Vein Enhanced Display Based on Curvature Feature and Morphological Method

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Abstract Vein-enhanced display technology can assist medical staff to perform venepuncture. It has practical application value for people who have difficulty in intravenous injection, such as infantile and obese. At present, near-infrared image is usually used for vein display, but the near-infrared image lacks colour information. The traditional fusion algorithm cannot highlight the vein and display the real background colour simultaneously. This paper presents a new vein display method based on near-infrared imaging. The developed algorithm can extracts the distribution of vein and then superimpose it on the visible light image. In this way, the vein can be enhanced display under the condition of real skin colour. The above algorithm avoids colour distortion and removes most of noise on the vein distribution.

1. Introduction
Vein-enhanced display can help doctors and nurses improve the success rate of venepuncture [1] and relieve the pains during the process, especially for who have difficulty in intravenous injection, such as infant and obese people. The haemoglobin in the vein strongly absorbs the near-infrared light. In the near-infrared image, the vein is darker than the surrounding skin. Therefore, the near-infrared image is commonly used for vein-enhanced display [2]. However, the resolution of the near-infrared image is low and the real colour of the skin cannot be displayed. An improved scheme is to fuse the near-infrared image and the visible band image. After that, the real colour of the skin will be preserved and the enhanced vein distribution will also be effectively displayed. But the present fuse algorithm usually lead to colour distortion and sometimes unable to highlight the position information of the vein.

The vein distribution extraction method is mainly divided into three kinds. The first method smooths the original image to eliminate noise, and then select the region of interest (ROI) for threshold processing [3] [4]. This kind of method usually require high image quality and a given ROI, the main vein cannot be accurately extracted by the global threshold method, and it is also affected by the noise caused by the uneven lighting condition. The second method adopts the vein matching model. Huang Di et al. use a Gauss matching filter to perform a secondary filtering process to get a refined vein skeleton [5]. However, this method cannot get the width of the vein and it has a lot of noise. Yang Jian et al. used the undecimated wavelet transform method to extract vein features, and then used piecewise spline method to match [6]. This method is better than the Gauss matching filter and it can also get better visual effects. However, it is need to estimate the width of the vein in advance. Thus, these two types of methods are only concerned whether the vein features can be extracted accurately, but do not care about the authenticity of display. Thus, these two types of methods are not suitable to be used as an auxiliary venepuncture. The third method [7], which is proposed by Miura N et al., can extract the position of the vein according to the curvature datum of the image. This is a more stable
extraction method, but the noise problem is still inevitably when the quality of the original image is low.

In order to solve the above problems, a vein enhanced display algorithm based on curvature feature and morphological method is proposed in this paper. First, according to the curvature feature, we extract the vein position and width from the near-infrared image, and then the vein distribution image is directly superimposed on the visible light image to retain the real background colour of the skin. In order to effectively select the main vein for puncture, in this paper, the morphological method is used to filter the noise point. By connecting the feature points, the display effect is improved. The method can accurately extract and enhance the display results of vein information.

2. Image Acquisition System
In this paper, two cameras are used to capture the near-infrared and visible bands images, respectively. Figure 1 is the schematic diagram of the dual cameras imaging system. One camera is a monochrome camera (4) and the near-infrared filter (5) is installed in front of it, so that it could only capture the near-infrared band image. Another camera is a colour camera (2) with a visible light filter (3) in front of it. This camera is only work in the visible light band. The near-infrared LED (1) is fixed around the two cameras. The experimental system is shown as Figure 2.

![Figure 1. Dual-bands pictures acquisition scheme](image1.png)

![Figure 2. The experimental imaging system](image2.png)
3. Image Process Algorithm
Firstly, the shape features of the vein are extracted from the infrared image, and then the features are superposed to the visible light image. The process can be divided into 5 steps, and the processing flow diagram is shown as figure 3.

3.1. Pre-Processing
The purpose of pre-processing is to remove the noise of the infrared image and to improve its contrast. Firstly, the rough area of the hand was obtained by the Otsu threshold segmentation method, and then enhanced the contrast for this area. Second, Gauss smoothness was performed on the area to filter the noise. The size of the Gauss filter should be as large as possible, but make sure that the changing trend of the gray value cannot be smoothed. Therefore, the size of the Gauss filter cannot be larger than the diameter of the vein. In this case, the size of the filter is 13x13.

\[
\text{Smoothing and contrast enhancement}\nonumber\nonumber
\]
\[
\text{pre-process to infrared image}\nonumber\nonumber
\]

\[
\text{Obtaining vein feature points and vein width by maximum curvature method}\nonumber\nonumber
\]

\[
\text{Eliminating of discrete points}\nonumber\nonumber
\]

\[
\text{Connecting the vacancy among the feature points to form the vein branches and vein network. Then, using the width expansion method to get the vein area.}\nonumber\nonumber
\]

\[
\text{Coloring the vein on the visible light image}\nonumber\nonumber
\]

