INTELLIGENT HAND VEIN IMAGE EXPOSURE SYSTEM TO AID PERIPHERAL INTRAVENOUS ACCESS

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INTELLIGENT HAND VEIN IMAGE EXPOSURE SYSTEM TO AID PERIPHERAL INTRAVENOUS ACCESS

by

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In the name of Allah the Most Gracious, the Most Merciful.

"Success is the ability to go from one failure to another with no loss of enthusiasm."

- Sir Winston Churchill (1874-1965)

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LIST OF ABBREVIATIONS

A/D	Analog to Digital
ADALINE	Adaptive Linear Neuron
ADWMF	Adaptive Spatial Distance-Weighted Median Filter
ANN	Artificial Neural Network
BMF	Binary Median Filter
BNC	British Naval Connector
BP	Back-propagation
CCD	Charge-Coupled Device
CHVD	Competitive Valley Checking Detection
CLAHE	Contrast Limited Adaptive Histogram Equalization
CMOS	Complementary Metal-Oxide Semiconductor
CNN	Cellular Neural Network
CRT	Cathode Ray Tubes
DC	Direct Current
DO	Dark Operate
FFNN	Feed-Forward Neural Network
FHH	Fuzzy Histogram Hyperbolization
FIR	Far-Infrared

FL	Fuzzy Logic
FN	False Negative
FP	False Positive
HE	Histogram Equalization
I/O	Input Output
IR	Infrared
IV	Intravenous
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LM	Leverberg-Marquardt
LO	Light Operate
MLFF	Multi-Layer Feed-Forward
MLP	Multilayered Perception Networks
MSE	Mean Square Error
MNR	Massive Noise Removal
NC	Normally Close
NO	Normally Open
NICE	The National Institute of Health and Clinical Excellence
NIR	Near-Infrared
NTSC	National Television Systems Committee

PC Personal Computer

PCB Printed Circuit Board

PSNR Peak Signal to Noise Ratio

PNN Probabilistic Neural Network

RBF Radial-Basis Function

ROAD Rank Ordered Absolute Difference

ROI Region of Interest

SAWMF Selective Adaptive Weighted Median Filter

SLFF Single-Layer Feed-Forward

SMF Standard Median Filter

SVMF Standard Vector Median Filter

SVM Support Vector Machine

TB Tuberculosis Bacilli

TN True Negative

TP True Positive

VCE Vein Contrast Enhancer

SISTEM PENDEDAHAN IMEJ SALUR DARAH TANGAN PINTAR BAGI MEMBANTU AKSES INTRAVENA

ABSTRAK

Kesukaran untuk mencapai persisian intravena pada sesetengah pesakit adalah suatu masalah klinikal. Kesukaran ini boleh membawa kepada beberapa kesan negatif seperti pengsan, hematoma (darah terkumpul di luar salur darah, di dalam tisu pesakit) dan kesakitan yang disebabkan oleh suntikan yang berulang kali. Rentetan itu, peralatan pengimejan ultrabunyi dan inframerah telah digunakan bagi membantu capaian kepada salur darah. Walaupun peralatan ini telah menunjukkan kebolehannya untuk membantu capaian kepada intravena, sistem inframerah tidak dapat menghasilkan kejelasan imej corak-corak vena yang memuaskan dan penggunaan ultrabunyi memakan masa yang lama. Oleh itu, penyelidikan ini tertumpu kepada pembangunan sistem pendedahan vena tangan dengan peningkatan kejelasan imej corak-corak vena tangan bagi membantu capaian kepada intravena. Ia terdiri daripada tiga sub-sistem utama iaitu sistem perolehan imej urat tangan, komponen pemprosesan imej dan sistem unjuran urat tangan. Sistem perolehan imej terdiri daripada empat puluh lapan biji diod pemancar cahaya inframerah dekat dengan panjang gelombang 0.89μm. Sistem pemprosesan imej dibahagikan kepada enam peringkat. Pada peringkat pertama, hingar asal corak vena tangan ditapis menggunakan rangkaian neural buatan suap hadapan dan penapis median piawai. Pada peringkat kedua, satu teknik baru berdasarkan ciri-ciri lembah dan hujung jari digunakan untuk mendapatkan rantau berkepentingan yang lebih besar. Pada peringkat ketiga, imej rantau berkepentingan dipertingkatkan dengan menggunakan gabungan hiperbola histogram kabur dan histogram penyamaan dan penyesuaian terhad. Kemudian, pada peringkat keempat, corak vena tangan diruas berdasarkan nilai ambang tempatan. Pada peringkat kelima, corak vena ta-

ngan berhingar dipertingkatkan dengan gabungan Pembetul Piksel Rangkaian Neural Buatan, penapis binari median dan penyikiran hingar besar-besaran. Dalam peringkat terakhir, corak vena tangan yang telah dipertingkatkan akan didaftarkan ke dalam imej vena tangan yang asal. Sub-sistem yang terakhir akan mengunjurkan corak urat tangan yang telah didaftarkan ke atas tangan pesakit. Gabungan teknik Pembetul Piksel Rangkaian Neural Buatan, penapis binari median dan penyikiran hingar besar-besaran yang dicadangkan telah meningkatkan kepekaan imej sehingga 10.664% daripada imej binari yang asal. Perbezaan purata sisihan piawai di antara imej-imej yang ditingkatkan dan imej sebenar ialah 0.02016. Nilai perbezaan ini adalah yang terkecil berbanding dengan imej-imej hasil daripada kaedah peningkatan imej yang lain. Secara keseluruhan, sistem yang dibangunkan telah menunjukkan kemampuan meningkatkan kejelasan imej corak vena tangan untuk memudahkan capaian kepada salur darah. Ia juga mempunyai potensi untuk menjimatkan masa dalam mengenalpasti salur darah yang sesuai dan yang paling penting boleh menghilangkan rasa takut pesakit kepada prosidur capaian salur darah.

