UNIVERSITI PUTRA MALAYSIA

NEAR INFRARED PALM IMAGE ACQUISITION AND TWO-FINGER VALLEY POINT-BASED IMAGE EXTRACTION FOR PALM VASCULAR PATTERN DETECTION

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FK 2019 127

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2019

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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May 2019

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Human palm vascular pattern is one of biometric modality that can be used for authentication purpose. It is concealed under the skin and unseen through human visual in visible light spectrum. To enable visibility of palm vascular pattern, additional illumination from near infrared (NIR) light is needed. With NIR-sensitive imaging device, the palm vascular pattern can be recorded. Even so, palm vascular pattern does not directly seen in the recorded image. As datasets available for research communities originated from multispectral palm print images that contain information other than vascular pattern, supplementary image processing is needed to reveal the vascular pattern in the image captured. Given variations imposed by human hand and specifications of imaging components, the enhancement processing in detecting palm vascular pattern differs accordingly. This thesis explores one of the options available in developing a NIR-sensitive imaging setup that can capture only palm vascular pattern. The setup was constructed using Raspberry Pi single board computer (SBC) to enable portability of the device. Experiments were conducted to observe different imaging setup and related components combinations that can help imaging the palm vascular pattern. Based on assessments of image contrast (Michelson contrast, standard deviation and RMS contrast) executed on acquired images through the experiments, an imaging configuration was finalized to acquire a self-developed dataset. Additional two palm image datasets were used in observing the related enhancement processing that can visually detect palm vascular pattern from a NIR illuminated palm image. The palm vascular detection processing was also executed on the self-developed dataset constructed earlier for validation. Based on the processing, a framework in extracting two fingers' valley points to identify region-of-interest (ROI) was proposed; based on the nature of the acquisition process either it is guided or unguided acquisition. The ROI extracted was assessed by mean squared error (MSE)

and structural similarity (SSIM) index to check the ROI stability, every time it is extracted from different palm samples. A vascular image enhancement processing comprises of several enhancement techniques were recommended based on their ability in enhancing palm vascular pattern visually. Assessment of the enhanced vascular pattern was done by biometric recognition process; measured in its correct recognition rate (CRR). The biometric recognition process was done by extraction of vascular line features by Local Binary Pattern (LBP), and classification by K-nearest neighbour (KNN) algorithm using cross-validation technique. The average CRR achieved were 13.8%, 38.7% and 64.2%; for the CASIA, PolyU and self-developed datasets respectively.Although the average CRR were quite low for an accurate biometric recognition system; it indicates that the palm image dataset developed in this thesis has distinctive ability such that it can be used as biometric data. This is because, the unguided image acquisition device in this thesis had been catered to capture only palm vascular pattern for recognition purpose compared to other datasets that contain additional information other than palm vein pattern. In summary, vascular pattern can be detected visually from the palm image acquired by the NIR palm image acquisition device developed in this research.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEROLEHAN IMEJ INFRAMERAH TAPAK TANGAN DAN PENYARIAN IMEJ BERDASARKAN TITIK TERENDAH DI CELAH DUA JARI UNTUK PENGECAMAN CORAK PEMBULUH DARAH TAPAK TANGAN

