

MULTISPECTRAL PALM VEIN IMAGE FUSION FOR CONTACTLESS PALM VEIN VERIFICATION SYSTEM

SOH SHI CHUAN

Master Of Science

UNIVERSITI MALAYSIA PAHANG



SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

(Supervisor's Signature)

Full Name : DR ZAMRI BIN IBRAHIM

Position : SENIOR LECTURER

Date :

(Co-supervisor's Signature)

Full Name : MARLINA BINTI YAKNO

Position : SENIOR LECTURER

Date :



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : SOH SHI CHUAN

ID Number : MEL16012

Date :

MULTISPECTRAL PALM VEIN IMAGE FUSION FOR CONTACTLESS PALM
VEIN VERIFICATION SYSTEM

SOH SHI CHUAN

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Electrical & Electronics Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2018

ACKNOWLEDGEMENTS

First and foremost, I am very grateful and thankful to God for giving me the strength and wisdom to discover and complete my graduate program. Under His guidance and blessing, I am able to complete my graduate study smoothly.

I would like to express my sincere gratitude to my supervisor, Dr. Mohd Zamri bin Ibrahim for giving me the opportunity and full support to complete my graduate study under his supervision. His continuous guidance, encouragement and relentlessly giving support and ideas, makes this research to be successful. I am also very grateful to Mrs Marlina binti Yakno as the co-supervisor for many valuable lessons and encouragements.

Not to forget, I would like to express my sincere thanks to Ministry of Higher Education Malaysia for supporting funding of this research project under Fundamental Research Grant Scheme (FRGS) with Grant Nos. RDU160108.

Moreover, I would also like to express my sincere gratitude towards the staff and lecturers of both Institute of Postgraduate Studies and Faculty of Electrical and Electronics Engineering Universiti Malaysia Pahang for providing help directly or indirectly to complete my studies. My special gratitude also goes to the Institute of Postgraduate Studies and Research and Innovation Department for financial support, without their funding, this work would not have happened

Last but not least, I would like to thank my beloved family members for their continuous supports to attain my goals. I am also grateful to my friends who always give me encouragement, determination and help to complete my study.

ABSTRAK

Sistem pengesanan biometrik semakin memberi perhatian dengan usaha untuk melindungi keselamatan dan maklumat kami dalam dunia penyamaran digital ini. Pengesanan urat tapak tangan adalah pengesanan biometrik yang terkenal kerana biometric ini menunjukkan tahap pengesanan yang tinggi. Walau bagaimanapun, kerumitan dan keunikan corak urat tapak tangan menyebabkan pengesanan yang kurang tepat. Imej berkualiti rendah akan memberi kesan kepada proses sistem walaupun proses pengekstrakan ciri urat tapak tangan adalah sempurna. Ini adalah sebab daripada imej kontras yang tidak jelas dan rendah. Terdapat kajian yang dibuat menunjukkan bahawa kemungkinan menggunakan kaedah gabungan imej akan meningkatkan ketepatan pengiktirafan ke tahap yang lebih tinggi. Imej gabungan adalah satu kaedah dengan mengumpulkan maklumat penting dari semua imej dan membuat imej baru yang mempunyai maklumat penting dari semua imej. Gabungan imej dapat memberi maklumat penting dengan meningkatkan kualiti dan kebolegunaan data daripada imej input tunggal sahaja. Dalam tesis ini, Discrete Cosine Transform (DCT) adalah salah satu algoritma gabungan imej yang dicadangkan dalam pengesanan urat tapak tangan. Imej akan dibahagikan kepada blok yang berturut-turut dan akan ubah menjadi pekali DCT. Pekali DCT akan melalui peraturan fusion dan akan diubah kembali ke imej gabungan dengan menggunakan IDCT. Dalam tesis ini, pangkalan data CASIA digunakan untuk memberi tiga jenis spectrum iaitu 700 nm, 850 nm dan 940 nm. Terdapat empat kombinasi gabungan imej yang boleh dibentuk dalam tesis ini iaitu kombinasi dua imej 700 nm dengan 850nm, 700 nm dengan 940 nm, dan 850 nm dengan 940 nm dan juga gabungan tiga imej dengan semua jenis spektrum. Gabungan imej dengan Multi-resolution DCT (MRDCT), DCT Partition Frequency DCT (FPDCT) dan Laplacian Pyramid DCT (LPDCT) diperkenalkan untuk menggabungkan maklumat dari pelbagai jenis spektrum jarak dan memberikan imej output yang lebih jelas dalam corak vein tapak tangan. Dalam tesis ini, gabungan imej antara tiga jenis spektrum mencapai tahap yang lebih baik daripada gabungan imej antara dua jenis spektrum. MRDCT melakukan kadar EER yang terbaik 5.53% berbanding dengan FPDCT dan LPDCT dalam imej gabungan tiga jenis spectrum. Kaedah konvensional seperti Multi-resolution Singular Value Decomposition (MSVD), Wavelet Transform dan Energy of Laplacian (EOL) hanya dapat mencapai kadar EER sebanyak 6.58%, 6.83% dan 8.64% masing-masing. Di samping itu, MRDCT dengan gabungan tiga jenis spektrum menunjukkan penurunan kadar EER sebanyak 9% berbanding dengan imej 700 nm tunggal, 7% berbanding dengan imej 850 nm tunggal, dan 6% berbanding dengan imej tunggal 940 nm. Ia membuktikan bahawa gabungan imej MRDCT sesuai untuk pengesanan urat tapak tangan. Terdapat dua jenis keadah Scale Invariant Feature Transform (SIFT) and Speeded Up Robust Feature (SURF) berdasarkan pengekstrakan ciri urat tapak tangan disiasat. Algoritma SIFT mencapai penurunan kadar EER sebanyak 12% pada 700 nm, 8% pada 850 nm, 7% pada 940 nm berbanding dengan algoritma SURF. Hasilnya menunjukkan bahawa algoritma SIFT mencapai kadar pengesanan yang lebih baik dan mengekstrak lebih banyak maklumat dan pasangan sepadan berbanding dengan algoritma SURF. Sebagai kesimpulan, gabungan imej MRDCT dengan pengekstrakan SIFT sesuai digunakan dalam sistem pengesanan biometric urat tapak tangan tanpa sentuhan sensor.

