TAF
Journal of Advances in Technology and Engineering Research
JATER
2018, **4**(5): 186-190

PRIMARY RESEARCH

Automatic venipuncture insertion point recognition based on machine vision

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Keywords

Machine vision
Automatic venipuncture
Image processing

Received: 6 August 2018
Accepted: 3 September 2018
Published: 2 October 2018

Abstract

Venipuncture is a common practice performed in medical institutions. It now relies on the well-trained medical staff. The work is inherently risky, requiring skills, experience, and a high degree of focus to avoid discomfort or even danger to the staff themselves or the patients. The proper insertion point for venipuncture is sometimes difficult to recognize. In recent years, many applications of machine vision and image processing technologies have been used to help physicians, nurses, and other medical practitioners determine the patients' physical conditions, make the appropriate diagnosis, and reduce fatigue or other human factors causing misdiagnosis. In this paper, the implement machine vision technologies to assist the recognition of venipuncture insertion points is studied. Two industrial CMOS cameras are used with an infrared light source. The two cameras are placed apart and tilted at a certain angle relative to each other to achieve the stereo vision of the arm. Light filters are also installed on the lens of the two cameras. The cameras are calibrated beforehand to eliminate distortion. Two images of the arm, one by each camera, are captured. The images are then processed through image binarization and morphological algorithms. Afterimage processing, the best needle insertion position, puncture depth, and angle are determined. The developed system can improve the efficiency of venipuncture, and reduce the risk to medical staff and patients.

I. INTRODUCTION

Many studies have pointed out that Percutaneous Injuries (PIs) are the most common occupational injuries for medical personnel [1, 2, 3, 4]. At present, medical institutes try to avoid the occurrence of percutaneous injuries through personnel training and the use of safety syringes. But studies show that many incidences of PIs are still happening and the resulting cost is high [5, 6, 7]. Medical images have long been used to assist medical staff. From simple X-ray techniques to various tomography imaging. They provide information about the human body that is difficult to obtain from human eyes or other methods.

In the retrieval of vascular images, hemoglobin in the blood absorbs infrared light [8, 9, 10]. Light can penetrate heme at about 600 nm of wavelength, and the largest difference in the penetration rate of oxygen-containing and deoxidizing hemoglobin is around the wavelength of 1000 nm. Based on the aforementioned principle, captured blood vessel images using infrared light source and cameras are used in the application of personal identification system [11, 12, 13]. In addition to retrieving finger vascular images for identification, hand vascular images are also used in personal identification [14, 15].

In this paper, three-dimensional information of venipuncture needle insertion point is obtained based on the vein images of the arm. Two cameras are placed at different angles to capture the vein images of the same arm. One is used as the base camera. The image captured by the base camera is processed first. The arm area is separated from the background by binarization. The image is then processed by Gaussian filtering and other image processing techniques to determine the optimal position for needle insertion. The image from another camera is then added to calculate the distance between the base camera and the skin surface. The

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image is further analysed for the puncture depth and the angle of needle insertion.

II. HARDWARE SETUP

A machine vision system usually includes the use of industrial cameras, frame grabbers, computers, light sources, lenses and filters and other equipment mounted on an inspection platform or robotic arm, combined with image processing software, operating system and hardware drivers. The images captured by the cameras are analysed by image processing software to obtain meaningful values such as the ideal position of needle insertion, puncture depth, as well as the angle of the vein on the arm. Since the distance of the vein is also necessary for a correct needle insertion, a binocular stereo vision system is developed for our study, as shown in Figure 1.

Fig. 1. A binocular stereo vision system

A. Camera Calibration

Before the arm image is taken, the cameras are calibrated to correct possible distortions caused by the geometry of the lenses. Most distortions are known as radial distortions. There are two common types of radial distortion: a. Barrel distortion as shown in Figure 2(a) and b. Pincushion distortion as in Figure 2(b).

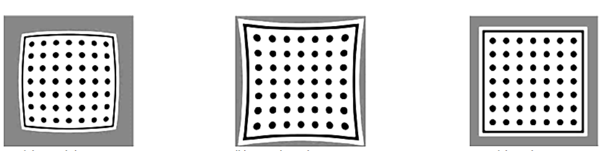


Fig. 2. Barrel, pincushion and no distortion

A camera has to be calibrated in order to get an undistorted image of the picture as in Figure 2(c). This is done through a calibration plate, Figure 3. The plate is placed on the platform to be taken a picture of. It is also necessary to have a picture of the plate in an inclined angle. In this case, the plate is placed on a fixture as in Figure 4.