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Corak pembuluh darah di tapak tangan adalah salah satu modaliti biometrik yang boleh digunakan untuk tujuan pengesahan. Ia terlindung di dalam kulit dan tidak kelihatan melalui penglihatan manusia dalam spektrum cahaya nampak. Untuk membenarkan kebolehlihatan corak pembuluh darah di tapak tangan, pencahayaan tambahan dari cahaya inframerah dekat (*NIR*) adalah diperlukan. Dengan peranti pengimejan sensitif-inframerah, corak pembuluh darah tapak tangan tersebut boleh direkodkan. Sungguhpun begitu, corak pembuluh darah tapak tangan tidak terlihat secara langsung dalam imej yang direkodkan tersebut.Sepertimana set data sedia ada untuk komuniti penyelidik yang berasal dari imej-imej cetakan tapak tangan berbilang spektrum mengandungi maklumat selain dari corak pembuluh darah,pemprosesan imej tambahan diperlukan untuk mendedahkan corak pembuluh darah dalam imej yang dirakamkan. Dengan variasi yang dimiliki oleh tangan manusia dan spesifikasi komponen pengimejan, pemprosesan peningkatan dalam mengesan corak pembuluh darah tapak tangan juga berbeza. Tesis ini meninjau salah satu pilihan yang ada dalam membangunkan sesebuah pemasangan pengimejan sensitif-*NIR* yang boleh merakamkan corak pembuluh darah tapak tangan. Pemasangan tersebut telah dibina menggunakan komputer papan tunggal *Raspberry Pi* untuk membolehkan kemudahalihan peranti terbabit. Ujikaji telah dijalankan untuk menilai pemasangan pengimejan dan kombinasi komponen yang berbeza, yang boleh membantu pengimejan corak pembuluh darah tapak tangan. Berpandukan kepada penilaian kontras imej (kontras *Michelson*, sisihan piawai dan kontras *RMS*) yang dijalankan ke atas imej yang dirakam melalui ujikaji tersebut, sebuah konfigurasi telah dimuktamadkan untuk membina sebuah set data terbangun-sendiri. Tambahan dua set data imej tapak tangan telah digunakan dalam menilai pemprosesan peningkatan berkaitan yang boleh mengesan ketampakan corak pembuluh darah tapak tangan dari sesebuah imej tapak

tangan yang disinari *NIR*. Pemprosesan pengesanan pembuluh darah tapak tangan juga telah dijalankan ke atas set data terbangun-sendiri yang dibina terdahulu untuk pengesahansahihan. Berdasarkan kepada pemprosesan tersebut, sebuah rangka kerja dalam mengekstrak titik terendah di celah dua jari untuk mengecam kawasan berkepentingan (*ROI*)daripada sesebuah imej tapak tangan *NIR* telah dicadangkan; berasaskan kepada kaedah proses perolehan imej sama ada ianya secara terpandu atau tidak. Pengekstrakan *ROI* tersebut telah ditaksir melalui purata ralat kuasa dua(*MSE*) dan indeks keserupaan struktur(*SSIM*)untuk menyemak kestabilan *ROI* tersebut, setiap kali ianya diekstrak dari sampel tapak tangan yang berlainan. Pemprosesan peningkatan pembuluh darah merangkumi beberapa teknik-teknik peningkatan imej telah disyorkan berpandukan kepada kebolehannya dalam meningkatkan ketampakan corak pembuluh darah tapak tangan. Penilaian corak pembuluh darah tapak tangan yang telah ditingkatkan telah dijalankan melalui proses pengecaman biometrik; diukur melalui kadar pengecaman tepat (*CRR*). Proses pengecaman biometrik tersebut telah dijalankan melalui pengekstrakan sifat garisan pembuluh darah menggunakan corak perduaan setempat (*LBP*), dan pengkelasan menggunakan algoritma jiran terdekat-*k* (*KNN*) berasaskan teknik pengesahsahihan silang. Purata *CRR* yang tercapai adalah 13.8%, 38.7% dan 64.2%; masing-masing untuk set-set data CASIA, PolyU dan terbangun-sendiri. Meskipun purata*CRR* tersebut agak rendah untuk sistem pengecaman biometrik yang jitu; ianya telah menunjukkan bahawa set data imej tapak tangan yang dibangunkan dalam tesis ini mempunyai kebolehbezaan yang mana ianya boleh digunakan sebagai data biometrik. Ini kerana, peranti perolehan imej secara tidak terpandu dalam tesis ini telah memenuhi keperluan untuk merakam hanya corak pembuluh darah tapak tangan berbanding dengan set-set data lain yang mengandungi maklumat tambahan selain dari corak pembuluh darah tapak tangan. Secara ringkas, ketampakan corak pembuluh darah boleh dikesan dari imej tapak tangan yang diperoleh melalui peranti perolehan imej tapak tangan *NIR* yang dibangunkan dalam kajian ini.

ACKNOWLEDGEMENTS

Deepest appreciation to the Ministry of Higher Education (Malaysia), Universiti Putra Malaysia (UPM) and Universiti Teknikal Malaysia Melaka (UTeM) in which with the assistance, support and facilities provided, I am blessed with this wonderful opportunity to pursue a Ph.D study. May these institutions continue to flourish and prosper; in moulding an educated nation to the world.

