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A Study of Feature Extraction Techniques and Image Enhancement Algorithms for Finger Vein Recognition

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Abstract: Finger vein biometric has many advantages which set it apart as a secure, convenient and reliable means of personal authentication. This paper provides a detailed study of the existing feature extraction techniques and image enhancement algorithms for finger vein recognition. A brief overview of the development and the key stages of the finger vein biometric are provided. The current trends, future directions and open problems in this field are also discussed.
Keywords: Finger vein image, recognition, feature extraction, enhancement.

Introduction

As a recently emerged biometric technic, finger vein recognition has been recognized as one of the most efficient and reliable biometric technology for personal authentication and security. Biometrics use physiological or behavioral characteristics of individuals for authentication. Automated methods are used to recognize a person through physiological characters such as finger print, iris,DNA or behavioral traits like signature, voice and gait. Conventional biometric systems have their own shortfalls, such as sensitivity to age and facial expression in face recognition, forgery using dummy finger fitted with a copied finger print in finger print recognition, psychological resistance of individuals against getting direct light in the eyes in iris recognition and forgery using recorded voice in the case of voice recognition. Finger vein biometric offers promising solutions to these challenges with its unique characteristics like resistance to forgery, high accuracy, uniqueness and consistency, noninvasive and contactless imaging, fast authentication speed, small and affordable capturing devices and living body identification [4].

Recently finger vein biometric has attractedincreasing interest from many researchers and thus considerable development is seen in the past decade. Hitachi Ltd. of Japan has been exploring the finger vein technology since 1997 and was the first to commercialize the finger vein authentication into product form which was released in 2002. Hitachi developed ATM applications in 2004 and commercialized them in 2005.Kono et al. [1],from the medical systems researcher department of Hitachi Ltd, Japan proposed finger vein pattern matching as a new method for identification of individuals. Miura et al.[2] suggested a feature extraction method based on repeated line tracking for finger vein images and another method using maximum curvature points[3].Yangawa et al.[5]described the diversity of finger vein images and its usefulness in personal identification using 2024 finger vein images from 506 persons. Another significant literature is by Kumar et al.[6]used Gabor to extract finger vein patterns and suggested fusion of finger vein and finger texture. They also published a data base which was a part of a homologous multimodal data base. Although there are some significant works in finger vein technology, there is always a scope for further research and improvement in this field.

The different stages of finger vein recognition systems can be broadlyclassified into image acquisition, preprocessing, feature extraction and matching.

Image acquisition

Finger vein images are acquired by exposing the finger to near infrared rays of 760 to 900 nm wavelength [7]and capturing the image using a CCD camera[4]. As deoxygenated hemoglobin in the vein absorbs the light rays, the vein pattern appears darker than the other regions in the image. For image acquisition either light reflection method or light transmission method is used. In light reflection method image sensor is placed on the same side of the light source and the light reflected from the surface of the finger is captured by the sensor as image. In light transmission method[2,3,6] the finger is placed between the image sensor and the light source and the near infrared light which penetrates through the finger is captured on the other side by the sensor. Normally the light source is placed in the finger dorsal side and the sensor underneath the finger. Some use side lighting where the light source and the sensor are placed on the two sides of a finger, which provides a high contrast imaging and convenient way of placing the finger on an open, ceiling less device[2]. Finger vein pattern from the acquired image is compressed and digitized so that it can be registered as a template of a person's biometric authentication data. Then the finger vein pattern of a person is authenticated by means of suitable pattern matching technique.

Preprocessing

Captured finger vein image needs to be preprocessed before extracting the features by (i)ROI detection,(ii)image size normalization and (iii)image enhancement.

To begin with,the captured image is trimmed and the Region OfInterest (ROI) is determined from vein image[8,9]. This step decides which part of the image is suitable for the feature extraction.The length of ROI is detected using phalangeal joints and width of ROI is calculated using the internal tangents of edges of fingers[10].

After determining the ROI, the finger vein image has to be normalized[2,11]in order to accommodate the geometric changes in the positioning or angle of the fingerused for authentication. A skewed image has to be detected and corrected. As there can be size variations due to the position of sensor and individual ROI variation, image should be resized to obtain the consistent size of images.

