots (1)$$

where,

$$F_M(r) = \frac{1}{2\pi} \int_0^{2\pi} f(r, \theta) e^{-jM\theta} d\theta \quad \cdots\cdots (2)$$

Here, $F_M(r, \theta) = F_M(r) e^{jM\theta}$ is said to be the m^{th} circular harmonic component(CHC) of the function $f(r, \theta)$, and M is integer. If the fingerprint rotated by angle α, the Eq.(1) is

$$f(r, \theta+\alpha) = \sum_{M=-\infty}^{\infty} F_M(r) e^{jM\alpha} e^{jM\theta} \quad \cdots\cdots (3)$$

Also if we express the real part of Eq.(1), it becomes

$$f(r, \theta) = F_0(r) + 2\sum_{M=1}^{+\infty} \mathrm{Re}[F_M(r) e^{jM\theta}]$$
$$= F_0(r) + 2\sum_{M=1}^{+\infty} |F_M(r)| \cos(M\theta + \phi_M) \quad \cdots\cdots (4)$$

where $F_M(r) = |F_M(r)| e^{j\phi_M}$.

To give shape to the real value, choose only single CHC M=k and define the standard function such as

$$P_{k1}(r, \theta) = 2|F_k(r)| \cos(k\theta + \phi_k) \quad \cdots\cdots (5)$$

$$P_{k2}(r, \theta) = 2|F_k(r)| \sin(k\theta + \phi_k) \quad \cdots\cdots (6)$$

These functions indicate real and imaginary part of $f_k(r, \theta)$. When P_{k1} is formed to standard function and take input $f(r, \theta+\alpha)$, the center value of the cross correlation $C_{k1}(r)$ is described by

$$C_{k1}(r) = \int_0^{2\pi} \int_0^{\infty} f(r, \theta+\alpha) P_{k1}(r, \theta) r\, dr d\theta \quad \cdots\cdots (7)$$

Substitute Eq.(5) and (6) on Eq.(7), it is expressed by Eq.(8).

$$C_{k1}(r) = \int_0^{2\pi} \int_0^{\infty} \{F_0(r) + 2\sum_{M=1}^{+\infty} |F_M(r)| \cos[M(\theta+\alpha) + \phi_M]\} \{2|F_k(r)| \cos(k\theta + \phi_k)\} r\, dr d\theta \cdots (8)$$

Eq.(8) shows that the correlation center value is the sum of every CHC, and if the rotation angle α changes, constant value cannot be remained. To execute constant fingerprint recognition on rotation, the correlation peak at the center of expansion should not be influenced by rotational angle α. But generally the central correlation peak changes by rotation of input images, it's because when the image rotates as α degree, each harmonic components gets effect as $M\alpha$. Accordingly, to implement the spatial matched filter by using a proper CHC, the strength of the center gets constant correlation peak without a relation to rotation degree. So find the best M value and compose the filter, and then the rotation constant spatial matched filter can be formed.

On the Eq.(8), the rest parts become '0' except M=k, then

$$C_{k1}(\alpha) = 4\pi \cos(k\alpha) \int_0^{\infty} r|F_k(r)|^2 dr$$
$$= 2C_k(0) \cos(k\alpha) \quad \cdots\cdots (9)$$

and the strength is

$$I_{k1}(\alpha) = 4C_k^2(0) \cos^2(k\alpha) \quad \cdots\cdots (10)$$

Eq.(10) indicates a change with a $\cos^2$ about direction of an object. In identical point of view, if the $P_{k2}(r, \theta)$ is used as the reference image function, the central correlation peak is like Eq.(11).

$$I_{k2}(\alpha)=4C_k^2(0)\sin^2(k\alpha) \quad \cdots\cdots (11)$$

Eq.(10) adds to Eq.(11) gets result of Eq.(12) that is unrelated to rotation degree.

$$I_k(\alpha)=I_{k1}(\alpha)+I_{k2}(\alpha)=4C_k^2(0) \quad \cdots\cdots (12)$$

Accordingly, Eq.(10) and Eq.(11) can be used to define the rotation angle α.

$$\alpha=\frac{1}{k}\tan^{-1}\sqrt{\frac{I_{k1}}{I_{k2}}} \quad \cdots\cdots (13)$$

3. Circular Harmonic BPEJTC

In this paper, to measure the similarity of input fingerprints by using proposed function of Eq.(5) and (6), we use nonlinear BPEJTC. To get rotation invariance on BPEJTC, we separated the input plane to the upper and lower halves, Eq.(5) and (6) are placed on the upper half plane which is CHC of standard fingerprint image, and input fingerprint image is placed on the lower half plane. Therefore they compose the input plane.