ABSTRACT

Biometrics recognition system are getting more attention in efforts to protect our security and information in this world of digital impersonation. Palm vein recognition are well-known in biometrics recognition where it shows a high level of authentication. However, there is still an unsolved issued in accuracy due to the complexity and uniqueness of palm vein pattern. Low quality image provides unclear and low contrast image affecting the process although palm vein feature extraction is perfect. There were studies to investigate the possibility that fusion methods would improve or enhance the accuracy to a higher level. Image fusion is a method to collect necessary information from all input image with different sources and create an output image that ideally has information from input image. Fused image can provide more information than single input image that improve quality and applicability of data. In this work, image fusion algorithms based on Discrete Cosine Transform (DCT) in palm vein recognition is proposed. Input image will be divided into consecutive blocks and transformed into DCT coefficients. Fusion rule will be applied within the DCT coefficients and transformed back into fused image using inverse DCT. In this work, CASIA database is used to provide three types of wavelength spectrum which are 700 nm, 850 nm, and 940nm. There are four combination of image fusion that can be formed, dual combination with 700 nm and 850nm, 700 nm and 940 nm, 850 nm and 940 nm and triple combination of all wavelength. Multi-resolution DCT (MRDCT), Frequency Partition DCT (FPDCT) and Laplacian Pyramid DCT (LPDCT) image fusion is introduced on fusing more informative information from different types of wavelength and resulting in an image with finer details of vein patterns in the output image. In this work, triple combination of image fusion achieve better than dual combination of image fusion. By fusing three wavelength spectrums, MRDCT performed the best at 5.53% in EER rate compared to FPDCT and LPDCT. The conventional method such as Multi-resolution Singular Value Decomposition (MSVD), wavelet transform and Energy of Laplacian (EOL), were only able to achieve EER rate of 6.58%, 6.83% and 8.64% respectively. In addition to that, MRDCT with triple wavelength spectrum fusion showed a significant drop in EER by 9% compared with single 700 nm image, 7% compared with single 850 nm image, and 6% compared with single 940 nm image. It proved that MRDCT image fusion is suitable for palm vein recognition. For feature extraction, two types of local invariant feature based method was investigated, Scale Invariant Feature Transform (SIFT) and Speeded Up Robust Feature (SURF). SIFT algorithm achieved a reduction in EER rate by 12% in 700 nm, 8% in 850 nm, 7% in 940 nm compared with the SURF algorithm. The result shows that SIFT algorithm achieved a better recognition rate and extract more information and matching pairs compared to SURF algorithm. In conclusion, MRDCT image fusion with SIFT feature extraction are suitable to use in contactless palm vein recognition system.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xiii
CHAPTER 1 INTRODUCTION	1
1.1 Background of work	1
1.2 Problem statement	3
1.3 Objective	4
1.4 Scope	5
1.5 Statement of contribution	5
1.6 Thesis outline	6
CHAPTER 2 LITERATURE REVIEW	8
2.1 Introduction	8
2.2 Palm vein image acquisition	8
2.3 Image pre-processing	10

