A fundamental study on vessel depth estimation based on refocusing using light field imaging

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ABSTRACT

Venipuncture is a medical practice which is ordinarily performed in hospital. However, it is a difficult procedure as the occurrence of many failure of the puncture and sometimes medical accidents such as nerve damage and blood vessel damage are reported. This is caused by the difficulty of visually identification of the blood vessel. Although the depth information of the blood vessel is also important, the existing system in clinical practice can visualize vessels only by two dimensional images. In this paper, to estimate the three dimensional position of the blood vessel, we propose the system based on refocusing using light field imaging. This method can obtain cross-sectional information of blood vessel emphasized using near infrared light at each depth. First, we organize the expression related our proposed system. Then, evaluate the basic principles of the proposed system by using blood vessel simulated object. Finally, we confirm the validity of the proposed method by applied to the human finger.

Keywords: Venipuncture, blood vessel, refocusing, light filed

1. INTRODUCTION

Venipuncture (inserting a hollow needle into a patient's limb for the purpose of injecting drugs, intravenous fluids or nutrients, or sampling blood) is a medical practice which is ordinarily performed in hospital. However, it is a difficult procedure as the occurrence of many failure of the puncture and sometimes medical accidents such as nerve damage and blood vessel damage are reported [1]. As a factor of these accidents, it is difficult to see veins due to the vein is obscured by subcutaneous fat or other biomedical tissue and moreover, there are large individual differences of each patient. In addition, they can not know the depth information of the vein. Although a medical staff is exploring the place suitable for venipuncture in the sense of hand and by visual observation, it require skill and long experience in order to perform accurate.

The visibility of a vein depends on the difference between the optical properties of the vessel and those of the surrounding tissues as well as the size and depth of the vessels. Generally, the amount of the light incident on the biological tissues absorbs and scatters after penetrating a millimeter or so, and observed as the reflected light. The longer wavelength, light deeply propagation into the biological tissue. A part of the light can be observed as reflected light, the other is transmitted light. Such dependence on wavelength caused by the specific absorption of the blood hemoglobin and light scattering property of biological tissue. It has been recognized that the light in near-infrared wavelengths (700-900nm) is strongly absorbed by hemoglobin in a vein, while this is hardly absorbed by other biological tissue. Hence, by irradiating the light in near-infrared wavelengths, only the blood vessels are emphasized. However, the near-infrared light is not visible to the human eye, and so it is not possible to see the blood vessels clearly.

In recent years, commercial vein visualization devices based on optical illumination and present a visualization vessels for medical staff, for example, the VeinViewer(Christie Medical Holdings Inc.), the AccuVein(AccuVein Inc.) and so on, have been released. Several clinical evaluations of the effectiveness of these devices also have been studied [2, 3]. These result suggest that these device are not sufficient to raise the success rate of venipuncture, while it is useful in the visualization of blood vessels. In contrast, it is reported that vein visualization devices using ultrasound improved the venipuncture [4]. The difference of these techniques is the direction of the obtained information. A method using near-infrared light can obtain vasculature information widely in the planar direction. By contrast, a method using ultrasonic waves can obtain a cross sectional image of vasculature, that having information in depth direction.

In this paper, we propose a system for three dimensional vessel position estimation based on refocusing using light field imaging. First, the near-infrared light informations are obtained, then an image focused on an arbitrary focal point is reconstructed by using light filed imaging. Then, the depth information of the blood vessel is obtained from the in-focus image. Finally, by integrating the depth information and the image, three dimensional vessel position can be estimated.

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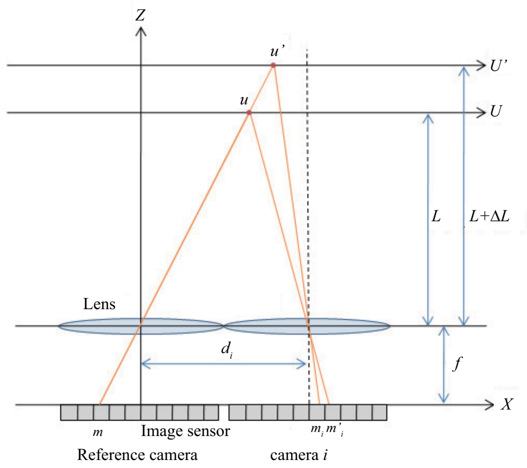

