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Research Article

Time and Cost-Efficient Vein Pattern Recognition and Injection Point Suggestion using Machine Vision Technology

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Abstract: Vein detection is an important task for venepuncture. Excessive venepuncture can cause significant problems during an emergency situation due to the lack of experienced medical staff. In this paper, time and cost-efficient portable vein pattern recognition system is proposed. A vein camera mobile application is used to obtain Near Infrared Light (NIR) image and then a set of machine vision algorithms are applied to the NIR image in order to find vein pattern and injection point. Infrared Radiation (IR) sensitive camera can be utilized to produce a Near-Infrared light (NIR) in a specified wavelength range. This camera roughly creates a brightness difference between the vein region and surrounding tissues in the captured image. The vein regions appear to be darker in comparison to surrounding tissues in the images. Past studies depict that cost, time and portability are the main challenges faced during the implementation of this type of camera systems. These challenges can be overcome by using a vein camera mobile application to take an infrared image instead of designing and using an expensive IR camera. The quality of the images captured by a vein camera application is almost the same as quality of the images captured by an expensive IR camera. The captured image is processed by a sequence of operations such as median filtering, Contrast-limited adaptive histogram equalization (CLAHE) operation, adaptive thresholding, morphological operations, perimeter extraction, and distance transform to determine the vein region, and suggests a location for injection. In particular, CLAHE is the key operation that is employed for contrast enhancement. Although there are techniques to handle vein pattern detection problem, this is the first time a machine vision algorithm including the CLAHE operation is applied to Near Infrared Light (NIR) images for vein pattern recognition. The proposed algorithm is also capable of injection point suggestion which is very important for venepuncture. Our approach is implemented in MATLAB software and can be applied to both fair and dark skin tones. Evaluations with 21 participants with varying skin tones (fair and dark) show that the proposed approach is especially effective for detecting vein patterns at the back of the hand (with 95.24% accuracy) and wrist (with 76.19% accuracy).

Keywords: *Vein pattern recognition, Cost and time efficient, Machine vision, NIR, MATLAB, Venepuncture.*

Makine Görme Teknolojisini Kullanarak Zaman ve Maliyeti Verimli Damar Tesbiti ve Enjeksiyon Noktası Önerisi

Özet: Damar tespiti veneponksiyon için önemli bir görevdir. Aşırı venopunktur, deneyimli bir tıbbi personelin bulunmaması nedeniyle acil durumlarda ciddi sorunlara neden olabilir. Bu yazıda, zaman ve düşük maliyetli portatif ven örüntü tanıma sistemi önerilmiştir. Near Infrared Light (NIR) görüntüsü elde etmek için bir ven kamera mobil uygulaması kullanılır ve daha sonra ven desenini ve enjeksiyon noktasını bulmak için NIR görüntüsüne bir dizi makine görme algoritması uygulanır. Kızılötesi Radyasyona (IR) duyarlı kamera, belirli bir dalga boyu aralığında bir Yakın Kızılötesi ışık (NIR) üretmek için kullanılabilir. Bu kamera, çekilen görüntüdeki damar bölgesi ve etrafındaki dokular arasında kabaca bir parlaklık farkı yaratır. Damar bölgeleri, görüntüdeki çevre dokulara kıyasla daha koyu görünüyor. Geçmişte yapılan çalışmalar, maliyet, zaman ve taşınabilirliğin, bu tür kamera sistemlerinin uygulanması sırasında karşılaşılan başlıca zorluklar olduğunu gösteriyor. Pahalı bir IR kamera tasarlamak ve kullanmak yerine kızılötesi bir görüntü elde etmek için bir ven kamera mobil uygulaması kullanılarak bu zorlukların üstesinden gelinebilir. Bir ven kamera uygulaması tarafından yakalanan görüntülerin kalitesi, pahalı bir IR kamera tarafından çekilen görüntülerin kalitesi ile hemen hemen aynıdır. Yakalanan görüntü, ortanca filtreleme, Kontrast sınırlı uyarlamalı histogram eşitleme (CLAHE) işlemi, adaptif eşikleme, morfolojik