To measure the correlation of a constant pattern of standard images and input images, we get JTPS of intensity distribution of Eq.(14) by Fourier transform of input plane.

$$\begin{aligned}E(r,\theta)&=|P_{k1}(r,\theta)+P_{k2}(r,\theta)+F_M(r)e^{jM\alpha}|^2\\&=|P_{k1}(r,\theta)|^2+|P_{k2}(r,\theta)|^2+|F_M(r)|^2\\&+P_{k1}(r,\theta)P_{k2}^*(r,\theta)+P_{k1}^*(r,\theta)P_{k2}(r,\theta)\\&+P_{k1}(r,\theta)F_M^*(r)e^{-jM\alpha}\\&+P_{k2}(r,\theta)F_M^*(r)e^{-jM\alpha}\\&+P_{k1}^*(r,\theta)F_M(r)e^{jM\alpha}\\&+P_{k2}^*(r,\theta)F_M(r)e^{jM\alpha} \quad \cdots\cdots (14)\end{aligned}$$

Eq.(14) includes autocorrelation terms and crosscorrelation terms of each CHC what are unnecessary interference part, and the last four terms which are interference components of input fingerprint images and standard fingerprint images. However if we subtract each power spectrum of standard and input images from the Eq.(14), that is, remove the crosscorrelation of each CHC and autocorrelation terms, nonlinearity JTPS of $E_{NL}(r,\theta)$ can be described by Eq.(15).

$$\begin{aligned}E_{NL}(r,\theta)&=|P_{k1}(r,\theta)+P_{k2}(r,\theta)\\&+F_M(r)e^{jM\alpha}|^2-[|P_{k1}(r,\theta)+P_{k2}(r,\theta)|^2\\&+|F_M(r)e^{jM\alpha}|^2]=P_{k1}(r,\theta)F_M^*(r)e^{-jM\alpha}\\&+P_{k2}(r,\theta)F_M^*(r)e^{-jM\alpha}\\&+P_{k1}^*(r,\theta)F_M(r)e^{jM\alpha}\\&+P_{k2}^*(r,\theta)F_M(r)e^{jM\alpha} \quad \cdots\cdots (15)\end{aligned}$$

If we inverse Fourier transform the Eq.(15), we can get correlation result of Eq.(16).

$$F^{-1}[E_{NL}(r,\theta)]=2[C_{k1}(\alpha)+C_{k2}(\alpha)] \quad \cdots\cdots (16)$$

Consequently, the intensity of correlation center is increased and rotation invariance is achieved.

4. Rotation invariant fingerprint identification system

The proposed rotation invariant fingerprint recognition system should be composed to have signal path as Fig. 1. In the Fig. 1, a solid line indicates the path of electric signals and a dotted line indicates the optical path.

This system starts to individual recognition move through a specific person calls the database with his own ID and input his fingers. At this time, we suppose that necessary informations for composition of individual fingerprints and CHF are registered on the database. From this process, general fingerprint recognition system use physical methods to sustain the direction of fingers on the prism for preventing fingerprint rotation but it's not required in this system.

If this system is called synchronously through ID with fingerprints input, recorded fingerprints on the database are read and formed

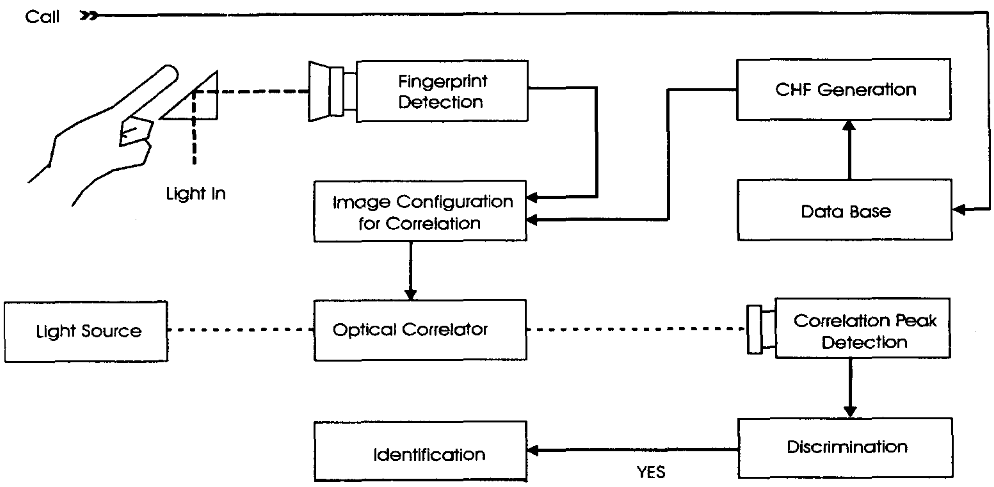


Fig. 1 Block diagram of a rotation invariant fingerprint identification system

to a circular harmonic filter. The circular harmonic filter composes to separate real part and imaginary part on a proper display according to algorithm. We also compose the input plane of BPEJTC by using above 3 images. The input plane separates to the upper and the lower halves plane. The real and imaginary part of the filter place evenly on the upper half plane and external input fingerprints on the lower half plane, and generates correlation optically. Then when the correlation peak occurs according to the similarity between two images, we infer the possibility of identical fingerprints of input fingerprint and database fingerprint.