INTELLIGENT HAND VEIN IMAGE EXPOSURE SYSTEM TO AID PERIPHERAL INTRAVENOUS ACCESS

ABSTRACT

Difficulty in achieving peripheral intravenous (IV) access in some patients is a clinical problem. These difficulties may lead to some negative impacts such as fainting, hematoma and pain associated with multiples punctures. As a result, ultrasound and infrared imaging devices have been used to aid IV access. Although these devices have shown to be able to aid IV access, infrared system has not been able to produce satisfactorily clear vein patterns and using ultrasound device is time consuming. Therefore, this research focuses on developing a hand vein exposure system with enhanced image of hand vein patterns to aid IV access. It consists of three major sub-systems namely, a hand vein image-acquisition system, image processing component and hand vein image-projection system. The image acquisition system consists of forty eight near-infrared light emitting diode with wavelength of 0.89μm. The image processing system involves six stages. In the first stage, a noisy hand vein image is filtered using a feed-forward neural network (FFNN) based on standard median filter. In the second stage, a newly proposed technique based on finger-webs and finger-tips characteristics is applied to obtain a larger region of interest (ROI). In the third stage, the ROI images are enhanced using a combination of fuzzy histogram hyperbolization and contrast limited adaptive histogram equalization. Then, in the fourth stage, vein patterns are segmented using local adaptive threshold. In the fifth stage, a noisy binary vein patterns are enhanced using a combination of FFNN pixel correction, binary median filter and massive noise removal. In the last stage, an enhanced vein patterns are registered into the original hand vein layout. Finally, the last sub-system projects the registered vein patterns onto a patient's hand. A combination of FFNN pixel correction,

binary median filter and massive noise removal as proposed has been able to increase the sensitivity of binary image of vein patterns up to 10.664% from the original binary image. The average difference in standard deviation between the enhanced images and their truth image is 0.02016. This difference is the smallest in comparison to images obtained based on existing image enhancement methods. The developed system has shown to be able to enhance hand vein image patterns for easy IV access. It has the potential to significantly reduce the average IV access time and most importantly, it could shed patients' fear towards IV access.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Peripheral intravenous (IV) is a process of providing an access for the purpose of blood drawing, IV fluid feeding or administration of medicine in a patient's blood vessel (Costantino et al., 2005). It is one of the most commonly used procedures in emergency clinical care as well as for various diseases and patient's treatment. An IV access is done on a patient by inserting a needle or short plastic tube, called a catheter, through the skin into a vein, usually in the hand or arm. It is often performed manually by phlebotomists, physicians, paramedics, anesthesiologist and other nursing staffs.

More than 300 million peripheral IV catheters are placed annually in United States alone (Oniaa et al., 2011). From the large number of practices, it is usually hypothesized that the paramedics are proficient with their insertion procedure. However, that is not always the case. It was reported that world-wide 10% of attempts to establish an IV line has failed (Encyclopedia, 2009). A study conducted in France reported that paramedics had 76% IV success rate during the first attempt and 98% at the second attempt for 669 enrolled patients (Minville et al., 2006). Another study in United States reported that 9% patients from a total of 249 required more than four IV attempts (Lininger, 2003).

IV access can be technically challenging due to factors related to the patients themselves and the skills of the paramedics. Patient-related factors can be associated to extreme age, body size, physical activity level, skin color, patient's medical history and patient's with chronic disease (Lynn, 2005). As an example, an injured or a critically illed elderly patient normally has inaccessible peripheral veins that makes IV access more difficult to achieve.

1.2 Problem Statements

Up to date, traditional methods such as distention (give a pressure to venous), palpation (method of feeling with the fingers or hands during a physical examination) and visualization are still employed by paramedics in the process of obtaining blood vessel. In addition, there is a number of approaches which can be used to enhance the visibility and palpability of peripheral veins, including gentle slapping of the overlying skin, applying proximal tourniquet, fist clenching, application of local warmth and nitroglycerin ointment (Roberge, 2004; Simhi et al., 2008). However, these approaches are still sometimes unable to guarantee the success of establishing peripheral IV line at the first attempt. This is particulary dangerous in an emergency case where fluid must be immediately administrated through IV access.

It is not surprising that despite being taught the correct techniques, paramedics may fail in performing IV access that multiple IV attempts are necessary before a successful access is achieved (McConnell and Mackay, 1996). Such problems are commonly faced by new paramedics who are lack of technical skills and experience in locating veins. The inability to establish an IV line after multiple attempts can also lead to negative emotional and psychological impacts on the paramedics, such as frustration, worry and diminished self-confidence.

Although the percentage of reattempts to gain IV access is small, it can lead to various negative impacts on patients such as fainting or feeling lightheaded, hematoma (blood accumulating under the skin) and pain. In addition, each IV access attempt not only simulates pain, but the frightful and stressful moments faced by children patients particulary, may eventually lead to the development of severe psychological problems such as needle phobia or worse still, hospital phobia (Emanuelson, 2011).

Apart from negative impacts towards patients, multiple attempts also require more time. The average time necessary for a peripheral IV access is reported to be about 2.5 to 13 minutes, sometimes even up to 30 minutes for patients with difficult peripheral veins access (Minville et al., 2006; Lapostolle et al., 2007). This situation can lead to a delay for necessary emergency treatment on an attended patient as well as other waiting patients.

Multiple attempts of peripheral IV access could also increase the cost of equipment. Lynn (2005) reported that an operational cost for inserting a short peripheral catheter is approximately USD32. Hygienically, every new attempt appropriately requires new needle. Hence, if three attempts are established, a short peripheral IV catheter could cost at least USD96 (Lynn, 2005). These costs could indirectly affect the financial viability of the facility.

The current technologies used to aid IV access, such as ultrasound imaging, transillumination and infrared devices are reported to have several disadvantages. Ultrasound approach requires extensive training on hand-eye coordination during the vein cannulation. Besides that, it takes time to locate suitable vein and a needle position accurately. Transillumination devices have been used but they have very limited application and are usually suitable for a baby's small hand. Infrared devices such as AV300 and VeinViewer sometimes produce unclear output image. They are also costly (Lovhoiden, 2004; Soujanya, 2007; Enerspect, 2009). Due to the discussed problems, it is clear that a more reliable device that could aid paramedics in finding veins for peripheral IV access is urgently needed.

1.3 Objectives of the Research

Owing to the problems explained in Section 1.2, this research focuses on the development of a hand vein image enhancement system using intelligent techniques. The objectives of the research are outlined below:

(i) To design and develop a hand vein image acquisition system using IR technology.