2.4	Image fusion	13
2.5	Pyramid based image fusion	15
2.6	Discrete transform based image fusion	16
2.6.1	Discrete cosine transform (DCT)	16
2.6.2	Discrete wavelet transform (DWT)	18
2.6.3	Singular value decomposition based image fusion (SVD)	19
2.6.4	Energy of Laplacian image fusion (EOL)	20
2.7	Feature extraction	20
2.7.1	Geometry based method	20
2.7.2	Statistical based method	22
2.7.3	Local invariant feature based method	25
2.8	Feature matching	27
2.9	Critical review	27
2.10	Summary	29
CHAPTER 3 METHODOLOGY		30
3.1	Introduction	30
3.2	Palm vein image acquisition	31
3.3	Pre-processing	33
3.4	Palm vein image fusion	36
3.4.1	Discrete cosine transform (DCT) fusion	36
3.4.2	Multi-resolution singular value decomposition (MSVD)	41
3.4.3	Energy of Laplacian (EOL)	43
3.4.4	Wavelet transform (WT)	44
3.5	Feature extraction	45
3.5.1	Scale invariant feature transform (SIFT)	45

3.5.2	Speed up robust feature (SURF)	48
3.6	Feature matching	51
3.7	Summary	52
CHAPTER 4 RESULTS AND DISCUSSION		53
4.1	Introduction	53
4.2	Pre-processing	53
4.3	Feature extraction	58
4.3.1	SIFT feature extraction	59
4.3.2	SURF feature extraction	61
4.4	Comparison with the feature extraction method	63
4.5	Image fusion	65
4.6	Comparison with the image fusion method	67
4.7	Comparison with the conventional method	71
4.8	Summary	72
CHAPTER 5 SUMMARY AND FUTURE WORK		74
5.1	Introduction	74
5.2	Summary of the work	74
5.3	Future work	75
REFERENCES		77
APPENDIX A IMAGE FUSION TECHNIQUES IN DUAL COMBINATION OF DIFFERENT TYPE OF WAVELENGTH SPECTRUM		85
APPENDIX B EER AND AUC FOR IMAGE FUSION IN DUAL COMBINATION OF 700 NM AND 850 NM WAVELENGTH SPECTRUM		86
APPENDIX C EER AND AUC FOR IMAGE FUSION IN DUAL COMBINATION OF 700 NM AND 940 NM WAVELENGTH SPECTRUM		88

APPENDIX D EER AND AUC FOR IMAGE FUSION IN DUAL COMBINATION OF 850 NM AND 940 NM WAVELENGTH SPECTRUM	90
---	-----------

APPENDIX E EER AND AUC FOR IMAGE FUSION IN TRIPLE COMBINATION OF 700 NM , 850 NM AND 940 NM WAVELENGTH SPECTRUM	92
--	-----------

LIST OF TABLES

Table 4.1	Euclidean Distance of 10 samplers 10°, 20°, and 30° degree of rotation	57
Table 4.2	Equal Error Rate and Area Under Curve for three different wavelength using SIFT and SURF classifier in 700 nm, 850 nm and 940 nm image	64
Table 4.3	Equal Error Rate in 700 nm, 850 nm and 940 nm image	71
Table 4.4	Area Under Curve (AUC) in 700 nm, 850 nm and 940 nm image	71
Table 4.5	EER in 700 nm, 850 nm and 940 nm image and MRDCT with triple combination of wavelength	72

LIST OF FIGURES

Figure 2.1	Basic principle of near infrared camera on capturing palm vein image	9
Figure 2.2	Palm vein ROI extraction, a) ROI extraction, b) Central of boundary point, c) Estimation of center of the web points	11
Figure 2.3	Block diagram for ROI extraction in palm vein images.	11
Figure 2.4	Block diagram for palm vein recognition system.	12
Figure 2.5	Process of CHVD algorithms, (a) 4 valley points, (b) ROI for left palm, (c) ROI for right palm.	13
Figure 2.6	Overall fusion in different fusion level.	14
Figure 2.7	Image fusion based on discrete transform function	16
Figure 2.8	Process flow of DCT based image fusion in JPEG format.	17
Figure 2.9	Generic framework of DWT based image fusion in palm print recognition system	19
Figure 2.10	Coordinate system of LBP operator	23
Figure 2.11	LDP operator with the radius of 6 from the center position	24
Figure 3.1	Overall process of palm vein recognition system	30
Figure 3.2	Process flow of palm vein recognition system	31
Figure 3.3	Multispectral Imaging Device in CASIA database	32
Figure 3.4	Different types of wavelength (a) 460nm, (b) 630nm, (c) 700nm, (d) 850nm, (e) 940nm, (f) Natural Light.	33
Figure 3.5	Block diagram of pre-processing stage	33
Figure 3.6	The main steps of coordinate systems, (a) Original image, (b) Binary image, (c) boundary tracking, (d) Coordinate system with tangent line, (e) Subimage extracted in center part, (f) ROI extraction in palm	35
Figure 3.7	Block diagram for image fusion	36
Figure 3.8	Computation of 2-D DCT in column and row wise.	37
Figure 3.9	Image fusion process using DCT	37
Figure 3.10	Separation of LF and HF coefficients with the coefficient factor.	38
Figure 3.11	Multi resolution image analysis using DCT.	39
Figure 3.12	(a) Downsampling from 8x8 blocks to 4x4 blocks. (b) Upsampling from 4x4 blocks to 8x8 blocks.	40
Figure 3.13	Laplacian Pyramid Construction and Reconstruction	41
Figure 3.14	MSVD decomposition structures with three level of decomposition.	42
Figure 3.15	MSVD fusion scheme	43
Figure 3.16	Schematic diagram of EOL based image fusion	43