The captured image can be of low contrast, non-uniform illumination or noisy and so image enhancement place an important role in finger vein pattern recognition. The subsequent feature extraction process become less complex if the contrast between vein structures and the surrounding tissue is increased. Different enhancement techniques can be adopted to enhance the captured image.

Feature extraction

After pre-processing finger vein patterns are extracted from the image. Finger vein extraction algorithms are the fundamental components of finger vein recognition systems. There are several feature extraction methods which have been proposed and successfully implemented in extracting the finger vein pattern.Next, these extracted biometric samples are reduced to mathematical templates and only these enrolled templates are stored in system database. A template size like 256 or 512 bytes should be fixed in order to reduce the storage space.

Image enhancement and feature extraction techniques

Gabor filter

Gabor filters are linear filters which have been found to be particularly appropriate for finger vein extraction due to its directional selectiveness, capability of detecting oriented features and fine tuning to specific frequencies. When a Gabor filter is applied to an image, it gives the highest response at edges and at points where texture changes. The simple cells of the visual cortex of mammalian brains are best modeled as a family of self-similar 2D Gabor wavelets[12] and image analysis with Gabor filters is thought to be similar to perception in the human visual system.

A Gabor filter can be viewed as a sinusoidal plane of particular frequency and orientation, modulated by a Gaussian envelope.The general form of even symmetric Gabor filtering is as follows:

$$R(x, y, f, \varphi) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left[-\frac{1}{2}\left(\frac{x_\varphi^2}{\sigma_x^2} + \frac{y_\varphi^2}{\sigma_y^2}\right)\right] \cos(2\pi f x_\varphi)$$

Here $\begin{bmatrix} x_\varphi \\ y_\varphi \end{bmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$ where φ is the orientation of the Gabor filter, f is the frequency of a sinusoidal plane wave.

- Ajay Kumar et al.[6] proposed a framework for the finger vein feature extraction using multi-orientation Gabor filters. The power spectrum sampling of each of the finger vein images using a set of self-similar even Gabor filters is performed in this work. It was clear from the experimental results that the extracted vein structure fits quite well in the original image vascular topologies and the accompanying noise is suppressed very well.
- Jinfeng Yang et al. [13] have used the circular Gabor filter enhance finger-vein region in an image. In [14] multi-channel Gabor filters are used to prominently protrude vein vessel information with variances in widths and orientations in images. The vein information in different scales and orientations of Gabor filters is then combined together to generate an enhanced finger-vein image using a reconstruction rule. A bank of even-symmetric Gabor filters with eight orientations is used to exploit vein information in images in [15].
- Jing Zhang et al.[16] proposed a combination of gray-level grouping (GLG) and circular Gabor filter (CGF) for finger-vein image enhancement. First, GLG is used to reduce illumination fluctuation and improve the contrast of finger-vein images. Then a circular Gabor filter is used to further strengthen vein ridges in images.
- Wang Kejun et al. [17] have used 2-D Gabor filter to filter the original vein image. Then the phase and direction texture features are extracted. An algorithm is used for fusion at feature level.
- Shan Juan Xie et al. [18] have described about Guided Gabor filter which is to extract the finger vein pattern without any segmentation processing, and lower performance reduction for poor quality images. The proposed filter is contributed for finger vein enhancement, noise reduction, and haze removal without being affected by the brightness of the vein. It performs well not only on ridge detection like the Gabor filter, but on image enhancement as an edge-preserving smoothing operator without the gradient reversal artifacts.
- SoRa Cho et al. [19] have enhanced the distinctiveness of finger-vein region in the finger vein image by applying an adaptive Gabor filter which is optimized to the measured direction and thickness of finger-vein area.