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Yakalanan görüntü, ortanca filtreleme, Kontrast sınırlı uyarlamalı histogram eşitleme (CLAHE) işlemi, adaptif eşikleme, morfolojik işlemler, çevre çıkarma ve damar bölgesini belirlemek için mesafe dönüşümü gibi işlemler dizisi ile işlenir ve enjeksiyon için bir yer önerir. Özellikle, CLAHE kontrast geliştirme için kullanılan kilit işlemdir. Damar paterni tespit problemini çözecek teknikler olmasına rağmen, ilk defa damar paterni tanıma için Yakın Kızılötesi Işığa (NIR) görüntülere CLAHE işlemini içeren bir makine vizyon algoritması uygulanır. Önerilen algoritma aynı zamanda damar delinmesi için çok önemli olan enjeksiyon noktası önerisi de yapabilir. Yaklaşımımız MATLAB yazılımında uygulanmıştır ve hem açık hem de koyu ten tonlarına uygulanabilir. Değişken cilt tonlarına (açık ve koyu) 21 katılımcıyla yapılan değerlendirmeler, önerilen yaklaşımın özellikle el arkasındaki (% 95.24 doğrulukla) ve el bileğinde (% 76.19 doğrulukla) damar desenlerini tespit etmede etkili olduğunu göstermektedir.

Anahtar Kelimeler: *Damar örüntü tanıma, Maliyet ve zaman açısından verimli, Makine görüşü, NIR, MATLAB, Venopunktur.*

1. Introduction

In medicine, venepuncture is the process of obtaining intravenous access for the purpose of intravenous therapy or for blood sampling of venous blood. However, for infants, elderly or dark skin toned people it is difficult to find the appropriate vein location for venepuncture. On an average basis, 2 to 10 attempts are made by an attending nurse to insert a needle successfully, although it can be accessed easily in a single attempt depending on the condition of the patient being admitted [1]. The main reasons for multiple attempts during intravenous access are the lack of experienced staff having appropriate venepuncture skills, and any medical situation causing difficulty in accessing vein [2-4]. Excessive improper venepuncture may lead to permanent damage to the vein, cause swelling and several allergic reactions [5]. In addition, it consumes a lot of time and resources during emergency situations [6-8].

Several techniques have been developed to handle the vein detection problem. The most common four strategies are: (i) the use of secondary light source to detect vein pattern, requires a darken room and may cause severe skin burn (ii) use of chemicals, but these are not applicable on infants and dark skin toned people (iii) use of ultrasound-guided hardware but it requires expensive equipment and well-trained staff (iv) use of NIR to visualize the vein pattern [9].

The skin is the largest organ of the human body consist of three main layers epidermis, dermis, and hypodermis (subcutaneous layer). Vein, arteries, and nerves are located in the lowermost hypodermis layer having a depth of 3mm underneath the skin as shown in Figure 1. However, children have thin skin layers as compared to adults.

Table 1. Literature review on related vein pattern recognition work.

Authors	Year	IR Camera Type	Advantages	Applications	Limitations
Naoya Tobisawa, et al. [17]	2011	Near Infrared CMOS camera	Trans-illuminated image is obtained. Deep-seated blood vessel images for adult forearm(67 mm)	Varicose-vein treatment Intravenous injection Intraoperative observation	Equipment cost
Manam Mansoor, et al. [18]	2013	Modified low-pass web camera	NIR ring of LEDs illuminates the desired vein pattern	Hand Vein pattern	No proper intravenous recognition
Deepak Prasanna.R, et al [19].	2012	Charge Coupled Device(CCD) Camera	High boost filter technique provides enhanced vein pattern	Hand Vein pattern	Not exact vein pattern is recognized
Aida Marcotti, et al. [20]	2013	CMOS optical Sensor	Artificial visualization of the venous network is obtained	Venous network detection	The detected vein pattern has some noisy signals
Septimiu Crisan, et al. [21]	2010	Charge Coupled Device(CCD) Camera	Improved NIR lightening system and feature extraction algorithm	Vein pattern recognition	Algorithm complexity and Equipment cost
Our Work	2019	Vein mobile camera Application [22]	Time efficiency and accuracy in terms of Vein pattern detection. Exact pricking point is determined based on Euclidian distance.	Time and Cost Efficient Vein Pattern Recognition and Injection Point Suggestion	Effect of ambient light not considered

Veins consist of deoxygenated blood which has a tendency to absorb 740 -760 nm wavelength of NIR light spectrum, differentiating from oxygenated blood rich arteries [11]. The NIR spectrum has an advantage of using different wavelength absorption scheme that can help to differentiate vein from arteries and surrounding tissues [11-12].