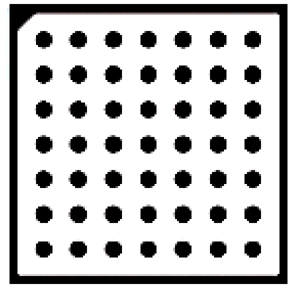


Fig. 3. A calibration plate

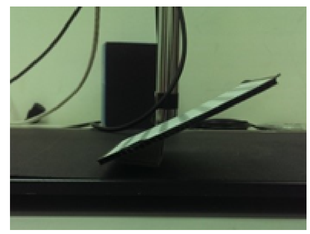


Fig. 4. The plate fixed on an angle

Each camera takes 15 pictures of the calibration plate. These pictures are then used to adjust the internal parameters of the cameras to eliminate or reduce possible distortions. Figure 5(a) and (b) show the plate images taken by left and right camera before calibration. They both have a slight barrel type distortion. Figure 5(c) and (d) shows the left and right images after calibration. The distortions are greatly reduced.

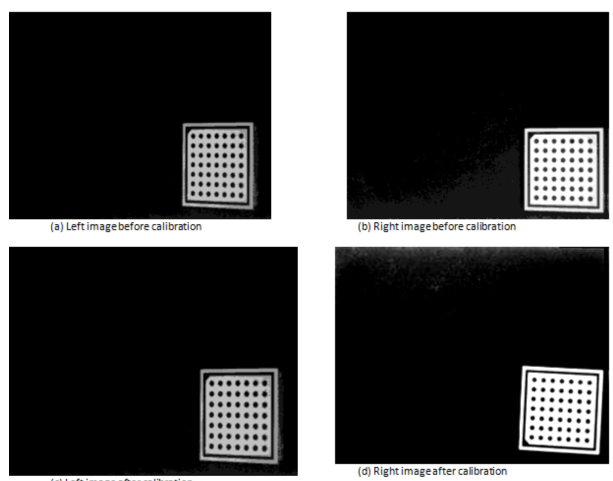


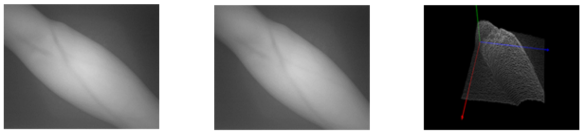
Fig. 5. The plate images were taken before and after camera calibration

B. Binocular Stereo Vision

In general, a single camera can only produce a two-dimensional image, Figure 6(a) and (b). Binocular vision uses two cameras placed apart to obtain disparity images of the same objet. The disparity images can then be used

ISSN: 2414-4592
DOI: 10.20474/jater-4.5.1

to calculate the distances and construct the 3D image of the object as shown in Figure 6(c).



(a) Left camera image of the arm (b) Right camera image of the arm (c) 3D image of the arm

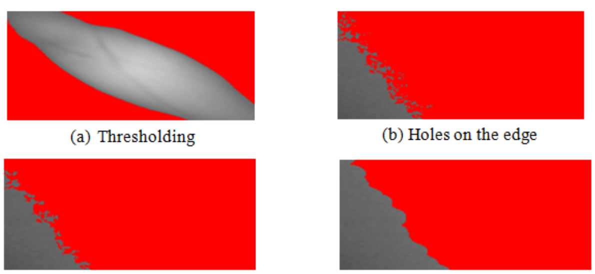
Fig. 6. Binocular stereo vision of an arm

III. IMAGE PROCESSING

After calibration, the cameras begin to retrieve the arm image. The left camera is used as the base camera. The image captured by the left camera is analysed first to obtain necessary 2D information of needle insertion point. The image from the right camera is then added to calculate the distance between the base camera and the skin surface.

A. Image Pre-Processing

First, the arm image is segmented using thresholding, the background is removed, and only the arm area to be analyzed is retained, as shown in Figure 7(a). The arm image is with many holes in the edges as in Figure 7(b). The holes are filled as shown in Figure 7(c). The edges are then smoothed, as shown in Figure 7(d).



(a) Thresholding (b) Holes on the edge (c) Hole filling (d) Smoothing

Fig. 7. Image pre-processing

B. Image Enhancing

In order for the subsequent inspection processes to have clearer pictures, the arm image is processed with a Gaussian filter to remove possible noise, Figure 8. The filtered image is then enhanced by extending its grey value to a minimum of 0 and a maximum of 255, Figure 9.