Repeated line tracking

Repeated line tracking is a method of tracing lines along the vein patterns in a preprocessed image. This process is repeated a specified number of times until the vein pattern can be extracted. For every iteration, a starting point in the form of a pixel is chosen. From this point, the algorithm attempts to trace a line in the direction of the vein pattern, based on a cross sectional profile of the image in a given direction .If the tracking point is inside a vein, the cross section will show a valley. The next tracking point is chosen in the direction of the deepest valley. Every time a pixel is chosen as a tracking point, its value is increased in a corresponding pixel map. When all iterations are completed, the created pixel map should have high intensities within the vein boundaries.

- Naoto Miura et al.[2] proposed line-tracking operations with randomly varied start points that are repeatedly carried out to extract the patterns from an unclear original image. Evaluation of its robustness against image darkness showed that it is far superior to the conventional method based on a matched filter. Further experiments showed that the equal error rate was 0.145% and the response time was 460 ms. Evaluation of its robustness against image darkness showed that it is far superior to the conventional method based on a matched filter.
- T Liu et al. [20] proposed a modified repeated line tracking algorithm to figure out the locus space of finger-vein based on the revised parameters and was found to be efficient.

Maximum curvature

Maximum curvature method utilizes the fact that a vein appears like a dent with high curvature in the cross-sectional profile. The curvature of the image profiles are checked and only the centerlines of veins are emphasized. The centerlines are detected by searching for positions where the curvatures of a cross-sectional profile of a vein image are locally maximal.

- Naoto Miura et al.[3] developed a method of calculating local maximum curvatures in cross-sectional profiles of a vein images with various widths and brightnesses. They extracted the vein center points by calculating the local maxima of each cross sectional profile. Experimental results show that the equal error rate for personal identification was 0.0009%, which is much better than that of conventional methods.
- Wonseok Song et al. [21] proposed the mean curvature method, which views the vein image as a geometric shape and finds the valley-like structures with negative mean curvatures. The method extracts the high curvature regions which have high possibility of being vein regions. In addition, it employs gradient normalization to prevent the variation of the curvature that is caused by the varying thickness and brightness of the veins. Experimental results show that, while maintaining low complexity, the proposed method achieves 0.25% equal error rate, which is significantly lower than what existing methods can achieve.
- Joon Hwan Choi et al.[22] proposed a finger vein extraction using and principal curvature where the principal curvatures are obtained from the eigenvalues at each pixel of the Hessian matrix which describes the local shape characteristics of an image at a particular point. As tubular-shaped regions have higher maximum curvatures than other regions, this method extracted the vein regions from the intensity surface by calculating the principal curvature.

Local binary pattern methods

Local Binary Pattern (LBP) is a very efficient texture operator which labels the pixels of an image by thresholding the neighborhood of each pixel and considers the result as a binary number. Due to its discriminative power and computational simplicity, LBP texture operator has been popularly used in finger vein extraction.

- EuiChul Lee et al. [23] proposed a finger vein extraction method by extracting a unique finger vein code using a LBP after aligning the finger vein image based on minutia points and this method was found to help in reducing the false rejection error and thus the Equal Error Rate (EER) significantly.
- BakhtiarAffendiRosdi et al.[24] used the Local Line Binary Pattern (LLBP) as feature extraction technique. The straight-line shape of LLBP can extract robust features from the images with unclear veins. Experimental results on the images from 204 indicated that the EER for the LLBP was lower than the LBP and the feature extraction time was faster.
- Hyeon Chang Lee et al.[25] used an extraction method using weighted local binary pattern code in which holistic codes were extracted through the LBP method without using a vein detection procedure, which reduced the processing time and the complexities in detecting finger vein patterns. After that different weights were assigned to the extracted LBP code according to the local area type .The optimal weights were determined empirically in terms of the accuracy of the finger vein recognition.
- Gongping Yang et al.[26] proposed a method based on a Personalized Best Bit Map(PBBM)which effectively removed noisy bits. From the samples of the LBP codes of an individual the Best Bit Map (BBM) is determined first and these are taken as the new LBP codes. These new LBP codes are used to get the PBBM.PBBMs are different from individual to individual and can be regarded as a personalized feature.
- XianjingMeng et al. [27] implemented Local Directional Code(LDC) method for vein extraction.In this method a finger vein image is converted into a code map with the same size. Each element is a directional code ranging from 0 to 7. The two components of the local direction is calculated first, then the gradient orientation is computed. At last, the gradient direction is further quantized.