(ii) To implement new intelligent techniques for hand vein image enhancement.

(iii) To design and implement a hand vein projection system.

(iv) To access the performance of proposed intelligent hand vein enhancement methods in comparison to several existing enhancement techniques.

This study focusses on developing a system that can solve the problem of unclear visualization of hand vein patterns. In general, this system consists of three main sub-systems. The first sub-system is developed to capture hand vein image using Near-Infrared (NIR) technology. The second sub-system, involves several processes for vein patterns image enhancement using intelligent techniques. Finally, the third sub-system aims at projecting the enhanced hand vein image onto a patient's hand.

1.4 Thesis Outline

This thesis is divided into six main chapters. This chapter presents the overview of peripheral IV access and the problems encountered in the existing techniques. The objectives are also presented. The rest of this thesis is organized as follows.

Chapter 2 briefly reviews four important topics which cover all aspects of this research work. It begins with an overview of peripheral IV access procedures, difficulties at attempting IV access and discusses the current technology utilized to aid paramedics in obtaining IV access. Then, the chapter elaborates on the main device components of a hand vein image acquisition and projection system. Following this is a section on image processing techniques which have been applied on hand vein images. Finally, intelligent techniques focusing on Artificial Neural Network (ANN) and Fuzzy Logic (FL) that have been employed to solve hand vein image-processing-related problems are also presented.

Chapter 3 explains the hardware components for development of a hand vein image acquisition system. This includes justification in determining the best design and features for each components to be used in the hardware system. A prototype of the full system is also presented. Finally, the chapter explains the process of acquiring hand vein images.

Chapter 4 explains the software implementation work involved in developing the proposed intelligent hand vein enhancement technique. In this work, ANN and FL have been applied at different stages. The proposed technique involves six stages of image processing; Feed-Forward Neural Network (FFNN)-based Standard Median Filter (SMF), region of interest (ROI) extraction, grayscale image enhancement, segmentation of vein patterns, binary image enhancement, image registration and projection. The details of each stage is thoroughly explained in separate sections.

Chapter 5 presents the results of the developed hardware and software systems. This includes a discussion on the optimal wavelength as a light source obtained for the image acquisition system. It also presents the results of each proposed techniques employed in all image processing stages as aforementioned.

Chapter 6 provides conclusions for the objectives of this research based on the attained results. This is followed by few suggestions that can be implemented for further improvement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter briefly overviews the process of obtaining peripheral IV access for medical purposes. It then introduces the difficulties in achieving successful peripheral IV access normally faced by the paramedics. A review of the current technologies used to aid IV access and their limitations are also presented. This is followed by a review of previous works carried out at developing similar hand vein pattern exposure systems. This includes discussion on the hardware modules and image processing techniques involved in developing such systems. Intelligent techniques, particulary of ANN and FL used in previous works for enhancement of medical images and their roles in hand vein enhancement are also summarized.

2.2 Peripheral Intravenous (IV) Access

Peripheral IV access is a process of inserting a needle known as a catheter, into peripheral veins. This procedure is normally performed by medical laboratory scientists, medical practitioners, paramedics, phlebotomists or other nursing staffs. It aims at obtaining blood specimen for laboratory analysis, administration of fluids or medications and inserting invasive monitoring instrument. The first step for obtaining an IV access is to find the potential peripheral insertion sites, which normally includes a vein on the back of the hand or inside the elbow. However, it is preferable to use veins at the back of the non-dominant hand because it has lower risk of phlebitis (effected tissues are often red and tender to touch) than vein on the wrist or upper arm (Hadaway and Doris, 2007). Besides that, it could avoid dislodgement through movement.

Figure 2.1 shows different parts of hand veins usually involved in peripheral IV access. The dorsal metacarpal, cephalic, basilic and dorsal venous networks and their branches are recommended sites to place a needle because of their size and ease of access (Hadaway and Doris, 2007).

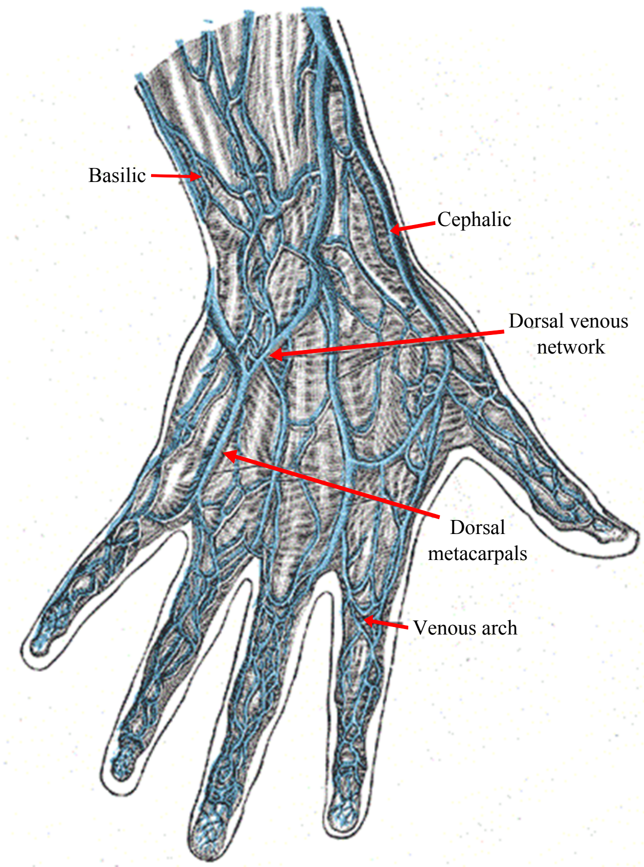


Figure 2.1: The vein on the dorsum of the hand (Crisan et al., 2007).

Once an appropriate location has been selected, the skin over the area is wiped with an antiseptic and an elastic band is tied around the arm. The band acts as a tourniquet, stopping the outflow of blood in the arm and making the veins more visible. The patient is asked to make a fist, and the paramedic feels the veins in order to select an appropriate one. When a vein is selected, the paramedic insert a needle into the vein and release the elastic band. After blood is drawn and the needle is removed, pressure is placed on the puncture site with a cotton ball to stop bleeding, and a bandage is applied (Smeltzer et al., 2009). Figure 2.2 shows the process of peripheral IV access on a patient's hand.