Figure 3.17	Block diagram of Wavelet based image fusion	44
Figure 3.18	DoG obtained by using the simple subtraction of different scale Gaussian level	46
Figure 3.19	Key points located by comparing pixel with its neighbors.	47
Figure 3.20	The key point descriptor generated by summarizing the contents in image gradients with the length of the arrow in eight directions.	48
Figure 3.21	Gaussian second order derivative from left to right in x and y direction and approximations using box filters.	49
Figure 3.22	Interest point detected in left picture and orientation is assign in the right picture with Haar wavelet response in the middle.	50
Figure 3.23	Diagram for building the descriptor in every interest points.	50
Figure 4.1	(a) Original Image, (b) Otsu Threshold, (c) Morphological Operation, (d) Centroid of the palm.	54
Figure 4.2	(a) ROI extraction in wavelength 700 nm, (b) ROI extraction in wavelength 850 nm, (c) ROI extraction in wavelength 940 nm.	55
Figure 4.3	Artificial rotation in one sampler (a) 10 degree of rotation, (b) 20 degree of rotation, (c) 30 degree of rotation.	56
Figure 4.4	CLAHE filter (left) and Median Filter (right) in ROI extraction, (a) 940 nm palm vein image, (b) 850 nm palm vein image, (c) 700 nm palm vein image.	58
Figure 4.5	SIFT feature extraction with feature points for few sampler for 700 nm in the left, 850 nm in the middle and 940 nm in the right, a) sampler number 38, b) sampler number 88, c) sampler number 89	60
Figure 4.6	SIFT matching in genuine and imposter pair, (a) without RANSAC mismatching point removal, (b) after RANSAC mismatching point removal.	61
Figure 4.7	SURF feature extraction with feature points for few samplers for 700 nm in the left, 850 nm in the middle and 940 nm in the right, a) sampler number 38, b) sampler number 88, c) sampler number 89.	62
Figure 4.8	SURF matching in genuine pair, (a) without RANSAC mismatching point removal, (b) after RANSAC mismatching point removal.	63
Figure 4.9	Equal Error Rate (EER) of SIFT and SURF matching in three different wavelength spectrum	64
Figure 4.10	FPDCT image fusion for several types of combination	66
Figure 4.11	Effect of number of matching points before and after one of the image fusion applied.	67
Figure 4.12	EER for dual type combination of wavelength spectrum, (a) 700 nm with 850 nm image, (b) 700 nm with 940 nm image, (c) 850 nm with 940 nm image	69
Figure 4.13	EER for triple combination of wavelength spectrum	70

LIST OF SYMBOLS

X	Determinant of hessian
I_{FU}	Fused image
ϕ	Fusion strategy
m	Gradient magnitude
H	Hessian matrix
A	Image sample
θ	Orientation
I	Original image
σ	Scale

LIST OF ABBREVIATIONS

AC	Alternating current
CCD	Charge-coupled device
CHVD	Competitive hand valley detection
CLAHE	Contrast limited adaptive histogram equalization
DoG	Difference of gaussian
DCT	Discrete cosine transform
DWT	Discrete wavelet transform
EOL	Energy of laplacian
JPEG	Joint photographic experts group
LBP	Local binary pattern
LDP	Local derivative pattern
LDTP	Local directional texture pattern
LTrP	Local tetra pattern
MIND	Maximal intra neighbour difference
MPC	Maximal principal curvature
MSVD	Multi resolution singular value decomposition
MF	Mutual foreground
NIR	Near infrared light
ORB	Oriented fast and rotated BRIEF
PINs	Personal identification numbers
RDF	Radian distance function
RANSAC	Random sample consensus
ROI	Region of interest
SIFT	Scale invariant feature transform
SVD	Singular value decomposition
SURF	Speeded up robust feature