Fig.1: *Optical system of the light filed camera.*

2. METHOD OF VESSEL POSITION ESTIMATION

2.1 Refocusing using light field imaging

The light filed is an information about the intensity, the direction, the color and the position of all the lightrays traveling in space, including emitted from the light source and reflected or scatted light on the object [5, 6]. In the light field imaging, a scene is treated as a collection of light, not as an image. Thus it is possible to reconstruct an image focused on an arbitrary focal point. Light filed can be obtained by using multi-camera arrays. An optical system of the light filed camera is shown in Fig.1. Here, for simplicity, Fig.1 shows top view in the case of two camera, and X is a horizontal axis of the image sensor, Z is a depth direction axis, f is a focal length, L is a length from lens to reference plane U, and d_i is a horizontal length from the camera i (any of camera array) to the reference camera (in this study, it is center of the camera array). Here, refocusing is performed at the position of reference camera.

Then, consider the correspondence between the pixel on each camera, that lightray emitted from the same point is recorded. The lightray emitted from the point u on the reference plane U is assumed to be recorded pixel m on the reference camera and m_i on the camera i, respectively. From a similar relationship, the correspondence between m and m_i can be expressed as follows:

$$m_i = m - \frac{f}{wL} d_i \tag{1}$$

Considering similarly on side view, the correspondence between the vertical pixel n on the reference camera and n_j on the camera j can be expressed as follows by using d_j, which is vertical length from the camera j (any of camera array) to the reference camera:

$$n_j = n - \frac{f}{wL} d_j. \tag{2}$$

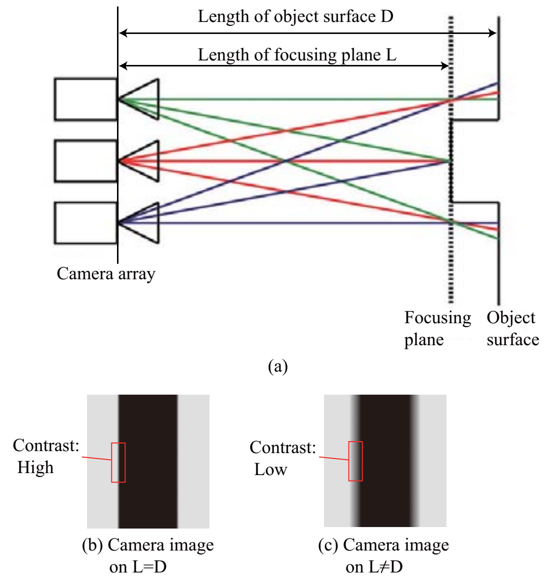

Fig.2: *Relationship between the focusing plane and the object surface.*

The sum of the intensity of light ray incident on the pixel (m, n) of the refocusing image $E(m, n)$ can be calculated by the following equation:

$$E(m, n) = \sum_i \sum_j I_{ij}(m_i, n_j) \tag{3}$$

where, I_{ij} is a information of light ray recorded on each camera. Then, consider that the distance of reference plane changes by ΔL. In this case, the sum of light incident on the pixel (m, n) of the refocusing image E'(m,n) is calculated by the following equation:

$$E'(m, n) = \sum_i \sum_j I_{ij}(m'_i, n'_j) \tag{4}$$

where,

$$m'_i = m - \frac{f}{w(L + \Delta L)} d_i \tag{5}$$

$$n'_j = n - \frac{f}{w(L + \Delta L)} d_j. \tag{6}$$

As described above, by adding the corresponding pixel calculated by equation (5) and (6), it can be focused in any position.

Then, let us consider the depth resolution of reference plane. Due to a light information is obtained in pixels of camera, the step size of the reference plane is limited. In this study, it is considered to be separated when the position of the light incident on pixel is changed more than one pixel. In other words, $m'_i - m_i \geq 1$ or $n'_i - n_i \geq 1$. Therefore, the depth resolution of reference plane ΔL can be expressed as follows from Equation(1) and (5), or (2) and (6).

$$\Delta L = \frac{wL^2}{fd_i - wL} \tag{7}$$

Table 1: *Specification of the experimental system.*

Number of view points	5 × 5
Camera pitch	5.0 mm
Pixel size w	3.75 μ m
Number of pixels	1280 × 960

or

$$\Delta L = \frac{wL^2}{fd_j - wL} \tag{8}$$

ΔL corresponds to the depth of field of reconstructed refocusing image.