We propose a system that can recognize the vein pattern irrespective of the skin color tone. It is time and cost efficient, it can prevent excessive pricking [13], and therefore reduce the pain of patients. The proposed system enhances the contrast, and indicates the dynamic range in an image for efficient vein pattern detection using various image filtering techniques. To achieve this, in particular we use Contrast-limited adaptive histogram equalization (CLAHE) operation, which plays a vital role in contrast enhancement of an image for accurate detection of vein pattern. After enhancement, a desirable intensity histogram shape appears [14] that is used for threshold selection and segmentation.

The proposed algorithm also suggests a pricking point for venepuncture.

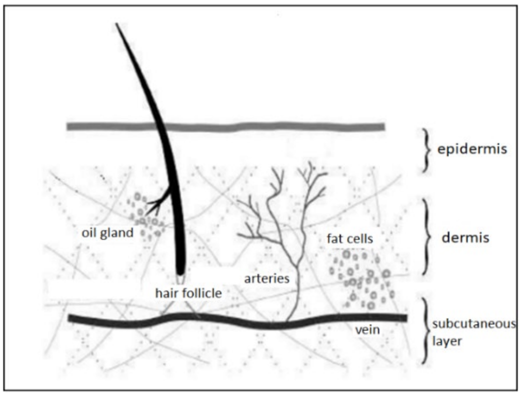


Figure 1. Human skin anatomy [10].

In this work, we address the vein pattern recognition and injection point suggestion problems with a novel system design. The main short comings include equipment cost, algorithm complexity and no proper intravenous recognition. The proposed system is novel since (i) the equipment cost is reduced by using an NIR mobile application rather than designing a NIR camera. We use an existing mobile application to capture NIR image of arm. (ii) Instead of the complex algorithms which will cause more delay, only a few filtering techniques are used which can detect vein pattern in a time efficient way. (iii) We apply CLAHE operation as well as ROI and Euclidean distance algorithms on the extracted vein pattern for providing the exact pricking point for venepuncture.

The rest of the paper is structured as follows: Section 2, discusses the related work about vein pattern recognition. Section 3 explains the proposed system architecture and implementation details. Section 4 discusses evaluations and experimental results. Finally, section 5 concludes the paper.

2. Literature Review

Vein pattern recognition is one of the most popular biomedical applications. For vein pattern recognition, various challenges are required to be solved such as proper lightening system to acquire the NIR image, and then an efficient system to recognize the proper vein pattern. Several designs have been proposed for vein pattern recognition as illustrated in Table 1. However, there are certain limitations which need special attention.

Table 1 also includes our work for qualitative comparison. We do mention about camera type, advantages, applications, and limitations while comparing with the baselines. In addition, it is worth to mention that none of the previous studies in this subject conducted accuracy and time evaluation for their work to the best of our knowledge. In our paper, we conduct both accuracy and time evaluation for our work.

3. System Architecture and Implementation

The proposed system consists of a vein mobile application for capturing NIR image of human arm. The acquired input image from the mobile phone is processed to separate the vein from surrounding tissues and to find a prominent vein pattern using a set of machine vision technologies in MATLAB software. The image acquire by the mobile phone app is transferred to the computer for processing in Matlab environment. The proposed system is implemented in quite efficient manner in terms of both time and cost. The system architecture is shown in Figure 2. Image processing will separate the desired vein from the surrounded arteries and tissues, which can assist medical staff to perform venepuncture.