*Figure 3. Image processing flow chart*

After Gauss smoothing, the contrast between the vein area and the surrounding area is reduced. Therefore, the contrast should be enhanced again to highlight the vein features. In this paper, the normalization method was used to enhance contrast. As mentioned above, the ROI region of the hand has been obtained by the method of threshold segmentation, and the normalization transformation will be carried out in this ROI region:

\[
om(x, y) = 255 \times \frac{(I_{ROI}(x,y) - \min(I_{ROI}))}{(\max(I_{ROI}) - \min(I_{ROI}))} \quad (1)\nonumber\nonumber\]

In the formula, the nom(x, y) is the normalized image, and the \(\min(I_{ROI})\) is the minimum in the ROI, \(\max(I_{ROI})\) is the maximum in the ROI. After the image enhancement process, the intensity difference between the vein and the surrounding skin was increased, which is beneficial for vein feature extracting.

3.2. Vein Feature Extraction
In this paper, the position of the vein was extracted by the maximum curvature method \[7\]. After image pre-processing, curvature was calculated in four directions, 0, 45, 90, and 135. The curvature of the point \(\rho(x)\) in the direction of each row, column and diagonal were calculated by the following formula:
At this time, the matrices in four directions (0, 45, 90 and 135 degrees) were obtained. Then the local curvature maximum of the four matrices was obtained respectively. The position of the maximum values is the basis for judging the position of the vein. In order to reduce the interference, the conditions of judgment are as follows:

1. The maximum value must be positive.
2. The monotonicity of the two sides is opposite.
3. The threshold conditions are met on both sides of the maximum value.

\[
\frac{\rho(x) - \rho(x_{max} - 1)}{\rho(x_{max}) - \rho(x_{max} + 1)} \geq \text{thresh} \quad \text{and} \quad \frac{\rho(x_{max}) - \rho(x_{max} + 1)}{\rho(x_{max}) - \rho(x_{max} + 1)} \geq \text{thresh}
\]

After the test, when the threshold value was 0.2, the extraction effect of the vein and the filtering effect of the noise could reach the best balance.

### 3.3. Discrete Noise Points Filtering

The distribution and width of the vein feature points were calculated, but some interference factors still existed. Because the back of hand is not smooth, uneven illumination would cause brightness changes. These brightness changes will also appear as a maximum of curvature. This kind of discrete noise point usually is isolated. In addition, there are some small veins that can be extracted. However, these small veins are not usable for venepuncture. Therefore, they also should be considered as noise points and to be filtered.

In the first step, it is necessary to determine discrete noise points. The determination method was as follows: searched and found the number of feature points around the feature point and if the number was less than a certain threshold, this point was considered to be an isolated point. At first, the search range was set as 3 × 3. If there is no other feature point adjacent to, it is considered as a discrete noise point and be eliminated. After that, the search range extended to 19 × 19. If the number of the feature points is less than a threshold, it is considered to be a discrete noise point and be eliminated.

### 3.4. Breakpoints Connecting

After the vein feature points were obtained by direct extraction, there will be a lot of breakpoints in the feature points. These points if directly were used for expansion process, the obtained vein grid would appear discontinuous. It not only will depress the display effect, but also increase the difficulty of venipuncture. As the distribution grid of the veins is relatively straight, the breakpoints of the vein can be re-connected.

Connecting breakpoints process has two situations that need consider. First, there will be discontinuity in the same segment of the vein and the discontinuous intervals vary greatly. Second, although the veins of different segments are connected, however, there is no obvious vein orientation at the junction of veins. The feature points extracted by the curvature method are often interrupted at the nodule. Therefore, we first need to connect the discontinuities at each segment of the vein and then connect these veins to form a network.

The connection process of the same piece of vein was divided into two steps. First, two feature points which were separated by one pixel can be connected directly. Next, we search all feature point-chains. Using the Random Sample Consensus (RANSAC) method to perform a straight line fitting calculation, and the linear parameters are obtained by the singular value decomposition method. Then determine whether the two feature points-chains belong to the same vein. If the length of the two points-chains are longer than 8 pixels and the shortest distance between the two points-chains is less than 8 pixels, moreover, the direction angle of two points-chains is less than 30 degrees, the nearest point of the two point chain can be connected in a straight line. If one of the two point-chains is shorter than 8 pixels, the results of the linear fitting will become inaccurate and the extension direction...
is also not easy to judge. At this time, we need to judge whether the shorter point-chain is at the end point of the longer point-chains, at the same time, the angle between the closest connection line of two point-chains and the longer point-chains is less than 30 degrees. Only in this condition, the closest points of two points can be connected in a straight line. The abovementioned parameters were empirical value determined by experiments. After completing this straight connection operation, we need to search all the feature point-chains again and continue to perform point-chains connection operation until the total number of point-chain is no longer reduced.