REFERENCES

- Aghagolzadeh, A. (2018). Multi-Focus Image Fusion in DCT Domain using Variance and Energy of Laplacian and Correlation Coefficient for Visual Sensor Networks, *6*(2), 233–250. <https://doi.org/10.22044/JADM.2017.5169.1624>
- Aishwarya, V.V, &Devipriyanga, V. (2016). Multibiometrics By Combining Left and Right Palmprint Images using SIFT Features, *2*(18), 186–197.
- Akbar, A. F., Wirayudha, T. A. B., &Sulistiyo, M. D. (2016). Palm vein biometric identification system using local derivative pattern. *2016 4th International Conference on Information and Communication Technology (ICoICT)*, *4*(c), 1–6. <https://doi.org/10.1109/ICoICT.2016.7571956>
- Article, R. (2014). Available Online at www.jgrcs.info A Survey On Biometric Authentication Techniques Using Palm, *5*(8), 2010–2013.
- Barra, S., DeMarsico, M., Nappi, M., Narducci, F., &Riccio, D. (2018). A hand-based biometric system in visible light for mobile environments. *Information Sciences*, *0*, 1–14. <https://doi.org/10.1016/j.ins.2018.01.010>
- Bharathi, S., &Sudhakar, R. (2018). Biometric recognition using finger and palm vein images. *Soft Computing*. <https://doi.org/10.1007/s00500-018-3295-6>
- B . K . Shreyamsha Kumar , M . N . S . Swamy (2013). Multiresolution Dct Decomposition For Multifocus Image Fusion, IEEE Department of Electrical and Computer Engineering , Concordia University , Montreal , Canada, 1–4.
- Daugman, J. G. (1993). High confidence visual recognition of persons by a test of statistical independence. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *15*(11), 1148–1161.
- Elnasir, S., &Shamsuddin, S. M. (2014). Palm Vein Recognition based on 2D-Discrete Wavelet Transform and Linear Discrimination Analysis, *6*(3).
- Fang, Y., Wu, Q., &Kang, W. (2018). A novel finger vein verification system based on two-stream convolutional network learning. *Neurocomputing*, *290*, 100–107. <https://doi.org/10.1016/j.neucom.2018.02.042>

- Giveki, D., Soltanshahi, M. A., &Montazer, G. A. (2017). A new image feature descriptor for content based image retrieval using scale invariant feature transform and local derivative pattern. *Optik, 131*, 242–254.
<https://doi.org/10.1016/j.ijleo.2016.11.046>
- Gurunathan, V., Sathiyapriya, T., &Sudhakar, R. (2016). Multimodal biometric recognition system using SURF algorithm. *2016 10th International Conference on Intelligent Systems and Control (ISCO)*, 1–5.
<https://doi.org/10.1109/ISCO.2016.7727020>
- Han, D., Guo, Z., &Zhang, D. (2008). Multispectral palmprint recognition using wavelet-based image fusion. *International Conference on Signal Processing Proceedings, ICSP, 2074–2077*. <https://doi.org/10.1109/ICOSP.2008.4697553>
- Han, W. Y., &Lee, J. C. (2012). Palm vein recognition using adaptive Gabor filter. *Expert Systems with Applications, 39*(18), 13225–13234.
<https://doi.org/10.1016/j.eswa.2012.05.079>
- Huang, D.-S., Jia, W., &Zhang, D. (2008). Palmprint verification based on principal lines. *Pattern Recognition, 41*(4), 1316–1328.
- Huang, W., &Jing, Z. (2007). Evaluation of focus measures in multi-focus image fusion, *28*, 493–500. <https://doi.org/10.1016/j.patrec.2006.09.005>
- Kang, W., Liu, Y., Wu, Q., &Yue, X. (2014a). Contact-free palm-vein recognition based on local invariant features. *PLoS ONE, 9*(5).
<https://doi.org/10.1371/journal.pone.0097548>
- Kang, W., Liu, Y., Wu, Q., &Yue, X. (2014b). Contact-Free Palm-Vein Recognition Based on Local Invariant Features, *9*(5).
<https://doi.org/10.1371/journal.pone.0097548>
- Kang, W., &Wu, Q. (2014). Contactless palm vein recognition using a mutual foreground-based local binary pattern. *IEEE Transactions on Information Forensics and Security, 9*(11), 1974–1985.
<https://doi.org/10.1109/TIFS.2014.2361020>
- Kang, W. X., &Deng, F. Q. (2009). Vein image enhancement and segmentation based on maximal intra-neighbor difference. *Acta Opt Sin, 29*, 1830–1837.