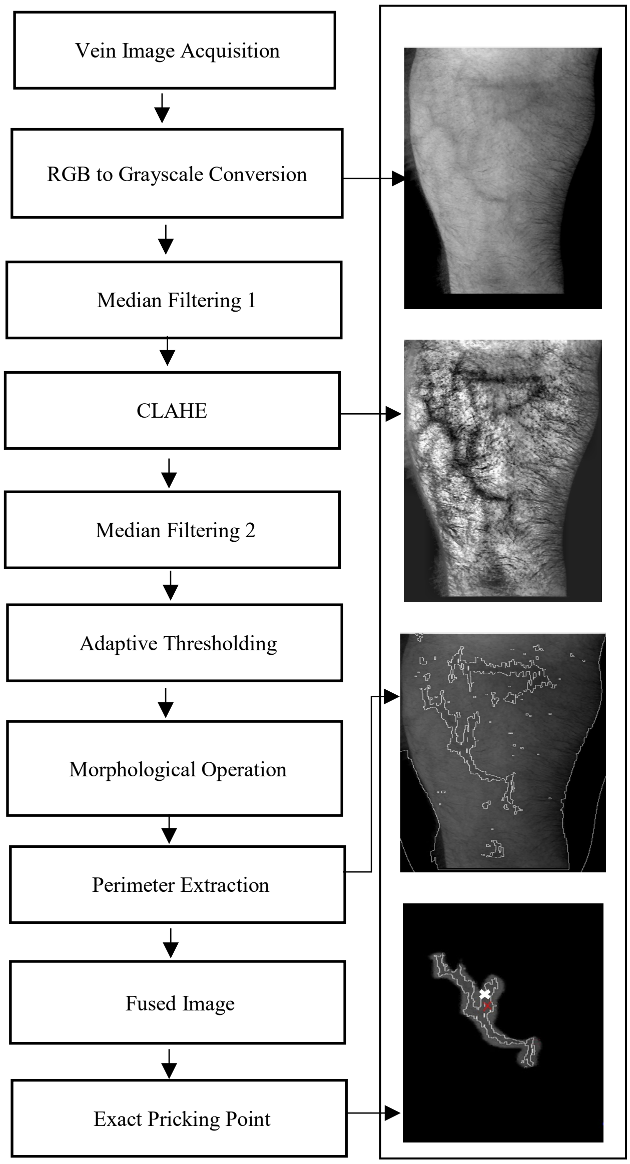
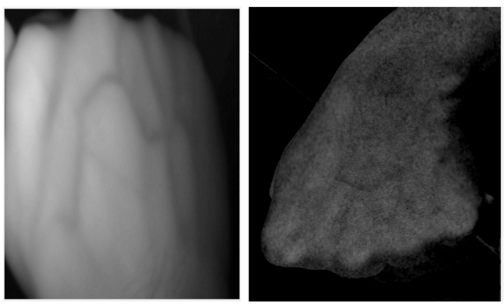


Figure 2. Hierarchy of image processing (fore-arm).



(a) (b)

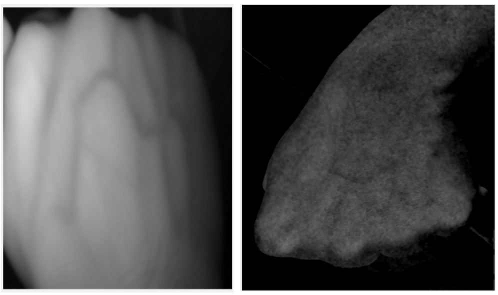
Figure 3. Grayscale image (a) Fair and (b) Dark skin tone.

First, vein mobile camera application designed by Alexandre Amato is used to acquire the NIR image of hand and forearm [22]. The image is captured using Iphone X on Apple A11 bionic processor using iOS 11 Operating System, dual 12 Megapixel Camera, 3 GB RAM and 256 GB storage. This application enhances the visualization of green channels, thus darkening the vein pattern for recognition. Moreover, this image is further processed through various algorithms in MATLAB environment to extract the exact pricking point for venepuncture. The time evaluation results are obtained using Matlab 2018b on a Windows 7 Operating System with Intel Core i5-3470, 3.20GHz- 3.19 GHz and 8GB RAM.

Image processing algorithms are applied on both fair and dark skin tone hand to recognize the vein pattern. The original input image captured from the NIR mobile application is read through MATLAB software and the RGB image is converted into a Greyscale image as shown in Figure 3. A median filter is applied on the 2-D grayscale image with a 3x3 neighbourhood kernel to remove noise as shown in Figure 4.