Figure 2.2: A peripheral IV access procedure on a patient (Hadaway and Doris, 2007).

2.2.1 Difficulties in Peripheral IV Access

Peripheral IV access is normally performed by a certified person who has been previously well-trained by a registered organization. Eventhough the right technique has been employed, it does not guarantee successful first attempt peripheral IV access. Hence, highly skilled and experienced paramedics are required to perform this task.

Despite improvements in care and training of paramedics, difficulties in establishing peripheral IV access still remains a problem, particulary in children. Several researchers have studied various aspects of this problem including medical equipment and patient's factors. According to Kuenstin et al. (2009), there are many factors contributing to success or failure of a peripheral IV access such as medical equipment used, patient-related illness or injury-related factors and skill-related factors.

For patient-related factor, it is closely related to a patient's age. IV access is especially problematic to neonates and infants. This procedure can be technically challenging because of the small size of infant's veins and their location deep in the subcutaneous tissue which makes them difficult to palpate or be visible (Janik et al., 2004). In addition, older children can easily become less cooperative and are apprehensive about vein injection. Anxiety can also cause patient's blood pressure to rise thereby narrowing the veins. This narrowed vein problem is a greater issue of concern in children as they naturally possessed small-sized veins. In addition, aging process results in changes in the skin causing it to become more rigid and less flexible. Patients with highly pigmented skin due to excessive exposure to sun creates similar changes in the skin, making peripheral IV access more difficult.

Patients who have repeated vein access in the past, like those chronically ill or drug users, have more visible veins but they may be blocked and not easily accessed. Thus, most of the time, paramedics looking for an accessible vein may have to make multiple attempts in order to find unblocked blood vessel. Another problem in chronically ill patients is that most of the accessible veins have been repeatedly used and are in various stages of healing. Therefore, paramedics have to search for another accessible veins at alternate sites which may be difficult to access (Hadaway and Doris, 2007).

In summary, it is concluded that major reasons for the failure in locating veins and IV access in patients are related to patient's conditions and type of treatment that they have received. Besides that, competency of the paramedics also plays a vital role in the success of locating a vein. Due to the aforementioned problems, there is a critical need for a tool or system which could facilitate peripheral IV access by increasing visibility of hand veins.

2.2.2 Current Technology in Peripheral IV Access

There are several available biomedical devices that are able to improve the visualization and successful veins access such as ultrasound imaging, transillumination and NIR devices. The following sub-section reviews these three devices.

2.2.2(a) Ultrasound Imaging

Ultrasound guided peripheral IV allows for noninvasive imaging to provide information such as size, location, position and depth of the vein inside a human body using pulse-echo technique (Soujanya, 2007). This information will then help a paramedic to identify an appropriate vein and finally guide the needle into the vein at appropriate site. From a survey conducted by the National Institute of Health and Clinical Excellence (NICE) on 250 respondences, ultrasound guidance has been recommended to be used as preference to blind puncture for adult temporary lines (Howard, 2002). Besides that, this approach has been proven safe to be applied on children of all ages (Arul et al., 2009).

Although this device have shown to give good quality images of the superficial and deep veins in obese patients and small veins in pediatric patient for real time approach, ultrasound pulse-echo technique requires an extensive training. It is particulary critical on hand-eye coordination during needle's tip handling when cannulating the vein because paramedic has to view the vein on the ultrasound display not directly on a patient's hand (Wells and Arul, 2010). Furthermore, ultrasound equipment is expensive and therefore is not cost-effective as a tool to examine IV sites on a routine basis. Figure 2.3 shows two paramedics searching an appropriate veins using ultrasonography guidance for the process of peripheral IV access.

Figure 2.3: Two paramedics accessing the peripheral IV access using ultrasonography guidance (Costantino et al., 2005).

2.2.2(b) Transillumination Device

Transillumination devices incorporate high intensity Light Emitting Diode (LED) as a light source to provide enhanced visualization of nonpalpable and nonvisible veins. Generally, there are two types of transillumination devices namely, reflection and penetration. For reflection type, a light source is usually placed in direct contact with the skin. The working principle starts with light entering the body through the skin and illuminates the region of interest (ROI). Some of the scattered light exits the ROI through the skin and is detected by the human eye.

On the other hand, penetration type uses a light source positioned behind the ROI. These illumination devices work best when the ROI is relatively thin, such as at the arm or hand of a small pediatric patient. This is because the performance is limited by how much light can penetrate the whole arm or hand and by the light-scattering properties of biological tissues for visible light. These devices are very compact and cause no damage to patients skin but it requires light in the room to be switched off for the paramedic to view the veins clearly. A marker is sometimes used to make a mark on the patient's skin after identification of the vein for later access when room light is switched on. Example of transillumination devices that utilized reflection and penetration techniques are summarized in Figure 2.4.

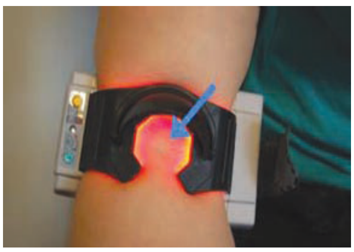
Device	Device Description	Disadvantage
1. Venoscope II 	- Reflection type. - Uses 6 high-intensity red and white LEDs to illuminate the tissue.	- Used to locate vein for a baby only.
2. Veinlite 	- Reflection type. - Comes in two types: halogen-light and fibre-optic Veinlite and LED based pocket Veinlite. - The LEDs are combination of bright orange and deep red for strong illumination.	- Used to locate vein for a baby only.
3. Wee Sight 	- Penetration type. - Uses two types of LED light at 0.629um to locate a vein. - It allows a hand-free operation.	- Used to locate vein for a baby only.
4. Veintector 	- Reflection type. - Uses 38 red and yellow LEDs to illuminate the tissue. -A colour-adjustment button that allows the user to change settings for optimal contrast.	- No approval as a medical instrument. - Heat emitting effects since the LEDs are directly in contact with patient's skin.

Figure 2.4: Transillumination devices to aid peripheral IV access.

In general, transillumination devices are suitable for use on pediatric patients only. In addition, some of the devices need to be in contact with the patient's skin and operate in a dark room in order to visualize the veins clearly.