Dimensionality reduction methods

A dimensionality reduction method transforms the data in the high-dimensional space to a space of fewer dimensions. Principal component analysis performs a linear mapping of the data to a lower-dimensional space in such a way that the variance of the data in the low-dimensional representation is maximized. The correlation matrix of the data is constructed and the eigenvectors on this matrix are computed. The eigenvectors that correspond to the largest eigenvalues (the principal components) can now be used to reconstruct a large fraction of the variance of the original data. The first few eigenvectors can often be interpreted in terms of the large-scale physical behavior of the system. The original space has been reduced to the space spanned by a few eigenvectors.

- Jian-Da Wu et al. [28] presented finger vein preprocessing with Principal Component Analysis (PCA). Finger-vein features are first extracted by PCA method to reduce the computational burden and removes noise residing in the discarded dimensions. The features are then used in pattern classification and identification. In [29] they have proposed a technique for finger-vein pattern identification where, PCA and Linear Discriminate Analysis (LDA) are applied to the image pre-processing as dimension reduction and feature extraction. For pattern classification, this system used a Support Vector Machine(SVM) and adaptive neuro-fuzzy inference system. The PCA method is used to remove noise residing in the discarded dimensions and retain the main feature by LDA. The features are then used in pattern classification and identification. The accuracy of classification using SVM is 98% and only takes 0.015 s.
- Gongping Yang et al. [30] proposed a finger vein recognition method based on (2D)2 PCA and metric learning. They applied (2D) 2 PCA to extract features of finger vein image, where (2D) 2 PCA reflects the information in both the row direction and the column direction and then train a binary classifier for each individual based on metric learning. Furthermore, we address the class imbalance problem by using SMOTE oversampling before the classifier is trained. The experimental results show that the proposed method achieves a recognition rate of 99.17%.
- Zhi Liu et al. [31] proposes a finger vein recognition technique with manifold learning using Orthogonal Neighborhood Preserving Projections (ONPP) to map the infrared finger vein images into a lower dimensional feature space. When an image data set is generated by varying some parameters, such as a combination of pose, lighting, or camera viewpoints, then this set can be considered to be sampling a continuous manifold of the space of all possible images. Manifold learning is understanding this manifold for a given a set of images and automatically parameterizing each image by its place on this manifold. ONPP is a linear dimensionality reduction technique and tends to preserve not only the local, but also the global geometry of high dimensional data samples.

Histogram equalization

Histogram equalization provides a sophisticated method for enhancing the contrast of a finger vein image by effectively spreading out the most frequent intensity values. An image histogram is a graphical representation of the intensity distribution of an image. It quantifies the number of pixels for each intensity value considered.Histogram Equalization is a method that improves the contrast in an image, in order to stretch out the intensity range. It employs a monotonic, non-linear mapping which reassigns the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities.

- Xue-bing Wen et al. [32] used histogram template equalization method for contrast enhancement of the vein images which have undergone wavelet denoising.
- Wei Pi et al.[33] used histogram equalization for enhancing the contrast of finger vein images which has undergone denoising using edge preserving filter and enhancement by elliptic high pass filter.

Fuzzy based methods.

Fuzzy techniques can manage the uncertainty and imperfection of a finger vein image which can be represented as a fuzzy set. Fuzzy logic can be used to process human knowledge in the form of fuzzy if-then rules. The accumulation of all these approaches comes up to the theory of fuzzy image processing, which is divided into 3 phases: Image fuzzification, membership values modification, and image defuzzification.

- Cheng-Bo Yu et al. [34] proposed an image enhancement algorithm based on fuzzy theory. The average of all adjacent points is as enhancement threshold and affiliation of each point is obtained by counting the average. Then, enhancement images are obtained with inverse transformation. Experiments have proved that contrast of vein and background is enhanced and effect of image segmentation and extraction is improved with the method.