A heartfelt gratitude goes to the Advisor and Chairman of the Supervisory Committee, Assoc. Prof. Dr. Abd. Rahman bin Ramli for his enthusiasm, patience, faith, and undivided attention in guiding me throughout the period of completing this thesis. It is his imparted wisdom that had been keeping me grounded and persevered in carrying out the work. Also to the Members of the Supervisory Committee; Prof. Dr. M. Iqbal bin Saripan and Dr. Marsyita binti Hanafi, warmest thanks for their continuous encouragement and support.

Last but not least to my family, friends (especially Norhidayah, Noor Hafizah and Nogol), colleagues, students and everyone in both UPM and UTeM; that I had encountered with and somehow had either directly or indirectly contributed to the completion of research work in this thesis, I wish a world full of happiness and contentment to you. Thank you for everything and have a nice day!

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

CRR	correct recognition rate
DNA	deoxyribonucleic acid
EER	equal error rate
FAR	false acceptance rate
FOV	field of view
KNN	K-nearest neighbour
LED	light-emitting diode
LBP	local binary pattern
MSE	mean squared error
NIR	near infrared
RMS	root mean square
ROI	region-of-interest
SBC	single board computer
SPST	single pole single throw
SSIM	structural similarity
USB	Universal Serial Bus

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Biometric data consists of any physical and behavioural characteristic of human such as iris, retina geometry, face, finger print, palm print, hand geometry, hand vein, speech signal, DNA, body odour, keystroke dynamics, and many others (Unar et al., 2014). Most of biometric data had been successfully used for authentication (identification) purpose while others are still in the state of introduction in consumer market (Fons et al., 2012). One crucial necessity of using biometric data for authentication is the need of an individual to be physically present to use the system. This necessity is not critical in conventional authentication mechanism that mostly utilizes human memorizing capability (passwords and signatures) and token availability (access cards and keys). The need of an individual to be physically present provides an added security advantage for biometric authentication system.

Among biometric data that had gained increasing interest for authentication is palm vein pattern(Lane, 2012). The growing interest is due to its distinctive attribute and unconventional method in acquiring the pattern. The distinctiveness is supported by a system developed by Fujitsu, where the False Acceptance Rate (FAR) is reported to be as low as 0.00008% for 140,000 palms (Watanabe et al., 2005). With its hidden nature under the skin, palm vein pattern can only be obtained using a specific acquisition system that enables the visibility of vein pattern. Besides, vein pattern can only be accessible with the consent and awareness of an individual. Therefore, this biometric data is not easily altered and manipulated. The mentioned traits enhance the security element of palm vein pattern as biometric data.

Research trend in the area of palm vein pattern shows that the work revolves on the image acquisition system and its processing algorithm in analysing the vein information(Han & Lee, 2012).With the promising advantages and additional secure traits, this biometric data can be applied as authentication mechanism for data transaction, access grant system and web-based log on (Bhattacharyya et al., 2009). In other words, it can be used in a biometric recognition system in general, such as for identification and verification purpose.

Biometric recognition with as high as 100% accuracy is preferable for a critically secure and reliable system (Jain et al., 2016). As approaches to achieve a high accuracy palm vein biometrics system mainly focuses on the vein feature extraction and analysis, it is important to note the necessity of a

reliable vein acquisition system (Liu et al., 2015).A reliable vein acquisition system ensures that the image acquired as the biometric data contain sufficient information related to the data intended. As illustrated in Figure 1.1, a general biometric authentication system starts with the acquisition process; which indirectly shows that the acquisition system is as important as its post-processing analysis. With regard to palm vein pattern biometrics, developing a reliable acquisition system is still an open problem (Soh et al., 2018).