2.2.2(c) Infrared (IR) Device

NIR light has wavelength of 0.75μm to 1000μm situated in the electromagnetic spectrum between the visible region and the mid-wave IR region. These waves have been used as an illuminator in biometric or medical imaging for insertion of IV (Zharov et al., 2004; Paquit et al., 2006, 2007; Brewer and Salisbury, 2010) and extracting feature points of vein pattern (Shahin et al., 2007; Zhao et al., 2008; Hegde et al., 2009; Yuan, 2010). The use of IR light has more advantages over transillumination and visible light because IR light allows the image to be greatly enhanced before viewing. Also, IR light is less absorbed by human skin compared to visible light.

A number of biomedical devices use NIR as an illuminator, such as the AV300 and Vein-Viewer manufactured by AccuVein and Luminetx Corporation respectively (Dennis, 2009). Both devices illuminates a patient's vasculature, allowing paramedics to have clear vision on the area of interest to stick the needle. The AV300 is a portable equipment, which emits an NIR light on the skin and reflects vein maps on the surface of the skin. The device is lightweight, sensitive and does not require pre-use calibration or adjustments. It can be used immediately by paramedics without extensive training. In principle, when the device is held and activated about seven inches above the skin, it detects the difference in the hemoglobin concentration between the veins and surrounding tissue. Once detected, the reflected NIR light indicates the size and position of veins beneath the skin by promptly projecting precise map of the veins on the skin (AccuVein, 2009). Figure 2.5 shows AV300 handheld device projecting vein maps on a patient's dorsal hand. The device is hygienic and does not need to be sterilized between usages since it does not come into contact with a patient's skin (Dennis, 2009; AccuVein, 2009). However, it is not be able to project precise vein map for some pediatric patients.

Figure 2.5: AccuVein's AV300 projecting vein maps on a patient's hand (AccuVein, 2009).

The VeinViewer is also designed to assist vascular access by using NIR light concentrated on a patient's skin to detect hemoglobin's presence. In contrast to AV300, VeinViewer used a camera, computer and projector as part of a complete system. The VeinViewer works using NIR light source directed on a patient's skin and the hemoglobin in the blood vessels absorb the light and its image reflection is captured by a digital camera. This image is then processed by enhancing its contrast and the resulting image is projected back on the skin at exact location in real time (Soujanya, 2007). Figure 2.6 shows a VeinViewer being tested on a patient.

The use of AV300 and VeinViewer in vein access have been reported to significantly improved the success rate of first-attempt, reduced the number of IV attempts per-patient and reduced the time required to successful vein access (Christie, 2009). Despite their success, the

AV300 produced unclear output image. VeinViewer on the other hand, is costly, approximately USD25,000 and requires a calibration (Kobus, 2009). The VeinViewer used unsharp masking edge-enhancement using Intel MMX instructions to perform the image processing part.

Figure 2.6: VeinViewer projecting vein maps on a patient's dorsal hand (Soujanya, 2007).

After having an extensive review on these three technologies used to aid peripheral IV access, it is realized that IR method is the best method in comparison to ultrasound and transillumination as it is non-invasive, non-contact, and fast for IV access. Besides that, an enhanced vein imaging method that is less expensive is desirable. Therefore, this work aims to contribute to the invention of a better vein imaging system which utilizes NIR technology in computer vision, with an enhanced contrast of vein patterns to aid IV access.

2.3 IR Hand Vein Imaging

A number of hand vein imaging researches in biometrics and medical diagnostic have been reported recently (Zharov et al., 2004; Soujanya, 2007; Wang et al., 2007; Wu and Ye, 2009; Cuper et al., 2010). The hand vein imaging system based on IR has been extensively used and its principle is relatively standard to other image acquisition system. In general, the system consists of a set of hardware and software modules designed to capture an image of hand vein. The image is then analyzed to identify or measure the desired properties. A typical image acquisition system includes the following components:

(i) A platform where the hand is positioned.

(ii) IR illuminator which enlighten the hand veins.

(iii) A detector, usually a camera to capture the hand image.

(iv) A frame grabber or converter which receives the image from the detector.

(v) A personal computer (PC) which stores the incoming image and runs specific application programs.

(vi) A display device, displaying the image to aid visualization.

The main image acquisition components are discussed in the following sub-sections.

2.3.1 IR Illuminator

In many medical practices, X-ray and ultrasonic scanners are used to form vascular images. Whilst these imaging modalities can produce high quality images, excessive doses of X-ray radiation and the application of a gel onto a skin in ultrasound imaging could give negative impacts to a patient or make patient uncomfortable (Wang et al., 2007). NIR on the other hand provides a contactless and requires no injection inside the human body in order to capture subcutaneous veins. It does this simply by exposing the patient's vein to NIR illumination at appropriate wavelength. An optimum illumination in hand vein imaging system is a crucial aspect and needs to be considered to attain good quality images. The quality of acquired image is dependent upon the selection of imaging principle, illumination technique, optimal wavelength and IR arrangement.