In previous studies, non-linear transfer functions are taken into consideration that use the cumulative distribution function (CDF) as the mapping function. The mapping function stretches or compresses the peaks and troughs of histogram, resulting in modified intensity levels [15]. It is a simple method but it fails to identify the vein pattern from surrounding tissues accurately [16]. Therefore, a novel method is proposed in this paper using CLAHE which plays a vital role in contrast enhancement of an image and accurately suggests the injection point.

CLAHE is used for contrast adjustment. In particular, it does not only enhance the contrast of a grayscale image but also provides histogram equalization. The function used in this paper consists of two main parameters for contrast enhancement. The first one is the contrast enhancement limit which refers to a clip-point (CP) and the second is the distribution. The CP parameter prevents the specified homogeneous areas inside the image from over-saturation, which adjusts and provides a better contrast enhancement.



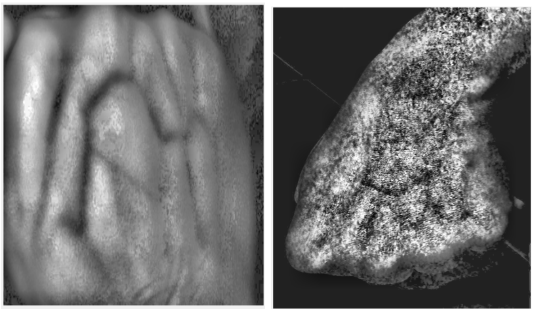
(a) (b)

Figure 4. Median filter 1 (a) Fair and (b) Dark skin tone.

Moreover, keeps the image in its original shape, which is expressed as follows:

$$CP = \frac{P}{D}\left(1+\frac{CF}{100}\,Slope_m\right) \quad (1)$$

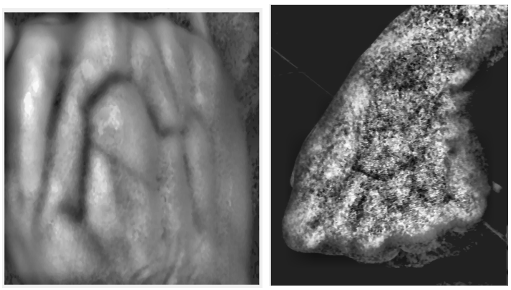
where P denotes the number of pixels, D is the dynamic range, CF is the clip-factor, and slope max is the maximum slope. When CF approaches 0, CP is P/D which depicts pixels having constant contrast. Whereas, higher values of CF (above 100), there will be more contrast enhancement. In the case when many pixels are falling inside the same grey levels, these specified homogeneous areas refers to a high peak in the histogram of a particular image which causes this over-saturation to happen and can affect the image contrast badly. However, CLAHE creates the contrast transform function as specified by the distribution [23]. Three kinds of distributions are performed depending on the type of input image in order to obtain the desired histogram shape. In this paper, Rayleigh distribution is used as it creates a bell-shaped histogram and provides a more natural visualization of the hand veins as shown in Figure 5.



(a) (b)

Figure 5. CLAHE (a) Fair and (b) Dark skin tone.

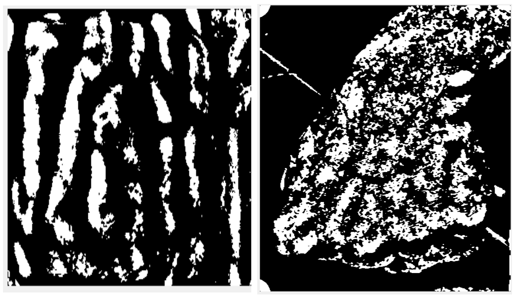
A dataset for 21 subjects were examined during this study. The accuracy results are based on whether the vein pattern is recognized accurately or not according to the aforementioned CLAHE algorithms. The algorithm will differentiate the darker region (vein) from the surrounding tissues and thus providing a clear pattern of vein. If the image after processing on Matlab is not showing a vein pattern accurately it means that the vein is not recognized by our system and thus based on these results accuracy is determined. Following CLAHE operation, the need for a second median filter is essential which will further remove the noise as illustrated in Figure 6. Moreover, it smoothens the image and removes the sharp transitions and blurring of the image for accuracy [24].



(a) (b)

Figure 6. Median filter 2 (a) Fair and (b) Dark skin tone.