- Kwang Yong Shin et al.[35] developed a fuzzy-based image fusion algorithm for enhancing the quality of a finger-vein images. The optimal weights for the fuzzy-based fusion method were determined using the mean and STD values in the local windows of the images produced by Gabor filtering and Retinex filtering, which were employed as the inputs for the fuzzy rule and fuzzy membership function. Based on the optimal weights obtained, finger-vein image enhancement was achieved by combining the Gabor and Retinex filtered images. The experimental results showed that the finger-vein recognition accuracy was enhanced.
- Lin You et al.[36] presented a finger vein enhancement technique based on both fuzzy sets and oriented filters. Fuzzy enhancement was used to reduce to remove the ambiguity of a poor-quality finger vein image then, a group of directional templates were applied to filter the image based on the orientation field. For fuzzy enhancement the membership function of the fuzzy set was defined which maps all elements of the image matrix into the real numbers in [0, 1]. Then the value of the membership function was modified by a nonlinear transformation. Then the fuzzy domain was mapped on to the spatial domain in order to reconstruct the image using the inverse transform of the membership function. In [37] they proposed a finger vein feature extraction method on fuzzy set theory and gray-scale morphology.

Matching

Matching is the key procedure of deciding whether a particular finger vein image is genuine or imposter using a set of appropriate matching algorithms. In finger vein authentication it is a one to one matching process where as in finger vein identification it is one too many.In effect feature matching is nothing but a task of similarity computation. For finger vein authentication, the user's identity is confirmed as genuine, if the similarity is greater than a threshold value fixed in advance. If the similarity is lesser than the threshold value the user is regarded as an imposter. In the case of finger vein identification, the user can be confirmed as the one whose finger vein data has maximum similarity score. There is some standard performance indicators used in evaluating the performance and accuracy of a finger vein recognition system quantitatively. False acceptance rate (FAR) is the probability of accepting an unauthorized individual as genuine. False rejection rate (FRR) is the probability of rejecting an authorized individual treating it as imposter. An ideal finger vein recognition system will have a low FRR and FAR [2].

There are several popular used approaches of similarity measurement used for finger vein matching. Some of the methods adopted for finger vein matching are matched pixel ratio method[21], matching using hamming distance[23,24], singular value decomposition based minutia matching[39],modified hausdorff distance [38] and matching using support vector machines40],phase only correlation[41].

Challenges and future research directions

Even though some remarkable research advancements have been done in the field of finger vein recognition during the past decade, there are many shortfalls that need to be addressed.

- The study of the available literatures at present assures that there is a vast scope of further research on application of the different image processing techniques in finger vein recognition system.
- Focusedstudy is needed on the permanence characteristic of finger vein pattern to prove the medical evidence about the stability of the vein pattern of an individual in his life time.
- Some large scale databases of finger vein images should be made available which will be useful in comparing the existing techniques of finger vein recognition.
- Bimodal biometric using finger vein along with finger print biometric should be studied further which provides an opportunity to employ the benefits of both.
- More focus should be given on miniaturization of the imaging device as well as on the cost reduction of the finger vein recognition system.
- Further research is needed on the application of finger vein authentication in portable devices such as mobile phones and grip type authentication for automobile doors and office doors which will ensure security without keys.

Conclusions

This paper provides a detailed study of the existing feature extraction techniques and image enhancement algorithms for finger vein recognition. A brief overview of the development and the key stages of the finger vein biometric are provided. The current trends, future directions and open problems in this field are also discussed. Accuracy and robustness of feature extraction techniques is essential to achieve a more precise and efficient finger vein recognition system. The analysis of the present literatures reveals the suitability of the vein tracking based algorithms and the scope of fuzzy based methods. In the future works, research could be concentrated on application of fuzzy and intuitionistic fuzzy based techniques in the finger vein recognition.