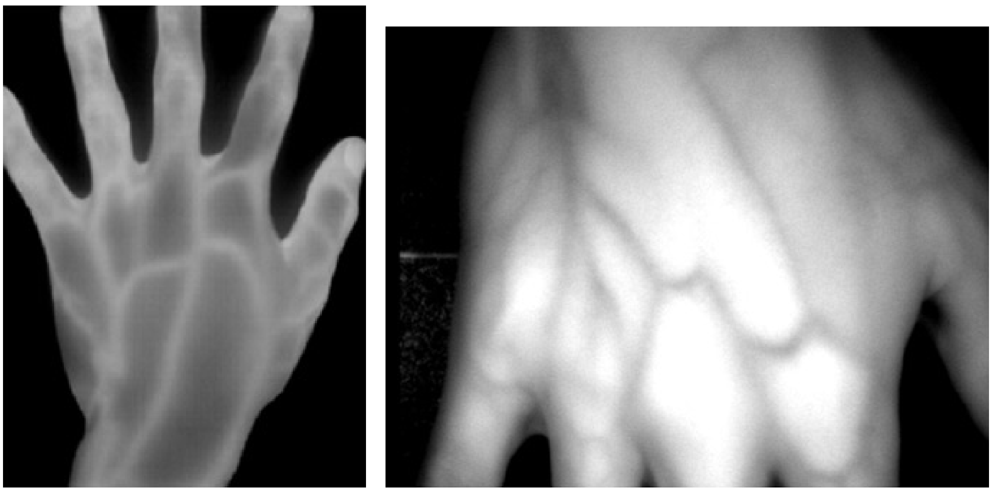
2.3.1(a) Principle of IR Imaging

In electromagnetic spectrum, IR typically refers to a wavelength region spanning from 0.75μm to 1000μm. This region can be further divided into four sub-bands; NIR in the range of 0.75μm to 2μm, middle IR in the range of 2μm to 6μm, far IR (FIR) in the range of 6μm to 14μm and extreme IR in the range of 14μm to 1000μm. However, only NIR and FIR regions are capable of capturing the superficial or the subcutaneous veins inside the human body. This have been proven by Cross and Smith (1995), Miura et al. (2004), Lin and Fan (2004), Toh et al. (2005), Wang et al. (2007).

Wang et al. (2007) has carried out a study on the principle of NIR and FIR imaging methods in developing a hand vein image acquisition system. FIR imaging technology formed images based on the IR radiation emitted from the human body. Medical researchers have found that human veins have higher temperature than the surrounding tissues (Kourkoumelis and Tzaphlidou, 2010). Therefore, the vein patterns can be clearly displayed via FIR thermal imaging as shown in Figure 2.7 (a). No external light is required for FIR imaging and hence FIR does not suffer from illumination problems as many other imaging techniques. However, there are two main drawbacks of this technology. Firstly, FIR imaging produced low levels contrast of output image (Wang et al., 2007). This makes it difficult to separate the veins from the background. Beside that, nearby tissues are heated up by heat radiation to temperature similar as veins and makes it difficult to locate the exact position of a vein. Secondly, it is only capable of capturing the major vein patterns, omitting other small veins which may be of interest (Wang et al., 2007). Moreover, this technology can be easily affected by external conditions like ambient temperature and humidity.

Wang et al. (2007) has summarized the advantages of NIR technology for hand vein imaging into two criteria. Firstly, NIR imaging is suitable for vein detection because it can penetrate into biological tissue up to 3mm in depth. Secondly, a reduced hemoglobin in venous blood, absorbs more NIR radiation than the surrounding (Cross and Smith, 1995). As such, vein patterns near the skin surface are discernible as they appear darker than the surrounding area. As shown in Figure 2.7 (b), NIR can capture the major vein patterns as effectively as the FIR imaging technique (refer to Figure 2.7 (a)). More importantly, it can detect finer veins lying near the skin surface. This increases the potential discriminative ability of the vein patterns. Apart from that, NIR has better ability than FIR to withstand the external environment and the patient's body temperature (Wang et al., 2007).

Due to the superiority and advantages of NIR as opposed to FIR, subsequent sections of this thesis only focus on NIR.



(a) (b)

Figure 2.7: The back of hand image captured using (a) FIR and (b) NIR (Wang et al., 2007).

2.3.1(b) Optimal NIR Wavelength

NIR light is well-known for its ability to make finer veins visible and it is tolerant to environmental changes in hand vein imaging. This has been proved by a majority of researchers who use NIR spectral region at 0.85μm to obtain high contrast image of subcutaneous veins (Wang et al., 2007; Crisan et al., 2007; Wu and Ye, 2009; Cuper et al., 2010; Brewer and Salisbury, 2010). Cross and Smith (1995) and Michael et al. (2010) have used NIR with wavelength of 0.88μm in their work for similar purpose. In another study by Paquit et al. (2007), a combination of wide range NIR comprising of six different wavelengths from 0.74μm to 0.91μm has been used. This paper has successfully proven that a combination of wavelengths can improve the contrast of vein images.

A comprehensive study on optimal wavelength for visualization of blood vessels in the NIR has been carried out by Cuper et al. (2008). In the study, contrast index has been determined from a ratio between the spectra of image pixels in skin area and spectra of image pixels of blood vessel. Based on the experimental setup, the contrast index appears to be highest in the range of 0.85μm to 0.90μm. This findings shows that, the optimal range of wavelength for NIR imaging of subcutaneous veins is in the range between 0.85μm to 0.90μm.

2.3.1(c) NIR Illumination Techniques

Choosing the right techniques of illumination, could minimized the illumination error and improve the contrast of vein and its surrounding. There are three types of IR propagation techniques which can be used to capture a hand vein image. These techniques are reflection, penetration and mixing. The difference among the three techniques is discussed.

Figure 2.8 shows a schematic diagram of an image acquisition system. From the figure, it can be seen that there are two groups of NIR sources; NIR LED array 1 and NIR LED array 2.

In NIR light reflection, the NIR LED array 1 and camera are positioned at the same side of the hand (Paquit et al., 2007). The principle of imaging is to capture the reflected NIR LED array from hand by the camera sensor.

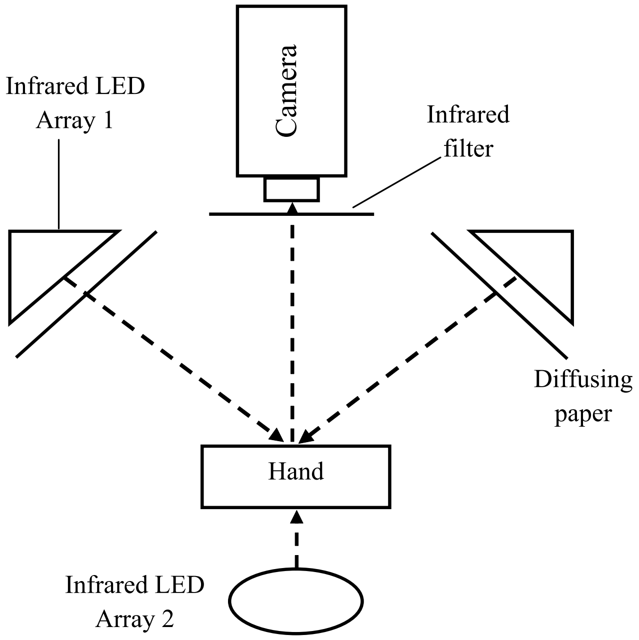


Figure 2.8: Schematic of image acquisition (Zhao et al., 2008).