Especially, according to the specificity of using circular harmonic, it's possible of constant recognition on rotation and measuring the rotated angle related against to the standard images. For the system composition, the real-time correlation is possible because of the optical property but needs to use the digital disposal system assistant for the filter production.

Fig. 2 is a OptoDigital hybrid system to give real-time implementation to Fig. 1. The standard fingerprint images and input fingerprint images compose an input plane with the separation of the upper and the lower halves plane from one spatial light modulator(SLM) as expressed on system diagram..

Optical correlation system is consisted of two parts again. In optical unit, real-time correlation manages by using SLM and FT Lens, and in digital unit, they are used for reproduction of a spectrum of BPEJTC and decision of similarity. The upper position of Fig. 3 is a part gets JTPS, the digital processor in the middle is phase extraction part, and the lower position is a part decides the similarity of fingerprint through inverse Fourier transform.

5. Simulation

To estimate the fingerprint recognition capacity of proposed system, we modeled the system according to Fig. 2 with a computer, and simulated it with the presented step on Fig. 1. We expressed it on Fig. 3 by inspection of the capability against the perfect identical fingerprint with the standard fingerprint to

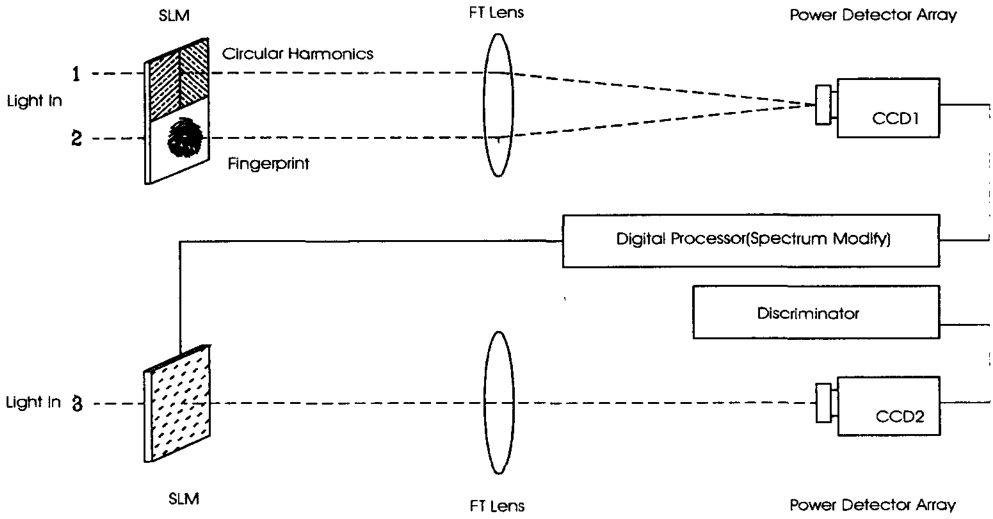


Fig. 2 OptoDigital set up for circular harmonic BPEJTC

provide the appraisal standard.

Fig. 3(a) is an input plane of BPEJTC which include real and imaginary part of circular harmonic of recorded fingerprint on the data base and input fingerprint externally. The input fingerprint is identical with the recorded fingerprint on the database. Fig. 3(b) is a power spectrum of BPEJTC which is made of a reproduction of JTPS that is from Fig. 3(a). The correlation result from inverse Fourier transform is on Fig. 3(c). Correlation similarity is obtained from the addition of correlation peak of the real part and imaginary part. Fig. 4 is the case that the identical fingerprint with the recorded fingerprint on the data base is input of rotated fingerprint about 7° to the left, and the BPEJTC input plane is expressed on Fig. 4(a), and it is expressed on Fig. 4(b) to the correlation output. The height of correlation peak get the value of 0.94 when we suppose Fig. 3(c) to 1.