2.2 Depth estimation

Next, we estimate depth information of blood vessel. On a refocusing image, all light is focused on the reference plane, as shown in Fig. 2(a). If an object exist on the reference plane, this is focused on the refocusing image. If an object do not exist on the reference plane, light from this object is not focused and this is not focused on the refocusing image. Therefore, the contrast between the object and its peripheral area is high, as shown in Fig. 2(b). On the reconstructed image at the depth position that is not in focus, the contrast is reduced due to the light emitted from the object diffuses, as shown in Fig. 2(c). Hence we can estimate that the object located the depth where the contrast becomes the maximum. The contrast ratio is calculated by

$$r = \frac{L_p - L_v}{L_p + L_v}, \tag{9}$$

where L_p and L_v are means of brightness value of the vascular peripheral part and blood vessel part near the boundary, respectively.

3. EXPERIMENT

In this paper, to acquire the light ray information, we use a single camera (FL2G-13S2M-C, Point Gray Research Inc.) moving parallel and taking picture from a plurality of view points, instead of a multi camera array. The specification of the experimental system is shown in Table 1. Here, we observed the transmissive light through the target as shown in Fig. 3(a).

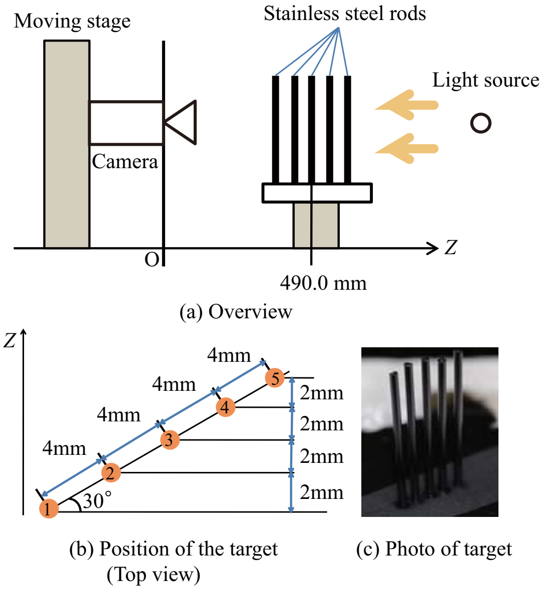

Fig.3: *Experimental setup using black-painted stainless rods in the air.*

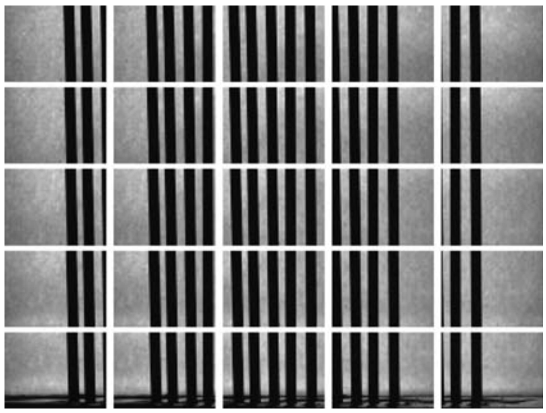

Fig.4: *Obtained parallax images (25 view points).*

3.1 Blood vessel simulated object

First, we evaluated the accuracy of the proposed method using the simulated object on air. In this experiment, the focal length F was 98mm, and the distance between lens and the focusing plane L was 392 mm. From Equation (8) and these parameters, the depth resolution ΔL = 0.6mm. The overview of experimental system is shown in Fig.3(a). As a blood vessel simulated object, a black-painted stainless steel rod with a diameter of 2mm was used. This rod placed in a 2.0 mm spacing as shown in Fig.3(b)(c). The distance from camera to rods are 486mm, 488mm, 490mm, 492mm, and 494mm, respectively. Figure 4 shows an example of obtained images. Using obtained parallax images, we reconstructed refocusing image at each length. Refocusing result at several distance calculated form Fig.4 and Equation(3) are shown in Fig. 5. It finds that the focal position is shifted little by little. Figure 6 shows the brightness value of center camera's image at vertical pixel 480 (Vertical center of the image). The brightness of the rod area is low since that is impervious to light. We assumed that the inflection point of the brightness value as a boundary of the rod, and then calculate the contrast ratio between the rod area and background area near the boundary. From equation (9), calculated contrast ratio is shows in Fig.7. The estimated depth by using maximum value of this