On the other hand, in NIR penetration, hand is closely positioned between the NIR LED array 2 and the camera (i.e. sensor), so that the NIR light passes through the hand and moves towards the camera (Cuper et al., 2010). Meanwhile, mixing NIR imaging is a combination of both NIR light reflection and NIR light penetration methods where both NIR LED array 1 and NIR LED array 2 are used as illumination in image acquisition. The characteristics of the three NIR imaging techniques are summarized as shown in Table 2.1.

Table 2.1: Comparison among three NIR imaging techniques (Zhao et al., 2007).

IR Imaging Technique	Reflection	Penetration	Mixing
Contrast	Low	High	Low
Noise	Low	High	Low
Imaging Depth	Low	High	High
Effect to skin	Low	High	High

2.3.1(d) NIR Arrangement

Crisan et al. (2007) have studied of NIR LED configurations. They have found that any arrangement of NIR produced a similar distribution of intensity. Figure 2.9 shows the various matrix arrangements of NIR LEDs array used in their vein image acquisition.

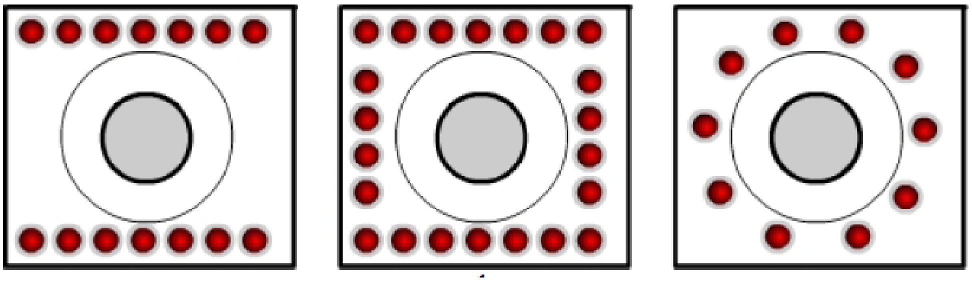


Figure 2.9: Various arrangement of NIR LED array (Crisan et al., 2010).

On the other hand, Zeman et al. (2001), Lovhoiden et al. (2002), and Noordmans et al. (2004) have found that various matrix arrangements of the NIR LEDs would modify the distribution of radiation intensity. Their finding is supported by Paquit et al. (2006) and Chakravorty et al. (2011). In their works, the LEDs were placed in three concentric circles in the same focal plane. The purpose of using this arrangement of lighting system was to ensure that the lighting is constant all over the region. At the end of the study, they concluded that a double or triple concentric circles of LED array as light source provides a very good radiation of distribution and uniformity.

2.3.2 Camera

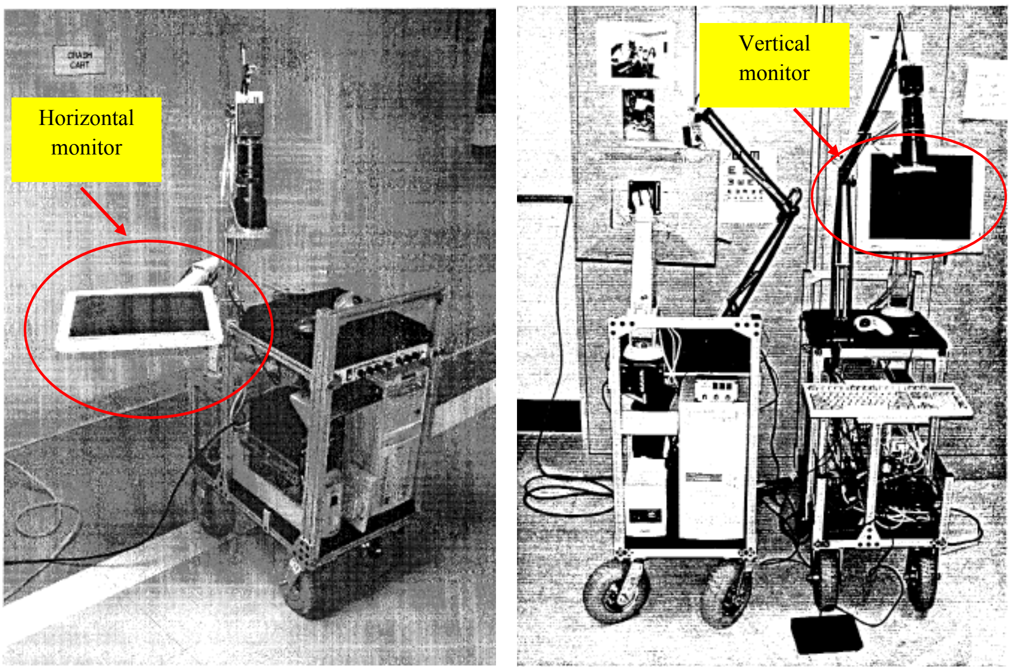
The selection of camera is one of the most critical steps in designing an imaging system. The purpose of a video camera is to convey images projected onto the sensor via lens, to a system for storage, analysis or display. In general, two types of camera are normally used for hand vein imaging; IR and progressive area-scan camera. IR camera offers a high degree of flexibility in terms of frame rate, user interface, temperature range and most importantly it can produce a high quality image in IR spectrum (National-Instrument, 2011). However, due to its high cost, its application onto hand vein imaging becomes limited.

A modern and reasonable priced camera, such as progressive area-scan camera has been widely employed by many researchers in IR imaging as an alternative to IR camera. These are due to the capability of photographing in the IR spectrum. Camera manufacturers use a special IR filter on the sensor to block most of the IR light in order to improve the quality of visible light being recorded. Noordmans et al. (2004), Crisan et al. (2007), and Chakravorty et al. (2011) used this property by removing the IR filter inside a camera and replaced it with an additional filter to obtain the image of the back of the hand.