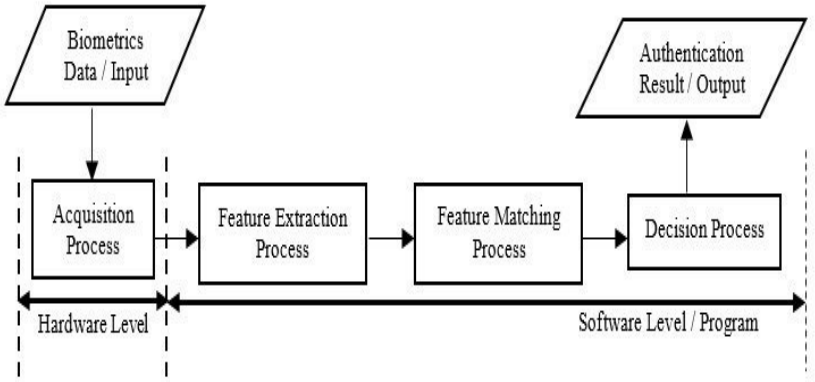
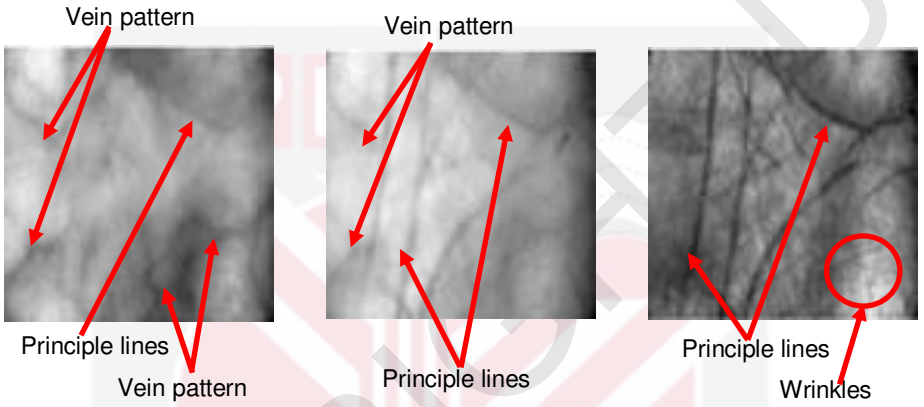


Figure 1.1: General illustration of biometrics authentication system.
(Source: Noh et al., 2018)

1.2 Problem Statement

Acquiring vein pattern in palm area is a challenging process as utilization of visible spectrum by an imaging device mostly captured palm print pattern but not the vein pattern (J.-G. Wang et al., 2007). Researchers had constructed their own palm vein datasets by developing their own image acquisition device (Han & Lee, 2012; Michael et al., 2011; Pascual et al., 2010) because up till now, there is no publicly available datasets for palm vein biometric research benchmarking purpose(Ahmed et al., 2013) except for two datasets originally prepared for palm print biometric research. The two palm print datasets which were originated from multispectral palm print images were constructed by the Chinese Academy of Sciences' Institute of Automation (CASIA) (Hao et al., 2008) and the Hong Kong Polytechnic University (PolyU) (Guo et al., 2011). The problem with these two datasets is that they are acquired by different tools using different subjects (in different region of the world) by different acquisition process (nature), hence utilization of these two datasets does not guarantee real-time results should an analysis be performed for real-time palm vein biometric system purpose. In addition, because these two datasets are originally multispectral palm print images, information on palm print features(Liang et al., 2015) (principle lines, creases and wrinkles) can also be found in the image.

Figure 1.2 shows a sample image from the CASIA dataset from different illumination sources. Palm vein and palm print features detected in Figure 1.2 are labelled accordingly for the three different illumination sources. Palm image acquired by near infrared (NIR) illumination recorded clearer vein pattern than palm print features compared to other illumination sources (Figure 1.2 (a)). In fact, palm vein pattern is almost invisible if a palm image is recorded by blue illumination source (Figure 1.2 (c)). Still, both principle lines and vein pattern were faintly recorded by red illumination source (Figure 1.2 (b)). The same observation can be seen from palm images in PolyU dataset shown by Figure 1.3.



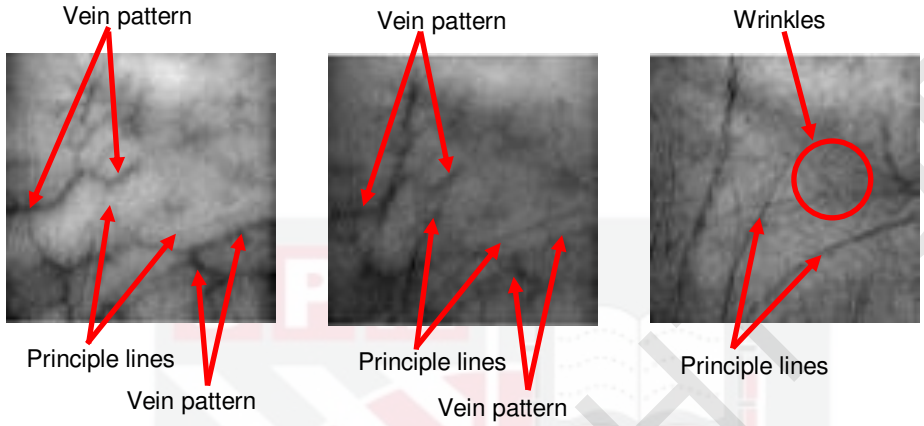
(a) Near infrared (NIR). (b) Red illumination. (c) Blue illumination.