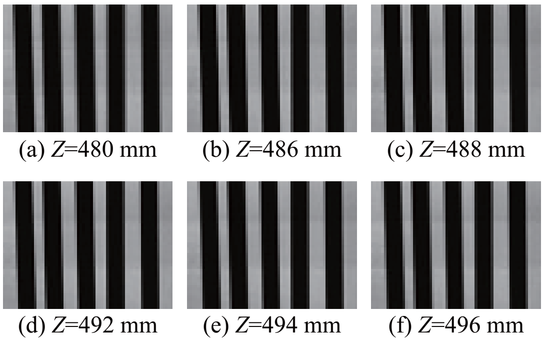

Fig.5: *Refocusing images calculated form Fig.4 and Equation(3).*

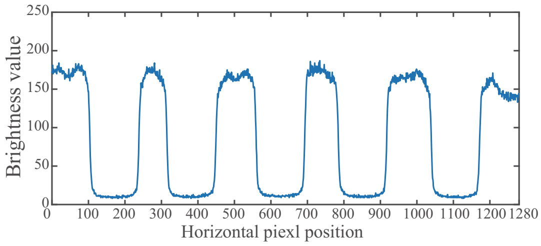

Fig.6: *Brightness value of the obtained image at vertical pixel n=480.*

contrast ratio shown in Fig.7 in order from the front of the target is 486.1, 487.2, 489.2, 490.1, and 490.1 mm, respectively, on the left boundary and 486.4, 487.3, 488.8, 489.3, and 489.6 mm, respectively, on the right boundary. The setting depth is 486, 488, 490, 492, and 494 mm, respectively. The estimated result include some errors. Considering the result on left boundary and one on right boundary are smiler, it is likely that the setting position include installation error due to the rod has round shape. These result suggest that the proposed system could estimate generally correctly depth length.

Similar experiment was performed using a biological phantom. In this experiment, two rods simulated vein were used for evaluation and fill soy milk and agar around the rod to simulate the optical properties of biological tissue as shown in Fig. 8. Light source was used the infrared light to transmit light through the scattering object. The setting depth of rod is 491 and 493mm, respectively. The estimated result is 489.0 and 493.5mm, respectively, on the left boundary, and 491.2 and 491.7mm, respectively on the right boundary.

3.2 Finger

Then, we verify the validity of the proposed system by using human finger. In this experiment, infrared light source was used to emphasize the blood vessel, and the focal length F was 12.7 mm, and the distance between lens and the focusing plane L was 127 mm. From Equation (8) and these parameters, the depth resolution ΔL is about 0.5mm.

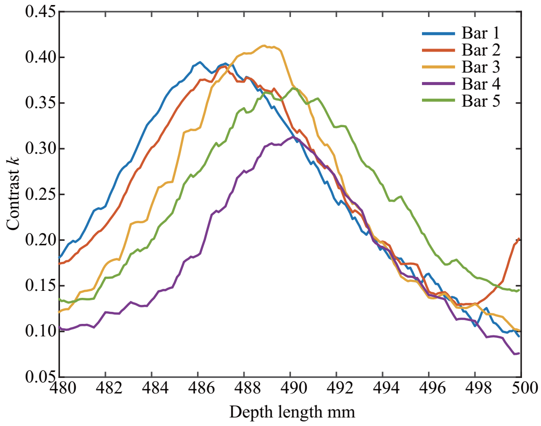

Fig.7: *Contrast ratio between target and background.*

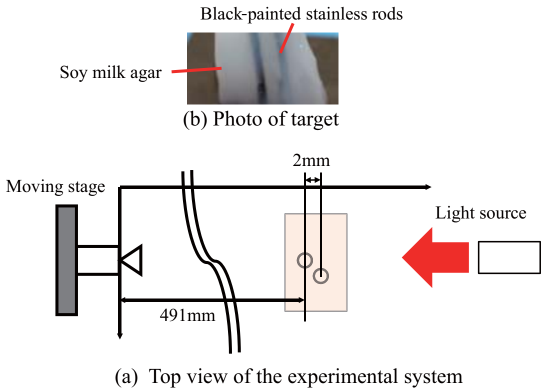

Fig.8: *Experimental setup using black-pained stainless rods in the biological phantom.*