- Karami, E., Prasad, S., &Shehata, M. (2015). Image Matching Using SIFT , SURF , BRIEF and ORB : Performance Comparison for Distorted Images Image Matching Using SIFT , SURF , BRIEF and ORB : Performance Comparison for Distorted Images, (February 2016). <https://doi.org/10.13140/RG.2.1.1558.3762>
- Kaur, V., &Kaur, J. (2015). Frequency Partitioning Based Image Fusion for, *6*(4), 3968–3972.
- Kisku, D. R. (2010). Multispectral Palm Image Fusion for Person Authentication using Ant Colony Optimization.
- Kisku, D. R., Rattani, A., Gupta, P., Sing, J. K., &Hwang, C. J. (2012). Human Identity Verification Using Multispectral Palmprint Fusion. *Journal of Signal and Information Processing*, *3*(May), 263–273. <https://doi.org/10.4236/jsip.2012.32036>
- Laboratories, N. A. (2011). Image Fusion Technique using Multi-resolution Singular Value Decomposition, *61*(5), 479–484. <https://doi.org/10.14429/dsj.61.705>
- Ladoux, P.-O., Rosenberger, C., &Dorizzi, B. (2009). Palm vein verification system based on SIFT matching. In *International Conference on Biometrics* (pp. 1290–1298). Springer.
- Ladoux, P. O., Rosenberger, C., &Dorizzi, B. (2009). Palm vein verification system based on SIFT matching. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *5558 LNCS*, 1290–1298. https://doi.org/10.1007/978-3-642-01793-3_130
- Lakshmi, K. D., &Vaithyanathan, V. (2017). Image Registration Techniques Based on the Scale Invariant Feature Transform. *IETE Technical Review*, *34*(1), 22–29. <https://doi.org/10.1080/02564602.2016.1141076>
- Lee, J. C. (2012). A novel biometric system based on palm vein image. *Pattern Recognition Letters*, *33*(12), 1520–1528. <https://doi.org/10.1016/j.patrec.2012.04.007>
- Li, W. (2018). Multiple palm features extraction method based on vein and palmprint. *Journal of Ambient Intelligence and Humanized Computing*, *0*(0), 0. <https://doi.org/10.1007/s12652-018-0699-1>
- Lowe, D. G. (2004). Distinctive image features from scale-invariant keypoints. *International Journal of Computer Vision*, *60*(2), 91–110.

- Lu, G.-M., Wang, K.-Q., & Zhang, D. (2004). Wavelet based independent component analysis for palmprint identification. In *Machine Learning and Cybernetics, 2004. Proceedings of 2004 International Conference on* (Vol. 6, pp. 3547–3550). IEEE.
- Lu, G., Zhang, D., & Wang, K. (2003). Palmprint recognition using eigenpalms features. *Pattern Recognition Letters*, 24(9), 1463–1467.
- Lu, L., Zhang, X., Xu, X., & Shang, D. (2017). Multispectral image fusion for illumination-invariant palmprint recognition. <https://doi.org/10.1371/journal.pone.0178432>
- Lu, W., Li, M., & Zhang, L. (2016). Palm Vein Recognition Using Directional Features Derived from Local Binary Patterns, 9(5), 87–98.
- Mallat, S. (1999). *A wavelet tour of signal processing*. Academic press.
- Manmohan, Saxena, J., Teckchandani, K., Pandey, P., Dutta, M. K., Travieso, C. M., & Alonso-Hernandez, J. B. (2015). Palm Vein Recognition using Local Tetra Patterns. *IWOBI 2015 - 2015 International Work Conference on Bio-Inspired Intelligence: Intelligent Systems for Biodiversity Conservation, Proceedings*, 151–156. <https://doi.org/10.1109/IWOBI.2015.7160159>
- Michael, G., Connie, T., Teoh, A., Connie, T., & Teoh, A. (2011). A Contactless Biometric System Using Palm Print and Palm Vein Features. *Image (Rochester, N.Y.)*. <https://doi.org/10.5772/19337>
- Mikolajczyk, K., & Schmid, C. (2005). A performance evaluation of local descriptors. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 27(10), 1615–1630.
- Mirmohamadsadeghi, L., & Drygajlo, A. (2011). Palm vein recognition with Local Binary Patterns and Local Derivative Patterns. *2011 International Joint Conference on Biometrics, IJCB 2011*. <https://doi.org/10.1109/IJCB.2011.6117804>
- Mishra, D. (2015). Image Fusion Techniques : A Review, 130(9), 7–13.
- Miura, N., Nagasaka, A., & Miyatake, T. (2004). Feature extraction of finger-vein patterns based on repeated line tracking and its application to personal identification. *Machine Vision and Applications*, 15(4), 194–203.