Then, adaptive thresholding is used to convert the intensity image (greyscale) into a binary image (BW) by computing a local adaptive threshold (first-order statistics) having a scalar sensitivity value of 0.5 [25]. This subsequently determines thresholding more pixels in an image as foreground as shown in Figure 7.



(a) (b)

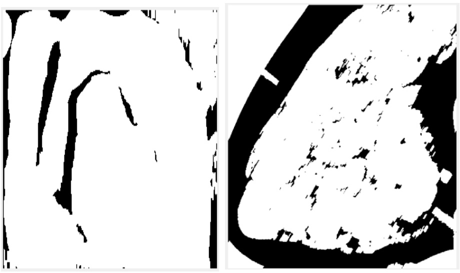
Figure 7. Adaptive thresholding (a) Fair and (b) Dark skin tone.

Foreground polarity is set as dark or bright for estimating an average background illumination. In this paper, as vein pattern is the prime focus, thus it is our foreground and the rest is background which is of no interest. Significantly, the foreground polarity is set as dark in order to make foreground darker than the background as shown in Figure 8. The Gaussian weighted mean is used for further computing the local threshold at each pixel [26]. The statistic Gaussian value will emphasize the foreground vein and the vein pattern is clearly observed with a dark segment.

(a) (b)

Figure 8. Foreground polarity with Gaussian weighted mean (a) Fair and (b) Dark skin tone.

Morphological dilation and erosion operation are used to identify the true pixels in a binary image. In this paper, we have used the dilated operation as it will increase the white pixels and reduce the black pixels that are assigned the maximum value to all pixels. Significantly, it detects the vein more specifically and shows it using a line structuring element which has a specified length of 11 and has an angle of 90 degrees [27]. Only the true pixels are considered, whereas showing the vein pattern and the background which are false pixels are eliminated as illustrated in Figure 9.



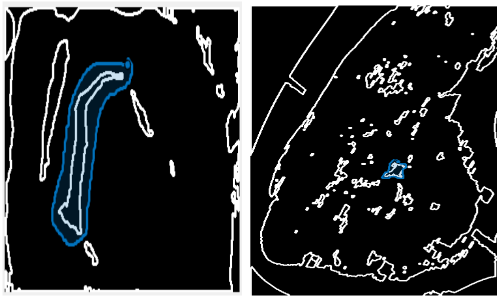
(a) (b)

Figure 9. Morphological dilation operation (a) Fair and (b) Dark skin tone.

Perimeter extraction comprises only the perimeter pixels of objects inside a binary image [28]. In case of a perimeter pixel, each pixel is non-zero and is linked to at least one zero-valued pixel to detect the vein pattern as illustrated.

Moreover, to clarify each pixel connection, the pixels are segmented and every two adjacent pixels are part of the same vein pattern if they are on the same pattern and connected along the desired direction.

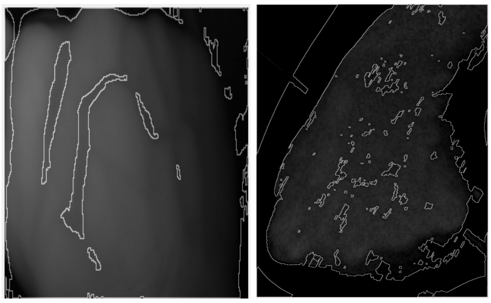
However, to detect a clear and solid vein pattern a solid line is designed against the edges or corners by using a disk structuring element having a specified dimension. Figure 10 shows the clearly observed vein pattern, extracted for further processing.



(a) (b)

Figure 10. Perimeter extraction (a) Fair and (b) Dark skin tone.

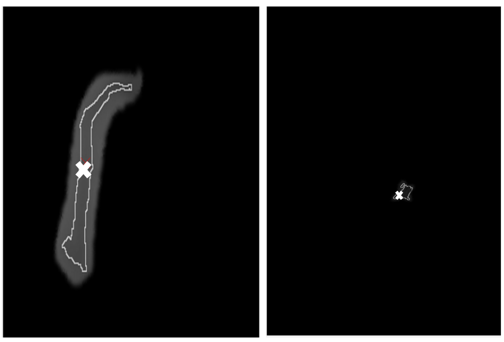
It combines two of the images by adding zero-padding to the one image with a smaller size relative to the other image [29]. In this paper, the flat morphological disk shape structured image is fused with the original image to get the desired vein pattern as shown in Figure 11. The blend is used to overlap these two images while scaling the intensities of these two images together as a single data set.