Figure 9 shows the experimental condition. 18 LED (860nm, SFH 4550, OSRAM Opto Semiconductors) arranged in two rows were used for a infrared light source, which arranged in two rows. The forefinger was placed between the camera and the LEDs. Figure 10(a) shows the obtained image from the center position. As shown in Fig. 10(a), blood vessel are dark. Since the infrared light is strongly absorbed of blood vessel, transmitted light through the vessels decrease compared with transmitted light through other tissue. However, blood vessel's boundary of image is not clear as the case of bars. Therefore, we use a image processing to determine the boundaries. After using the Gaussian filter for sharpening, blood vessel are more emphasized as shown in Fig. 10(b). We use the emphasized image only for the determination of boundaries of the blood vessel and the other tissue. To verify the validity of the basic principal of the proposed system in biomedical tissue, we focus on one vertical line shown in Fig. 10 only.

Figure 11 shows the mean brightness value of Fig. 10(b) at horizontal pixel from 693 to 696. In Fig. 11, there are two points that the value is reduced. These position corresponds to the blood vessel. We assumed that the inflection point of the brightness

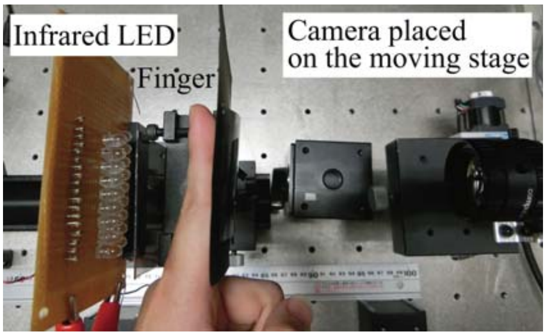

Fig.9: *Experimental photo.*

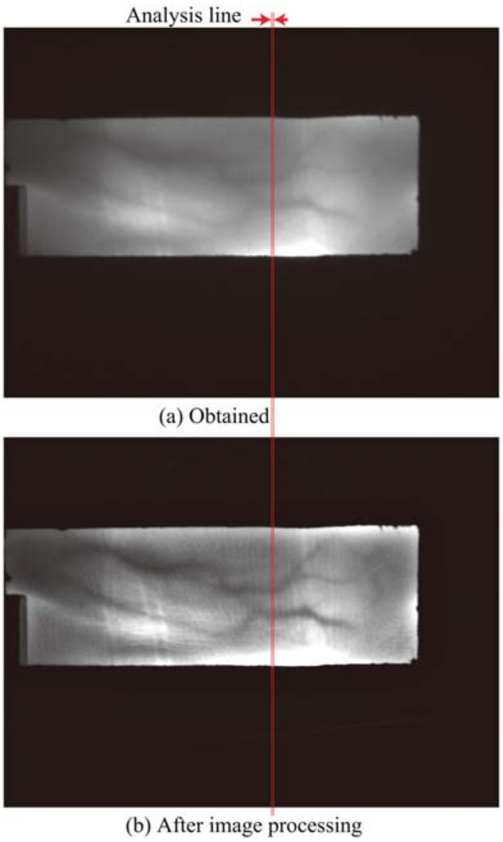

Fig.10: *Obtained finger image from center position of camera. (a) Original image. (b) Emphasized the blood vessel by the Gaussian filter.*

value as a boundary of the blood vessel and the other tissue. Through the same procedure as before experiment, refocusing images at each length were calculated. Fig. 12 shows the contrast ratio between blood vessel and around area calculated by the equation (9) at each depth. In the Fig. 12, The blue line shows the contrast ratio of upper vessel (existing near the vertical pixel n = 400), and the red line shows one of lower vessel (existing near the vertical pixel n = 480). The estimated depth of the upper and lower vessel by using maximum value of this contrast ratio is 128.2mm and 130.2mm, respectively. Figure Fig. 13 shows the refocusing result at Z=126.2, 128.2(estimated position of the upper vessel), 130.2(estimated