Fig. 5 is the case that the damaged fingerprint of about 40% of the recorded data of the database. On Fig. 5(a), we indicated BPEJTC input plane, and the correlation output plane on Fig. 5(b). The height of correlation peak

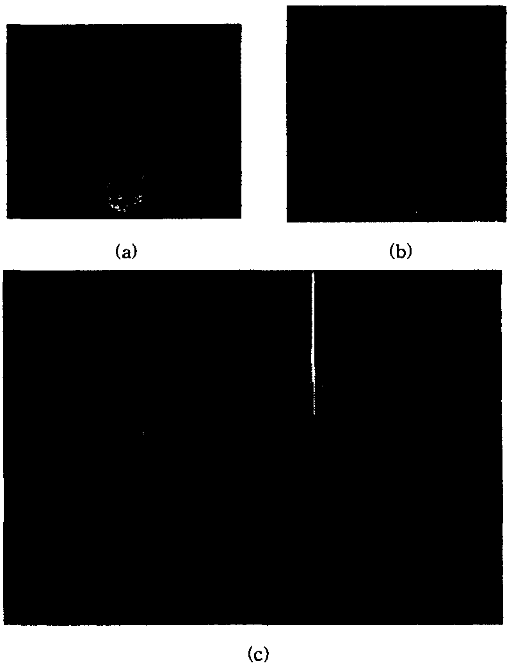
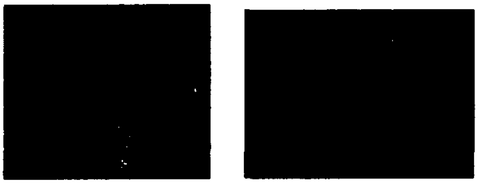


Fig. 3 Identical class fingerprint recognition
(a) the input plane of BPEJTC
(b) the JTPS of BPEJTC
(c) the correlation output

valued 0.8. These two cases show high similarity relatively against the identical input image with the filter images. Fig. 6 is a case that a fingerprint of different person is input, it expresses input plane of BPEJTC on Fig. 6(a), and Fig. 6(b) expresses the correlation output. The occurred height of correlation peak is 0.54.

(a) (b)

Fig. 4 Rotated fingerprint recognition
(a) the input plane of BPEJTC
(b) the correlation output



(a) (b)

Fig. 5 Partially damaged fingerprint recognition
(a) the input plane of BPEJTC
(b) the correlation plane

(a) (b)

Fig. 6 Different classes fingerprint recognition
(a) the input plane of BPEJTC
(b) the correlation plane

When we used the correlator that is used with circular harmonic from the above recognition results, we could obtain excellent rotation constant characteristic and found out of effective results when it's applied on fingerprints. Especially, If we use the optoelectronic system, the hybrid real-time system is possible according to the BPEJTC of real-time correlation system is used. But for a practical application of circular harmonic, it's very important to find the center of circular harmonic, and after the place of the center is known, it will show very strong rotation capability.

6. Conclusion

In this paper, we composed a BPEJTC system with CHF which recognizes fingerprint pattern of the most effective individual verification information and analyzed the fingerprint recognition characteristic. In the result of the performance testing, the proposed system showed strong capability on fingerprint damages, and on rotation and shifting of input images. But we still have problems of getting the center value of CHC, and we need to research about quantization to implement CRC effectively which appear in continuous level.

이 논문은 1998년도 광운대학교 교내학술연구비에 의하여 연구되었음.

REFERENCE

1) B. Moayer and K.S. Fu, "A Syntactic Approach to Fingerprint Pattern Recognition", Pattern Recognition, Pergamon Press, Vol. 7, pp. 1~23, 1975.
2) A. Vander Lugt, "Signal Detection by Complex Spatial Filtering", IEEE Trans. Inf. Theory, Vol. IT-10, pp. 139~145, 1964.
3) C.S. Weaver and J.W. Goodman, "A Technique for Optically Convolving Two Function", Appl. Opt. Vol. 5, No. 7 pp. 1248

~1249, 1966.
4) H.H. Arsenault, T. Szoplik, and B. Macukow, Optical Processing and Computing Academic Press. Ch.10, pp. 315~342, 1989.
5) F.T.S.Yu, X.Li, E.Tom, S.Jutamulia, and D.A.Gregory, "Rotation invariant pattern recognition with a programmable joint transform correlator", Appl. Opt., Vol. 28, No. 22, pp. 4725~4727, 1989.
6) B.V.K. Vijaya Kumar and T.K. Ng, "Multiple circular-harmonic function correlation filter providing specified response to in-plane rotation", Appl. Opt., Vol. 35, No. 11, pp. 1871~1878, 1996.
7) B. Javidi, "Nonlinear Joint Power Spectrum based Optical Correlation", Appl. Opt., Vol. 28, No. 12, pp. 2358~2367, 1989.
8) K.H. Fielding, J.L. Horner, and C.K. Makekau, "Optical fingerprint identification by binary joint transform correlation", Opt. Eng., Vol. 30, No. 2, pp. 1958~1961, 1991.
9) S.Y. Yi and E.S. Kim, "A BPEJTC-based segmentation for a nonstationary image", Opt. Comm., Vol. 123, No. 4-6, pp. 716~724, 1996.
10) S.H. Lee, S.Y. Yi, and E.S. Kim, "Optical fingerprint identification based on Binary Phase Extraction Joint Transform Correlator", Proc. SPIE, Vol. 2752, pp. 224~232, 1996.