(a) (b)

Figure 11. Fused images (a) Fair and (b) Dark skin tone.

Finally, the masking operation is applied which shows only the ROI with the help of Euclidean distance function. It will calculate the width of each vein pattern and highlight the one with higher width. Furthermore, using an insert marker function identifies the most accurate pricking point by comparing the distance between the highlighted vein patterns as shown in Figure 12. The pricking point is determined using the Euclidian distance to the closest vein edge point. We use Euclidian distance metric since it is has a fast algorithm. The Euclidean distance finds the maximum distance to the edges within the vein region. This point, which has the maximum distance, is assumed to be the centre of vein region. The centre of vein region becomes the exact pricking point. In this study, the accuracy is determined based on the 21 subjects considered during the experimentation but it is not confirmed by any medical staff. This can assist medical staff to detect the most appropriate vein location for venepuncture.



(a) (b)

Figure 12. Exact pricking point (a) Fair and (b) Dark skin tone.

4. Evaluations

4.1. Efficient Vein Recognition System

The subjects were classified according to Fitzpatrick Skin Types. The fair skin group is the Fitzpatrick Skin Type II, and the dark skin group is the Fitzpatrick Skin Type V. In our study, 10 male and 5 female subjects are in fair skin group. On the other hand, 4 male and 2 female subjects are in dark skin group.

The proposed vein recognition system is evaluated on 21 different subjects for three localized areas. Both fair and dark skin toned male and female are considered for this study. The 21 subjects considered belong to same-age group. The experimental results depict that the accurate vein pattern is recognised for majority of the localized back of the hand area as illustrated in Table 2. In particular, results show that the proposed approach can effectively detect vein patterns for back of hand with 95.24% accuracy and wrist with 76.19% accuracy. The accuracy is the percent of correct classification.

In addition, when we compare fair and dark skin tones, it is seen that results are almost very similar to each other. For instance, for back of hand vein pattern detection, 90%-100% for fair and dark skin male respectively and 100%-100% for fair and dark skin female respectively. For other localization areas results are similar as well. Finally, we also observe that for wrist and back of hand vein pattern detection, we achieve 100% for both fair and dark tone skin females. Whereas, for male subjects, there is an accuracy loss of both fair and dark skin tones compared to female subjects.

Table 2. Data set for vein pattern recognition.

Localized Area	Fair skin Toned		Dark Skin Toned		Overall
	Male	Female	Male	Female	
No. of subjects	10	5	4	2	21
Fore Arm	5 (50%)	2 (40%)	2 (50%)	1 (50%)	10 (47.62%)
Wrist	7 (70%)	5 (100%)	2 (50%)	2 (100%)	16 (76.19%)
Back of hand	9 (90%)	5 (100%)	4 (100%)	2 (100%)	20 (95.24%)

4.2. Time Evaluation

The self-time describes the time spent by the individual functions applied on the image to acquire vein pattern. However, the total time describes the overall time consumed by all function to detect and show the results. The Comparison between the total time consumed by fair and dark toned image illustrates that the fair image requires half of the time to detect the vein pattern than the dark toned image as shown in Table 3.

Table 3. Time evaluation.

Vein Detection Time	
Image Tone	**Total Time(sec)**
Fair skin Tone	1.52
Dark skin Tone	2.83

5. Conclusion

The stand-alone portable vein pattern recognition is designed in this paper for venepuncture. The NIR still images taken from a mobile camera is processed in MATLAB software by applying different machine vision algorithms on the NIR images. In particular, CLAHE algorithm is applied, which works best for input images by applying contrast to differentiate the vein pattern from the surrounding tissues. The vein pattern recognition technique can not only be applied for the fair skin toned people but also for dark skin toned people. Our evaluations on 21 subjects show that the proposed system can be applied to both fair and dark skin tones with high accuracies. Finally, the provided exact pricking point is located with the help of Euclidean distance which would be quite helpful for the medical staff for venepuncture.

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