Figure 1.2: A sample of raw palm image from CASIA dataset (CASIA, 2014), acquired by different illumination sources.

Palm image acquired by NIR illumination source in Figure 1.3 (a) revealed clearer vein pattern compared to other illumination sources. However, the principle lines were faintly existed in the image compared to the CASIA datasets. It is due to the different nature of acquisition process; where CASIA dataset is acquired in unguided way compared to guided process for PolyU dataset. While vein pattern and palm print features co-existent in both datasets using NIR illumination, biometric analysis performed on these images may have mixed both modalities (palm print and palm vein) in the proceeding analysis. Hence, this thesis will address the gap by configuring a palm vein image acquisition device that can best acquire vein pattern information, just enough for biometric recognition purpose.

Palm vein pattern can be recorded if the illumination source of the acquisition device employs NIR light (L. Wang et al., 2007). In this thesis, experiments that utilized different values of peak NIR wavelengths in the acquisition device will reveal the best peak NIR wavelength that can be used for palm vein pattern acquisition. Besides, acquisition settings such as the acquisition distance also affects the ability of the device in acquiring vein pattern. Combinations of filtering materials in the acquisition device will also influenced the vein pattern

visibility in the image especially if the image recorded contained only NIR scene or/and other light wave spectrum. Experiments that address the mentioned concern will give the related configuration for the acquisition device that can best acquire palm vein pattern information.



(a) Near infrared (NIR). (b) Red illumination. (c) Blue illumination.

Figure 1.3: A sample of raw palm image from PolyU dataset (PolyU, 2014), acquired by different illumination sources.

In addition, a framework of enhancement processing will be performed on the acquired image to reveal the palm vein pattern for vein features extraction. As vein pattern image acquired usually is of low quality and contrast, further image processing techniques are needed to enhance its vein information (Kang et al., 2014; Zhou & Kumar, 2011). One of the processing is the region-of-interest (ROI) extraction. Various reported methods in ROI extraction doesn't reveal the exact steps in mapping the region, but rather, a conclusive approach used for the processing. The defined ROI also varied according to the processing intended in the respective biometric system (Michael et al., 2010b; Mirmohamadsadeghi & Drygajlo, 2011; Zhou & Kumar, 2011). This gap will be addressed in this thesis through ROI extraction processing described for both guided and unguided acquisition system. The ROI extraction processing will be used throughout this thesis for enhancement processing later on.

Besides ROI extraction, approaches in enhancing palm images to highlight the vein pattern information are sparse and directly related to the post-processing involved in the biometric system (Al-Juboori et al., 2014; Lee, 2015; Shahzad et al., 2015). The scarce information provide an ambiguous ground rule on how the image acquired need to be enhanced for vein detection purpose (Prasanna et al., 2012). A clearer basic requirement for enhancement purpose is useful for extracting meaningful vein information. The gap in basic requirement will be addressed in this thesis based on the acquired palm images and the available processing techniques that can deal with it. The addressed enhancement

processing can provide a solution oriented approach for researchers with the same interest, in developing their own enhancement processing framework.

Motivated by its application as palm vein pattern descriptor (Holle et al., 2017); the combination of local binary pattern (LBP) for vein features extraction and K-nearest neighbour (KNN) for classification (identity matching) will be demonstrated in this thesis. This is to obtain the accuracy of the acquired vein pattern image developed in this thesis; for validation whether the dataset by the configured acquisition system has comparable recognition accuracy with respect to the palm images from the CASIA and PolyU datasets. As part of the starting point in the area of palm vein biometrics research, comparison of the accuracy of the acquired biometric data obtained real-time (self-developed dataset) with the off-line (CASIA and PolyU datasets) is crucial. The obtained recognition accuracy will indirectly show the distinctive properties possessed by the palm images in the three datasets; to indicate their applicability as biometric data (with respect to the pre- and post-processing of the images).

