บทความวิจัย (Research Article)

A Development of Low-Cost Optical Image Device for Tuberculin Skin Test

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Abstract

Tuberculin skin test is done by measuring the maximum size of infectious area. Normally, it is done using a ruler and human eyes. Error can easily occur from this conventional measurement method as the infectious site is in millimeter scale. Different person could interpret different size of the area, which could lead to false diagnosis. To standardize the process, image processing along with optical imaging knowledge are used for creating a system that can determine the size of infectious area with least human action involved. A compact model based on low-cost USB camera and a software that calculates the size of an object in captured image are established. The whole system is tested with variation of samples, with 5 measurements repeatedly done on each sample to find the average size result. In the final stage, the system can properly measure out the redness area on the skin.

Keywords: Tuberculin, TB test, Optical Image Device

1. Introduction

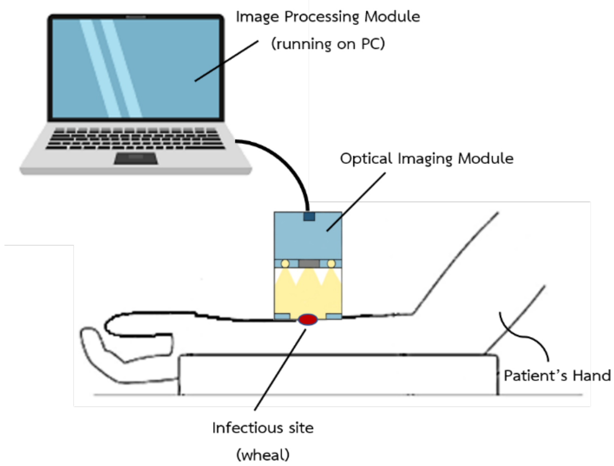
Tuberculin (TB) skin test is a common method used for diagnosing Tuberculosis. Generally, in TB skin test, it is diagnosed by using millimeter ruler to measure the size of the infectious site, or wheal. The positive-result wheal size, meaning that the patient happens to have tuberculosis infection, will then be categorized into 3 levels, from low risk to high risk depending on the backgrounds of the patients [1]. By the method of measurement, it may result in error diagnosis as it is a manual measurement, and there can also be a possible consequence of the error from wrongly diagnosing. As a result, many researchers have been trying to minimize this error by using scientific and engineering-related knowledge. One of the common approaches is to create a measurement system with the use of image processing along with the test and make the test able to function either automatically or semi-automatically. According to Pedro and Barfeh's research [1], they mimic their approach onto tuberculin test by applying a marker onto a wheal for the system, the same way it was apply for manual measurement and use edge detection to measure the Euclidean distance of the infection site. This approach has an accuracy of 91.53%. However, the approach still relies on marking the infection site, and the mark depends on the judgement of the technician because it is done manually. Sabliov and her team [2] have proposed a method to compute the area of the object that does not require any human action, for uses in the field of agricultural. They first convert the input pictures into binary image and utilize the different in contrast of the object compared to background in order to distinguish the edge and measure out the pixels. Easlon et al [3], have also proposed a method similar to Sabliovs' but rather use a different color pixel instead of the binary image. This makes it applicable for varieties of application. Base on Lymperis's research [4], there are several factors that need to be calibrated for use with human skin, such as hair removal, vein removal. Geometric aspect is also another big factor to be considered. The height and angle of the camera and subject can affect the results.

In this work, we propose a low-cost optical image device which composes of 1) optical imaging module and 2) image processing module running on pc. Optical imaging module is developed based on low-cost USB camera available widely in market. Image processing module is simply developed based on Python and OpenCV [5]. Calibrating and setup procedure for optical imaging module is provided. Lighting is adding into a system to enhance overall contrast. The camera is calibrated with a known size circular shape as reference to lessen geometric aspect difficulty.

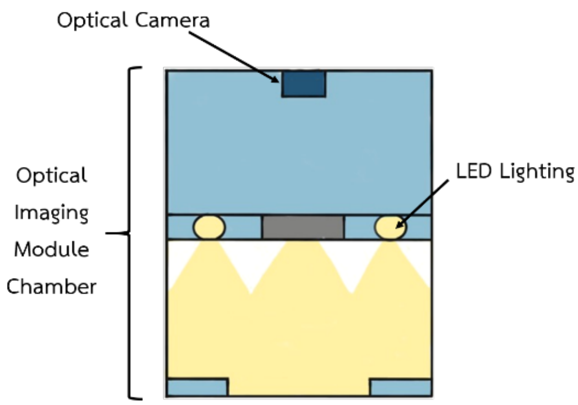
2. Design Requirements

The proposed system is shown in Fig. 1 which composes of two parts: 1) optical imaging module and 2) image processing module.

For optical imaging module, a hardware part of the whole system, is used to obtain a picture of infectious site which will be sent to the image processing module to process. The characteristic of TB skin test infection area is red and mostly circular, therefore image obtained must include all infectious area and these characteristics. Hence, this module is designed with the following requirements



(a)



(b)

Fig. 1 a) Overall proposed device and b) Optical imaging module

- Image capturing component should have enough resolution and low-cost for making the tool accessible for wide-range of users.
- LED light system is required to brighten up the closed system as well as reducing noises from shadows inside. White LED light was previously choosing for the system to get rid of the color shift, in order to remain original color of the infectious redness.
- The module must be a closed system covering the area of infection site, in order to get rid of ambient light.
- To make the cost of overall system is low, components of optical imaging module must be assembled as a compact system using 3D printing method.