References

1. M. Kono, H. Ueki, S. I. Umemura, A new method for the identification of individuals by using of vein pattern matching of a finger, Proceedings of the 5th symposium on pattern measurement, Yamaguchi, Japan,2000, pp 9-12.
2. N.Miura, A. Nagasaka, T. Miyatake, Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification, Machine Vision and Applications, 2004, Vol 15, pp 194-203.
3. N.Miura, A.Nagasaka, T. Miyatake, Extraction of finger-vein patterns using maximum curvature points in image profiles, IEICE TRANSACTIONS on Information and Systems, 2007, Vol 90, pp 1185-1194.
4. J. Hashimoto, Finger vein authentication technology and its future, In VLSI Circuits, Symposium on Digest of Technical Papers, 2006, pp. 5-8.
5. T. Yanagawa, S.Aoki, T. Ohyama, Human finger vein images are diverse and its patterns are useful for personal identification, MHF Preprint. Series, 2007, Vol12, pp 1-7.
6. A.Kumar, Y. Zhou, Human identification using finger images, IEEE Transactions on Image Processing, 2012, Vol 21, pp 2228-2244.
7. L.Wang, G. Leedham, Near-and far-infrared imaging for vein pattern biometrics, IEEE International Conference on Video and Signal Based Surveillance, 2006, pp. 52-52.
8. L.Yang, G. Yang, Y. Yin, R. Xiao, Sliding window-based region of interest extraction for finger vein images, Sensors, 2013, Vol 13, pp 3799-3815.
9. J.Yang, Y.Shi, Finger–vein ROI localization and vein ridge enhancement, Pattern Recognition Letters, 2012, Vol 33, pp 1569-1579.
10. J. Yang, X. Li, Efficient finger vein localization and recognition, 20th International Conference on Pattern Recognition (ICPR), 2010, pp 1148-1151.
11. B. Huang, Y. Dai, R. Li, D. Tang, W. Li, Finger-vein authentication based on wide line detector and pattern normalization, 20th International Conference on Pattern Recognition (ICPR), 2010, pp 1269-1272.
12. J. P. Jones, L. A. Palmer, An evaluation of the two-dimensional Gabor filter model of simple receptive fields in cat striate cortex, Journal of neurophysiology, 1987, Vol 58, pp 1233-1258.
13. J. Yang, Y. Shi, J. Yang, L. Jiang, A novel finger-vein recognition method with feature combination, 16th IEEE International Conference on Image Processing (ICIP), 2009, pp 2709-2712.
14. J. Yang, J. Yang, Multi-channel gabor filter design for finger-vein image enhancement, Fifth International Conference on Image and Graphics, 2009, pp. 87-91.
15. J. Yang, Y. Shi, J. Yang, Finger-vein recognition based on a bank of Gabor filters, Computer Vision, 2009, pp 374-383.
16. J. Zhang, J. Yang, Finger-vein image enhancement based on combination of gray-level grouping and circular Gabor filter, International Conference on Information Engineering and Computer Science, 2009, pp 1-4.
17. W. Kejun, L. Jingyu, P. P. Oluwatoyin, F. Weixing, Finger vein identification based on 2-D gabor filter, 2nd International Conference on Industrial Mechatronics and Automation (ICIMA), 2010, Vol 2, pp 10-13.
18. S. J.Xie, J.Yang, S. Yoon, L. Yu, D. S. Park, Guided Gabor filter for finger vein pattern extraction,Eighth International Conference on Signal Image Technology and Internet Based Systems (SITIS), 2012, pp 118-123.