Fig. 8. Gauss filtering

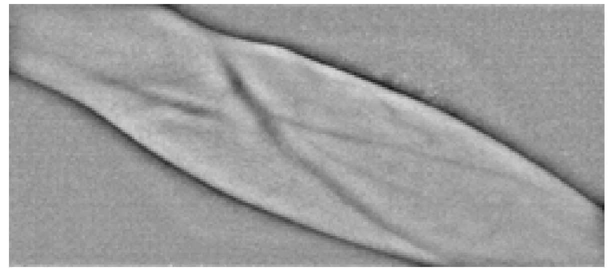
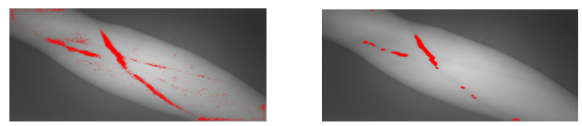


Fig. 9. Image enhancement

C. Vein Feature Extraction

The grey values of Figure 9 are analysed to obtain the vein features based on thresholding. Combined with the results from pre-processing, Figure 7, the possible vein features are shown in Figure 10(a). After hole filling and other morphological operations, noise and disconnected, less obvious vein are removed, Figure 10(b).



(a) Possible vein features based on thresholding (b) Vein features after morphological operations

Fig. 10. Vein features for needle insertion judgement

D. Needle Insertion Point Judgement

In this study, the best needle insertion point is determined based on the vein area with the largest diameter. For this purpose, a circular template with an initial radius of one pixel is fitted to the vein features in Figure 10(b). The number of areas is counted. If the number is larger than one, the radius of the circular template is increased by one. The same process is repeated until the number of the area the circular template can be fitted into is one. The center of the circular template is then taken to be the insertion point as shown in Figure 11 marked by a red cross.

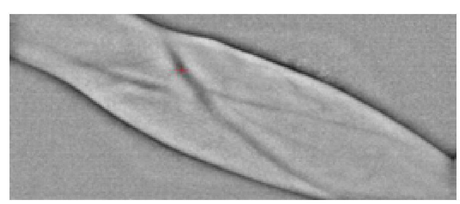


Fig. 11. Needle insertion point

E. Puncture Depth and Needle Angle

In the next steps, the puncture depth required for the needle to reach the vein will be decided. The light used in this study is a near-infrared light source with a wavelength of 810 nm. It can penetrate the skin surface to about 5 to 10mm while veins lying beneath subcutaneous tissue are about 3 to 5mm under skin surface. Therefore, the width of the vein feature in the image can assumed to be the diameter of the vein. The

ISSN: 2414-4592
DOI: 10.20474/jater-4.5.1

puncture depth is taken to be the radius of the vein. To find the angle of the vein. A minimum circumscribed rectangle of the circle found in section 3 is used, Figure 12(a). The angle of the vein is decided by the orientation of the rectangle as in Figure 12(b).

(a) A circumscribed rectangle (b) Vein angle judgement

Fig. 12. Needle angle judgment

F. Vein Distance Calculation

After the two dimensional information of the needle insertion point is obtained, the vein distance is calculated using two pictures, one taken from the left camera, the other from the right, as in Figure 6(a) and (b). A disparity image, Figure 13, can then generated.

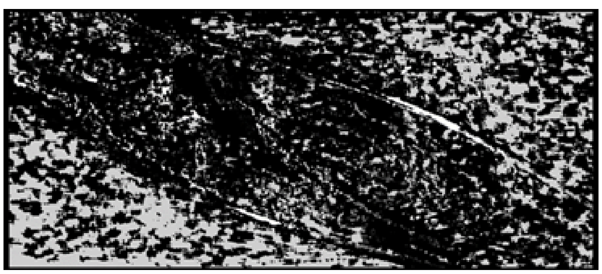


Fig. 13. A disparity image of the arm

The distance of the insertion point is obtained by inputting its two dimensional coordinates. The results, including the 2D coordinates in pixel, puncture depth and vein angle, are shown in Figure 14.

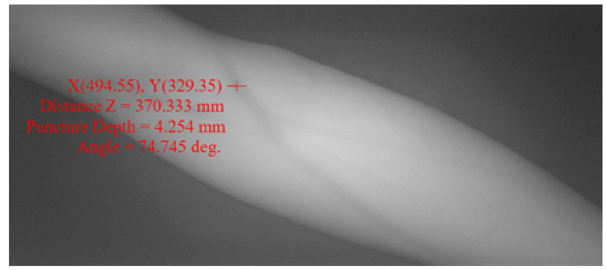


Fig. 14. Inspection results

IV. CONCLUSION

In this experiment, two CMOS cameras with a resolution of 1.3 million pixels are used, along with two wavelengths 780±10 nm filters and a wavelength 810 nm led infrared light source. Through image processing, it is able to find the arm blood vessel distribution successfully. The coordinates of the needle insertion point are determined by developed algorithms. The depth of the needle is detected by the disparity image. And finally, the puncture depth and needle angle are determined by using the two-dimensional information obtained. This method can assist the medical personnel in carrying out venipuncture, improving the efficiency of the work, and reducing the risk of medical personnel and patients.

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ISSN: 2414-4592
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ISSN: 2414-4592
DOI: 10.20474/jater-4.5.1