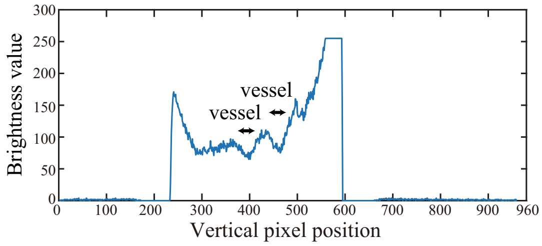

Fig.11: *Brightness value of Fig. 10 at horizontal pixel m = 693 - 696.*

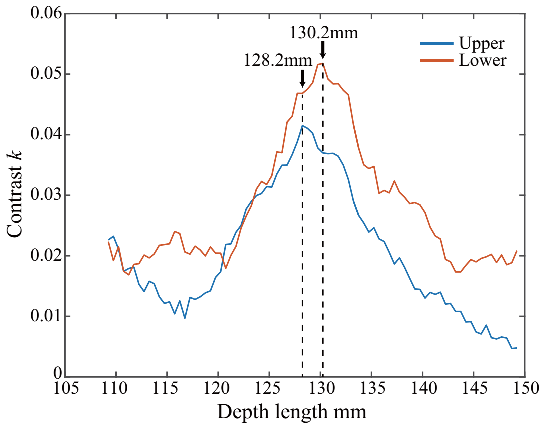

Fig.12: *Contrast ratio between blood vessel and the around area*

position of the lower vessel), and 136.2 mm.

4. DISCUSSION

Experimental results using black-painted rod suggest that the proposed system could estimate generally correctly depth length. The shape of the contrast ratio in real biomedical tissue shown in Fig. 12 is similar to the experiments using black rods. It is suggest that the proposed system could use for real blood vessel.

Finger image showed in Fig.10(a) is lower contrast than rod image in Fig, 4. The image processing technique is useful for improving the contrast. However, wrinkles of the finger are also emphasized as shown in Fig. 10(b), and this could inhibit the depth estimation of the blood vessel. This is a subject for future analysis as well as optimization of the system.

5. CONCLUSION

In this paper, we proposed a system for three dimensional vessel position estimation based on refocusing using light field imaging. This system can obtain the emphasized blood vessel image at each depth by using near-infrared light and light filed imaging. We evaluated the validity of a proposed system using a blood vessel simulated target in air and human finger. In the future, we will optimize and design the optical system for observation of the biomedical tissue at once and develop algorithm for detecting the

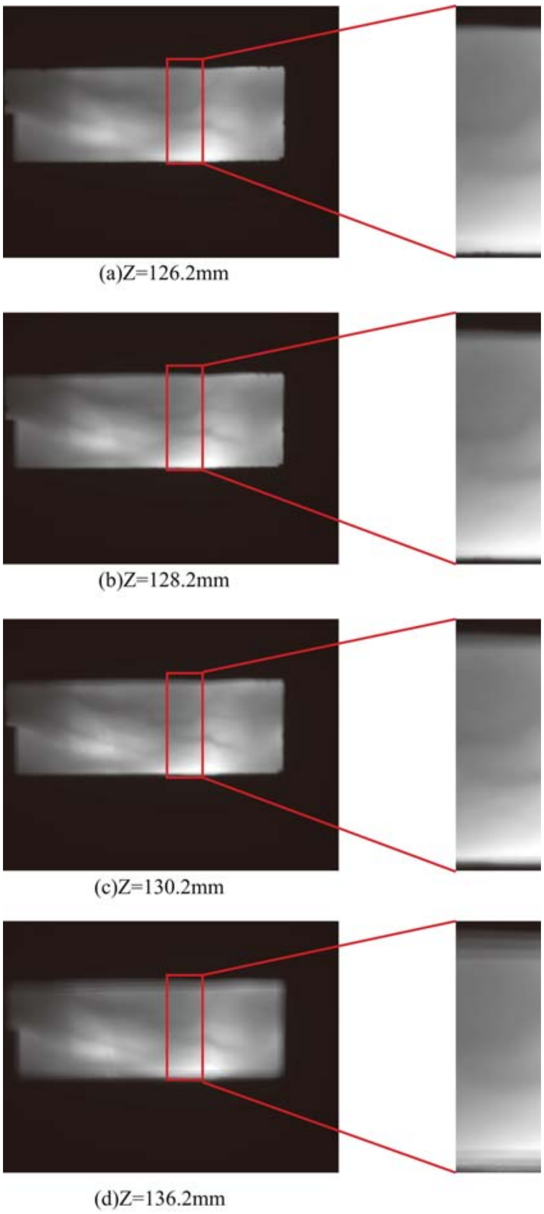

Fig.13: *Refocusing images of finger*

depth of the vessels automatically, and presenting the position real time. This system is useful for medical professionals and patients.

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