19. S. R.Cho, Y. H.Park, G. P. Nam, K. Y. Shin, H. C.Lee, K. R. Park, H. C. Kim, Enhancement of Finger-Vein Image by Vein Line Tracking and Adaptive Gabor Filtering for Finger-Vein Recognition, Applied Mechanics and Materials,2012, Vol 145, pp 219-223.
20. T.Liu, J. B. Xie, W. Yan, P. Q. Li, H. Z.Lu, An algorithm for finger-vein segmentation based on modified repeated line tracking, The Imaging Science Journal,2013,Vol 61, pp 491-502.
21. W.Song, T. Kim, H. C. Kim, J. H. Choi, H. J. Kong, S. R.Lee, A finger-vein verification system using mean curvature, Pattern Recognition Letters, 2011,Vol 32,pp 1541-1547.
22. J. H.Choi, W.Song, T. Kim, S. R. Lee, H. C. Kim, Finger vein extraction using gradient normalization and principal curvature, International Society for Optics and Photonics, 2009,pp 725111-725111.
23. E. C.Lee, H. C.Lee, K. R. Park, Finger vein recognition using minutia-based alignment and local binary pattern-based feature extraction, International Journal of Imaging Systems and Technology,2009, Vol 19,pp 179-186.
24. B. A.Rosdi, C. W.Shing, S. A. Suandi, Finger vein recognition using local line binary pattern. Sensors, 2011, Vol 11, pp 11357-11371.
25. H. C.Lee, B. J. Kang, E. C. Lee, K. R. Park, Finger vein recognition using weighted local binary pattern code based on a support vector machine, Journal of Zhejiang University SCIENCE C, 2010, Vol 11, pp 514-524.
26. G.Yang, X. Xi, Y. Yin, Finger vein recognition based on a personalized best bit map. Sensors, 2012, Vol 12, pp 1738-1757.
27. X.Meng, G.Yang, Y.Yin, R. Xiao, Finger vein recognition based on local directional code. Sensors, 2012, Vol 12, pp 14937-14952.
28. J. D.Wu, C. T. Liu, Finger-vein pattern identification using principal component analysis and the neural network technique, Expert Systems with Applications, 2011, Vol 38, pp 5423-5427.
29. J. D.Wu,C. T. Liu, Finger-vein pattern identification using SVM and neural network technique, Expert Systems with Applications, 2011, Vol 38, pp 14284-14289.
30. G.Yang, X.Xi, Y. Yin, Finger vein recognition based on (2D) 2 PCA and metric learning, BioMed Research International, 2012.
31. Z.Liu, Y. Yin, H.Wang, S. Song, Q. Li, Finger vein recognition with manifold learning. Journal of Network and Computer Applications, 2010, Vol 33, pp 275-282.
32. X. B. Wen, J. W. Zhao, X. Z. Liang, Image Enhancement of Finger-vein Patterns Based on Wavelet Denoising and Histogram Template Equalization, Journal of Jilin University (Science Edition), 2008.
33. W.Pi, J.Shin, D. Park, An effective quality improvement approach for low quality finger vein image,International Conference on Electronics and Information Engineering (ICEIE), 2010, Vol 1, pp V1-424.
34. C. B.Yu, D. M. Zhang, H. B. Li, F. F. Zhang, Finger-vein image enhancement based on muti-threshold fuzzy algorithm,2nd International Congress on Image and Signal Processing, 2009,pp. 1-3.
35. K. Y. Shin, Y. H. Park, D. T.Nguyen, K. R. Park, Finger-vein image enhancement using a fuzzy-based fusion method with Gabor and retinex filtering, Sensors, 2014, Vol 14, pp 3095-3129.
36. L.You, L. Sun, J.Zhang, Finger Vein Images Enhancement Method Based on Fuzzy Set and Oriented Filter, International Journal of Digital Content Technology and its Applications, 2012, Vol 6, p 271.
37. L.You, J.Zhang, L. Sun, Finger Vein Feature Extraction Method Based on Fuzzy Set Theory and Gray-scale Morphology, Journal of Convergence Information Technology, 2013,Vol 8, p 152.
38. C. B.Yu, H. F.Qin, Y. Z.Cui, X. Q. Hu, Finger-vein image recognition combining modified hausdorff distance with minutiae feature matching, Interdisciplinary Sciences: Computational Life Sciences, 2009, Vol 1, pp 280-289.
39. F.Liu, G.Yang, Y. Yin, S. Wang, Singular value decomposition based minutiae matching method for finger vein recognition, Neurocomputing, 2014, Vol. 145, pp 75-89.
40. H. C.Lee, B. J.Kang, E. C. Lee, K. R.Park, Finger vein recognition using weighted local binary pattern code based on a support vector machine, Journal of Zhejiang University, 2010, Vol 11, pp 514-524.
41. N.Mahri, S. A. S. Suandi, B. A. Rosdi, Finger vein recognition algorithm using phase only correlation. International Workshop on Emerging Techniques and Challenges for Hand-Based Biometrics (ETCHB), 2010, pp 1-6.

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