- Miura, N., Nagasaka, A., & Miyatake, T. (2007). Extraction of finger-vein patterns using maximum curvature points in image profiles. *IEICE TRANSACTIONS on Information and Systems*, 90(8), 1185–1194.
- Multispectral Palm Image Fusion For Accurate Contact-Free Palmprint Recognition National Laboratory of Pattern Recognition , Institute of Automation , CAS. (2008), 281–284.
- Naidu, V. P. S. (2010). Discrete cosine transform-based image fusion. *Defence Science Journal*, 60(1), 48.
- Naidu, V. P. S. (2013). Novel Image Fusion Techniques using DCT, 5(1), 1–18.
- Naidu, V. P. S., Aerospace, N., & Naidu, V. P. S. (2015). Discrete Cosine Transform-based Image Fusion Discrete Cosine Transform-based Image Fusion, (September). <https://doi.org/10.14429/dsj.60.105>
- Ojala, T., Pietikainen, M., & Maenpaa, T. (2002). Multiresolution gray-scale and rotation invariant texture classification with local binary patterns. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 24(7), 971–987.
- Palmprint, C. M., & Database, I. (2012.). Note on CASIA Multi-Spectral Palmprint Database, 1–4.
- Pan, M., & Kang, W. (2011). Palm Vein Recognition Based on Three Local Invariant Feature Extraction Algorithms *, 116–124.
- Pandey, N., Verma, P. O. P., & Kumar, A. (2018). A Hand-Based Biometric Verification System Using Ant Colony Optimization, 7(2), 693–717.
- Piciucco, E., Maiorana, E., & Campisi, P. (2017). Biometric Fusion for Palm-Vein-Based Recognition Systems BT - Digital Communication. Towards a Smart and Secure Future Internet. In A. Piva, I. Tinnirello, & S. Morosi (Eds.) (pp. 18–28). Cham: Springer International Publishing.
- Qiu, X., Kang, W., Tian, S., Jia, W., & Huang, Z. (2017). Finger Vein Presentation Attack Detection Using Total Variation Decomposition. *IEEE Transactions on Information Forensics and Security*, 13(2), 465–477. <https://doi.org/10.1109/TIFS.2017.2756598>
- Rahul, R. C., & Cherian, M. (2015). A Novel MF-LDTP approach for contactless palm vein Recognition, 793–798.

- Rivera, A. R., Castillo, J. R., &Chae, O. (2015). Local directional texture pattern image descriptor. *Pattern Recognition Letters*, 51, 94–100.
- Roopa, B., &Manvi, S. S. (2014). Image Fusion Techniques for Wireless Sensor Networks : Survey.
- Saxena, J., Tec, K., Travieso, C. M., &Alonso-hernández, B. (2015). Palm Vein Recognition using Local Te etra Patterns, 151–156.
- Sharma, M. (2016). A Review : Image Fusion Techniques and Applications, 7(3), 1082–1085.
- Singh, S., &Rajput, R. (2014). Multiple Image Fusion Using Laplacian Pyramid, 3(12), 9442–9446.
- Smorawa, D., &Kubanek, M. (2013.). Biometric Systems Based on Palm Vein Patterns.
- Soh, S. C., Ibrahim, M. Z., &Yakno, M. (2018). A Review: Personal Identification Based on Palm Vein Infrared Pattern. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, 10(1–4), 175–180.
- Soh, S. C., Ibrahim, M. Z., Yakno, M. B., &Mulvaney, D. J. (2018). Palm Vein Recognition Using Scale Invariant Feature Transform with RANSAC Mismatching Removal. In *IT Convergence and Security 2017* (pp. 202–209). Springer.
- Sun, X., Ma, X., Wang, C., Zu, Z., Zheng, S., &Zeng, X. (2017). An Adaptive Contrast Enhancement Method for Palm Vein Image BT - Biometric Recognition. In J.Zhou, Y.Wang, Z.Sun, Y.Xu, L.Shen, J.Feng, ...S.Yu (Eds.) (pp. 240–249). Cham: Springer International Publishing.
- Thamri, E., Aloui, K., &Naceur, M. S. (2018). New approach to extract palmprint lines. *2018 International Conference on Advanced Systems and Electric Technologies (IC_ASET)*, 432–434. <https://doi.org/10.1109/ASET.2018.8379895>
- Vi, C., &Vi, W. G. (2015). An Integrated Ransac And Graph Based Mismatch Elimination Approach For Wide-Baseline Image Matching, *XL*, 23–25. <https://doi.org/10.5194/isprsarchives-XL-1-W5-297-2015>