Charge-Coupled Device (CCD) and Complementary Metal-Oxide Semiconductor (CMOS) image sensor are two different technologies for capturing images digitally. Both methods produced darker vein patterns than the surrounding parts. Paquit et al. (2006), Paquit et al. (2007), and Bouzida et al. (2010) are among the researchers that applied a progressive scan CMOS camera attached with an IR filter. However, most of researchers used CCD camera as a hand vein capturing device (Zeman et al., 2001; Lovhoiden et al., 2002; Zharov et al., 2004; Katrasnik et al., 2009; Cuper et al., 2010). This is due to the advantages of CCD in term of high sensitivity to NIR, dynamic range, uniformity and less noise compared to CMOS technology (Optics, 2010). In addition, as recommended by the manufacturer, CCD image sensor is suitable for applications that require superior image quality (Optics, 2010; National-Instrument, 2011).

2.3.3 Display Device

Finally, the last equipment in hand vein image acquisition is a device used to display the images which have been captured or processed. In the early research of NIR imaging, monitor-based vein contrast enhancer by Lovhoiden et al. (2002) has been assembled on a small computer table with a wheel to visualize subcutaneous structure as shown in Figure 2.10 (a) and (b). A Samsung Syncmaster liquid crystal display (LCD) monitor has been positioned horizontally flat on the table with extra area for a patient's arm next to it (see Figure 2.10 (a)). In the next prototype, the LCD monitor are no longer positioned horizontally but are mounted on standard LCD monitor stands as shown in Figure 2.10 (b). Later, Zharov et al. (2004) also explored the capability of NIR imaging to visualize subcutaneous structures and develop a rather similar system as Lovhoiden et al. (2002). The output of the real-time contrast enhancement by Zharov et al. (2004) was then displayed on a cathode ray tubes (CRT) computer or head mounted display.



(a) (b)

Figure 2.10: (a) Horizontal monitor-based and (b) vertical monitor-based vein contrast enhancer (Lovhoiden et al., 2002).

Although this monitor-based approach have shown to give good results, the similar problem as in ultrasound-guided, reflecting on hand-eye coordination are similar to those reported by Lovhoiden (2004). In order to overcome this problem, Lovhoiden (2004) has proposed a new approach called a projection-based system as shown in Figure 2.11. The system used a standard-sized projector, InFocus LP130. As the sizes of resolution and focal length are not suitable for the output design, some modifications have been made in order to project a 64×48mm image on a screen. This is done by replacing the original projection lens by a 90mm f4.5 Voss enlargement lens. The advantages of the projector-based system is it provides a vascular road-map directly on a patient's skin. Hence, no hand-eye coordination is required as through a TV or computer monitor to provide the paramedics with the location of veins.

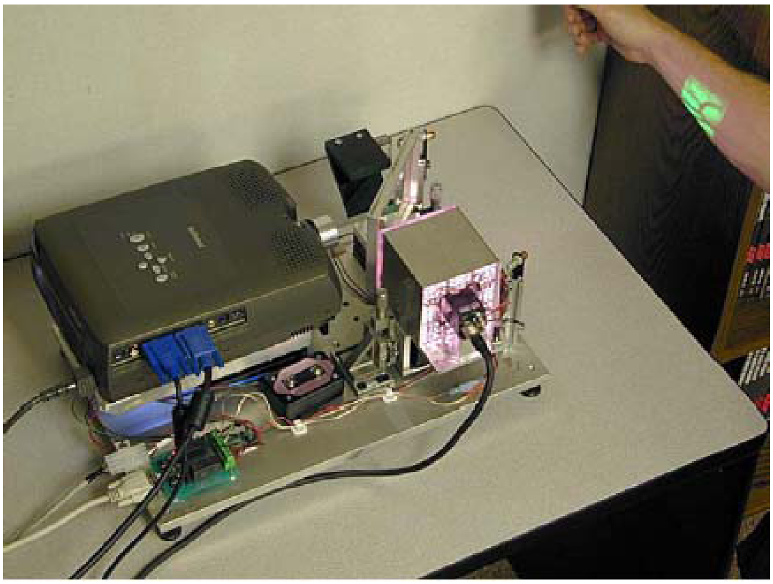


Figure 2.11: Prototype of projection-based system (Lovhoiden, 2004).

2.4 Image Processing of Hand Vein Images

Image processing of hand vein images is an active and rapidly growing research field. Despite the development of IR technology over the past years, some factors have led to the acquisition of images which are inferior than the desired levels of detailed visibility contrast. This is due to image acquisition stage which is effected by various unnecessary information, such as background noise, irregular shades due to muscle and intensity fluctuations. Image processing aims to eliminate such unnecessary information and enhances the vein patterns of interest.

A typical image processing process for hand vein imaging involves several stages as illustrated in Figure 2.12. Regularly, the first step is image pre-processing. In pre-processing stage, the ROI selected from a hand vein image is generally de-noised and enhanced using several techniques. Following image pre-processing is segmentation which allows partitioning of hand vein image to foreground and background. The last step corresponds to removal of small objects or unwanted noise to enhance the wanted portion of the image.

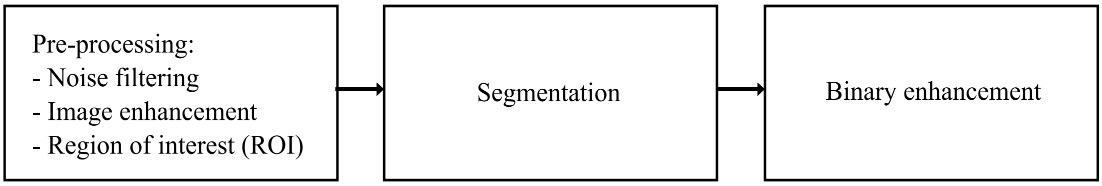


Figure 2.12: Block diagram of common image processing stages on hand vein images.

2.4.1 Noise Filtering

Corruption of image by impulse noise is a common problem in digital imaging (Gonzalez and Woods, 2010). In hand vein imaging, impulse noise is generated during image acquisition using a CCD camera and transmission of captured image in a noisy channel. Impulse noise, even at low noise percentage can change the appearance of vein images significantly. This is because noise is a set of random pixel values which normally has very high contrast from its surrounding. These properties can easily make any kind of subsequent processing such as segmentation, edge detection or object recognition, difficult or sometimes impossible. Therefore, the suppression of impulse noise is a requirement in pre-processing stage of an image particularly vein images where precision is critical. Primarily, the goal of removing impulse noise