At this point, the connection of the same piece of vein was basically completed. Then, the different piece of veins needs to be connected to form a vein network. We regard the longest point-chain as the main vein. Searching the point-chain around the main vein feature point-chain and get the nearest long point-chain (length greater than 8), then judging whether the two point-chains meet the conditions. Set point P1 and point P2 as the closest points of the two point-chains. P1 and P2 is the center of the neighborhood ROI1 and ROI2, respectively. The main feature point-chain in ROI1 is set as 1 and the other point-chain in ROI2 is set as 2. The RANSAC linear fitting is performed for 1 and 2 respectively to find the parameters of the local line. If the angle of 1 and 2 is greater than 30 degrees, connect the line from the nearest point of two point-chains to the intersection of two point-chains. Searching all the feature point-chains again and if the total number of point-chains is reduced, the above connection steps will be carried out again until the total number of point-chains is no longer changed.

During the above process, the mentioned parameters were empirical values determined by experiments. Using the average width of vein obtained in the section 3.2 and performs expansion operation on the feature point-chains. In this way, the distribution of the vein was obtained.

3.5. Superposition
In the visible light image, the colour of the vein area needs to be adjusted to make it more obvious. In this paper, the cyan is used as the basic colour because it is similar to the real colour of vein. At the same time, the vein area is coloured according to the brightness distribution of the back of the hand in the visible light image. The average gray values of three channels in vein area are set as \( aveR, aveG, aveB \), respectively. The standard deviation is set as \( \text{stdR}, \text{stdG} \) and \( \text{stdB} \). The three channel bottom colour values are set as \( \text{setR}, \text{setG} \) and \( \text{setB} \). The colour standard deviation of the vein is set as \( \text{stdSet} \). The colour superimposed on the visible light image is calculated by the following formula:

\[
\begin{align*}
    r(x, y) &= \text{setR} + \frac{\text{stdSet}}{\text{stdR}} \cdot (r(x, y) - \text{aveR}) \\
    g(x, y) &= \text{setG} + \frac{\text{stdSet}}{\text{stdG}} \cdot (g(x, y) - \text{aveG}) \\
    b(x, y) &= \text{setB} + \frac{\text{stdSet}}{\text{stdB}} \cdot (b(x, y) - \text{aveB})
\end{align*}
\]

Finally, the superimposed image was obtained.

4. Results and Comparison
In this article, based on the Visual Studio and OpenCV, a program was used to verify the algorithm. At the same time, the method proposed in this paper is compared with the common Brovey image fuse method. The results are shown in figure 4.

Fig. 4(a) is the near-infrared image and fig. 4(b) is the corresponding visible light image. Fig. 4(c) is the vein enhancement display image obtained by the algorithm proposed in this paper. Fig. 4(d) is the image obtained by the traditional Brovey fused algorithm.
As the figure shown, by the algorithm proposed in this paper, the position of the vein is superposed directly on the visible light image. Compared to the traditional Brovey fusion method, the colour of background skin is not distorted while the veins are highlighted. Moreover, the enhanced display effect of vein distribution is also better than that of Brovey fusion method. This is because the resolution of the infrared image is low and the texture information of the visible light image is difficult to match with the infrared image. This could cause the fusion image become blurred.

5. Conclusions
In this paper, we proposed a vein enhanced display algorithm based on curvature feature and morphological method. This method uses the curvature of the near-infrared image to extract the position and width of the vein. Compared with the traditional image fusion method, this method has a better effect on vein display. In order to improve the visual effect of vein display, we use morphological method to connect vein feature points. From the experimental results, it can be seen that this method can accurately find the position of the vein. The final result is the main vein network on the back of the hand, which can directly provide necessary information for the medical staff. Because this algorithm does not fuse the whole image, the clarity of the image is guaranteed and the colour of background skin is not distorted.

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7. References
[1] Kim D, Kim Y, Yoon S, Lee D 2017 Sensors 17 304
[2] Juric S, Zalik B 2014 BMC Medical Informatics and Decision Making 14 100.
[3] Wu Z, Zhou Y, Hu X, Zhou M, Dai X, Li X and Wang D 2013 IEEE International Conference on Imaging Systems and Techniques 332
[4] Vlachos M, Dermatas E 2015 Computational and mathematical methods in medicine 2015 868493
[5] Li X, Huang D, Zhang R, Wang Y, Xie X 2016 IEEE International Conference on Image Processing ICIP 3146
[6] Ai D, Yang J, Fan J, Zhao Y, Song X, Shen J, Shao L, and Wang Y 2016 Biomedical Optics Express 7 2565
[7] Miura N, Nagasaka A, Miyatake T 2007 Ieice Transactions on Information & Systems 90 1185