1.3 Objectives

The aim of research in this thesis is to configure a palmvein image acquisition device and improve an image enhancement framework for vein pattern information extraction. To achieve that, the following objectives are observed:

1. Develop an image acquisition device that can capture palm vein pattern information through illumination of NIR lights.
2. Enhance palm image to reveal vein pattern information using appropriate image processing techniques including detection of the region-of-interest (ROI) extraction processing.
3. Demonstrate the palm vein pattern extraction using local binary pattern (LBP) descriptor to obtain biometric recognition accuracy; and compare the performance with other palm image datasets via K-nearest neighbour (KNN) classifier.

1.4 Scope

The scope of this thesis is on the acquisition and enhancement of NIR palm image in detecting vein pattern information. The acquisition of palm image is achieved through development of an image acquisition device using a single board computer (SBC) environment. Images are acquired in unguided way where subjects were instructed orally to place their palm at ±13 cm distance facing the image sensor. The lighting and ambience of the location during the image capturing process follows the standard office buildings environment, occupied by fluorescent lights with no influence of sunlight (indoor). The enhancement of palm image is achieved through specific image processing techniques that enhance and detect the vein pattern contained in the identified ROI. Performance of the configured acquisition device will be compared with the CASIA and PolyU datasets in terms of recognition accuracy. The recognition accuracy is obtained by KNN classification using palm vein pattern information extracted by LBP descriptor.

1.5 Research Contribution

Major research contribution is on the configuration of a NIR palm vein image acquisition device that can capture palm vein pattern information. Specifically, the contributions are summarized as follows.

1. Development of an image acquisition device that can capture palm vein pattern information through combination of two NIR lights as illumination source that radiates 850 nm and 870 nm peak wavelengths.
2. Framework of enhancement processing that enhance vein pattern information in NIR palm image using image processing techniques such as contrast limited adaptive histogram equalization (CLAHE), bilateral filtering and morphological dilation operation; including specific region-of-interest (ROI) extraction by detecting two fingers' valley point catered for different nature of acquisition process.
3. Extraction of palm vein pattern information using local binary pattern (LBP) descriptor that can be used for biometric recognition to compare the performance of the acquisition system with the CASIA and PolyU palm image datasets.

1.6 Thesis Organization

This thesis is organized in five chapters including this chapter. Chapter 2 covers the overview and information related in the design and development of palm vein biometric system. It reveals the theory behind the use of NIR illumination in recording the vein pattern, to the vein features contained in a NIR palm image. Combination of components that can be configured as acquisition device in acquiring vein pattern in the palm area is also described in this chapter. In addition, the processing techniques involved in enhancing and detecting palm vein features are also shared. Related assessment metrics for image quality and brief description on biometric performance measure are also presented in this chapter. At the end of the chapter, approaches adapted for the research in this thesis will be summarized.

Chapter 3 presents the methodology of research in this thesis following the summarized adapted approaches in the previous chapter. It consists of three main parts. The first part elaborates the steps taken in developing the palm vein image acquisition device, and the acquired image assessment method. The second part describes the operations involved in enhancing the palm vein pattern in a NIR palm image. Operations in the second part are separated into two subsections which are: (1) ROI extraction steps, and (2) framework of image processing techniques for palm vein pattern enhancement. The third part of the chapter presents the steps for biometric recognition performance measure, specifically for identification purpose involving the correct recognition rate (CRR).

Results and related discussions are given in Chapter 4. It is divided into two parts following the methodology described in Chapter 3. The first part shows and discusses outcomes of images captured by the image acquisition device

developed in this research. The second part demonstrates outputs of ROI extraction steps and image processing techniques in extracting palm vein pattern in a palm image. The palm vein enhancement processing are executed on three different palm image that are from: (1) CASIA (CASIA, 2014), PolyU (PolyU, 2014), and (3) self-developed datasets acquired through this research. Analysis and assessment of image quality resulted from the experiments and processing are also presented; together with the dataset recognition accuracy measured in the value of average CRR.

The last chapter concludes the work done in this thesis. Future works are also given in the same chapter.

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LIST OF PUBLICATIONS

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