- Victy, Y. A., &Amutha, R. (2014). Discrete Cosine Transform based fusion of multi-focus images for visual sensor networks. *Signal Processing*, 95, 161–170. <https://doi.org/10.1016/j.sigpro.2013.09.001>
- Wang, C., Zeng, X., Sun, X., Dong, W., &Zhu, Z. (2017). Quality assessment on near infrared palm vein image. *Proceedings - 2017 32nd Youth Academic Annual Conference of Chinese Association of Automation, YAC 2017*, 0(1), 1127–1130. <https://doi.org/10.1109/YAC.2017.7967580>
- Wang, L., Leedham, G., &Siu-Yeung Cho, D. (2008). Minutiae feature analysis for infrared hand vein pattern biometrics. *Pattern Recognition*, 41(3), 920–929. <https://doi.org/10.1016/j.patcog.2007.07.012>
- Wu, X., Wang, K., &Zhang, D. (2004a). A novel approach of palm-line extraction. In *Image and Graphics (ICIG '04), Third International Conference on* (pp. 230–233). IEEE.
- Wu, X., Wang, K., &Zhang, D. (2004b). Palmprint recognition using directional line energy feature. In *Pattern Recognition, 2004. ICPR 2004. Proceedings of the 17th International Conference on* (Vol. 4, pp. 475–478). IEEE.
- Wu, X., Zhang, D., &Wang, K. (2003). Fisherpalms based palmprint recognition. *Pattern Recognition Letters*, 24(15), 2829–2838.
- Wu, Y., Ma, W., Gong, M., Su, L., Jiao, L., &Member, S. (2015). A Novel Point-Matching Algorithm Based on Fast Sample Consensus for Image Registration, *12*(1), 43–47.
- Xin, Y., Kong, L., Liu, Z., Wang, C., Zhu, H., Gao, M., ...Xu, X. (2018). Multimodal Feature-Level Fusion for Biometrics Identification System on IoMT Platform. *IEEE Access*, 6, 21418–21426. <https://doi.org/10.1109/ACCESS.2018.2815540>
- Xu, A., &Namit, G. (2008). SURF : Speeded - Up Robust Features. *European Conference on Computer Vision*, 1–30. https://doi.org/10.1007/11744023_32
- Yan, X., Deng, F., &Kang, W. (2015). Palm vein recognition based on multi-algorithm and score-level fusion. *Proceedings - 2014 7th International Symposium on Computational Intelligence and Design, ISCID 2014*, 1, 441–444. <https://doi.org/10.1109/ISCID.2014.93>
- Yan, X., Kang, W., Deng, F., &Wu, Q. (2015a). Neurocomputing Palm vein recognition based on multi-sampling and feature-level fusion. *Neurocomputing*, 151, 798–807. <https://doi.org/10.1016/j.neucom.2014.10.019>

- Yan, X., Kang, W., Deng, F., & Wu, Q. (2015b). Palm vein recognition based on multi-sampling and feature-level fusion. *Neurocomputing*, *151*, 798–807.
<https://doi.org/10.1016/j.neucom.2014.10.019>
- You, J., Li, W., & Zhang, D. (2002). Hierarchical palmprint identification via multiple feature extraction. *Pattern Recognition*, *35*(4), 847–859.
- Zhan, K., Teng, J., Li, Q., & Shi, J. (2015). A novel explicit multi-focus image fusion method A Novel Explicit Multi-focus Image Fusion Method, (January).
- Zhang, D., Kong, W.-K., You, J., & Wong, M. (2003). Online palmprint identification. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *25*(9), 1041–1050.
- Zhang, H., & Hu, Q. (2011). Fast image matching based-on improved SURF algorithm. *2011 International Conference on Electronics, Communications and Control, ICECC 2011 - Proceedings*, (1), 1460–1463.
<https://doi.org/10.1109/ICECC.2011.6066546>
- Zhang, H., Tang, C., Li, X., Wai, A., & Kong, K. (2015.). A Study of Similarity between Genetically Identical Body Vein Patterns.
- Zhang, X., & Gao, Y. (2009). Face recognition across pose: A review. *Pattern Recognition*, *42*(11), 2876–2896.
- Zhang, Z., & Blum, R. S. (1999). *A Categorization of Multiscale-decomposition-based Image Fusion Schemes with a Performance Study for a Digital Camera Application*.
- Zhou, Y., Kumar, A., & Member, S. (2011). Human Identification Using Palm-Vein Images, *6*(4), 1259–1274.