For image processing module, since the image capturing module is a closed system and is under control, processing a capture image sent to image process module running on PC is simple and straightforward. Also, related parameters in this module can be adjusted empirically.

3. Implementation

3.1 Hardware: Optical imaging module

3.1.1 Finding depth of field

Regarding hardware requirement, USB wire optical camera with built-in LED light is chosen as shown in Fig. 2. Its specification provided by manufacturer is also indicated in Table 1. Note that this type of camera is easy to find in market with low price. However, depth of field's specification [6] of the optical camera is sometimes not provided so that it has to be identified.

Depth of field of the camera is investigated to define the range of the distance that the object can be placed in order to obtain the sharp focus image. Basic experiment setup to estimate depth of field can be done by measuring of nearest and farthest distance between camera and object that still gives out sharp and clear image. From the experiment, the nearest distance is 4 cm. while the farthest distance is 7 cm. Hence, Depth of Field ≈ 3 cm.

3.1.2 Optical imaging module chamber

Optical imaging module chamber has two parts which are base and body. The base part is in contact with human skin, while the body part is the part where camera and wire for computer connection are located as shown in Fig. 3.

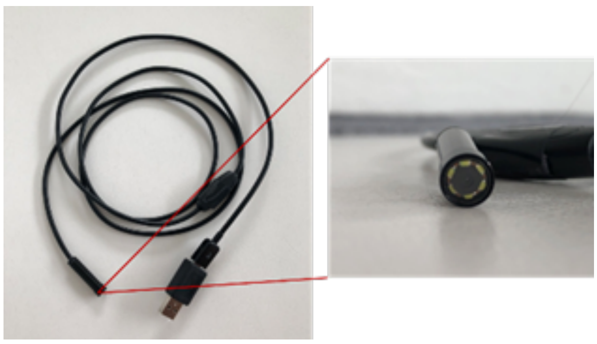


Fig. 2 USB wire optical camera with built-in LED light

Table 1 Specification of USB wire optical camera and built-in LED light

USB Wire Optical Camera	
Wire Length	1 m.
Camera View Angle	67°
Focal Distance	8 cm. to infinity
Resolution	640 x480
LED Light	
Number of Bulbs	6 Bulbs
LED Color	White
Brightness	Adjustable

Value of x, or object distance in Fig. 3 should be corresponding to estimated depth of field. All sizes and dimensions are designed to precisely match with chosen USB optical camera and estimated depth of field. CAD program used in the design is Autodesk Fusion 360. The complete optical imaging module after assembling is demonstrated in Fig. 4

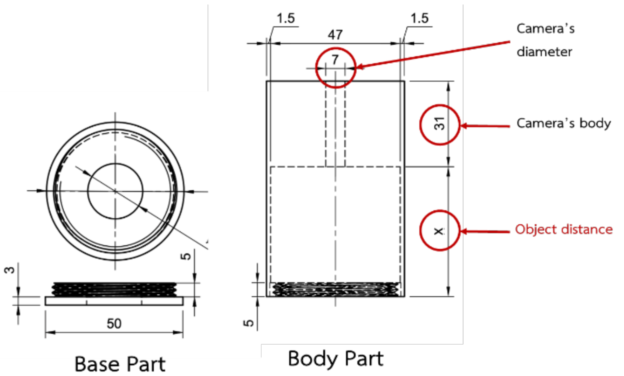


Fig. 3 Base and body part of optical imaging module chamber

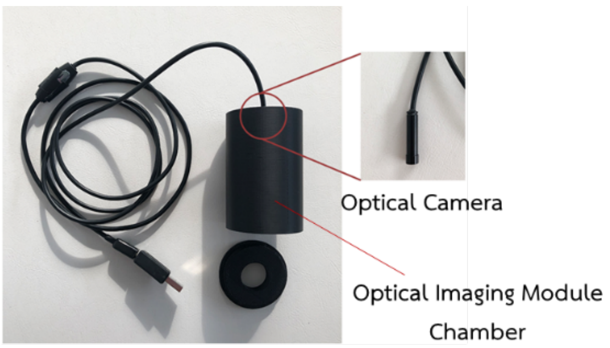


Fig. 4 Optical imaging module after assembling

3.2 Software: Image Processing Module

The flowchart of image processing module is shown in Fig 5. After the program is initiated, the captured RGB image from optical imaging module will be fetched into this module. The image will then be converted to HSV image and filtered with red channel mask [7], leaving only the red portion of it. After that, the program will detect edge based on Canny edge detection [8] and then draw out the outline of infectious site using the combination of simple morphology and contour finding algorithm [9] available in [5]. Finally, the determination of size is normally made using the largest diameter of the redness area. A circle will be drawn over the outline at the maximum length and then diameter of the mark will be calculated as the diameter of the circle outline as shown in Fig. 6. The diameter's size is estimated by computing ratio between number of pixels along diameter of drawn circle and pixel/millimeter ratio as in (1)

$$\text{Diameter} = \frac{Number\ of\ Pixels}{Pixel/millimeter\ ratio}, \qquad (1)$$

where pixel/millimeter ratio is number of pixels per millimeter based on optical imaging set-up mentioned in previous section. This value is fixed and is calculated in advance as in [10].

Lighting that is added into a system to enhance overall contrast also causes shadow. Shadows from wheal sometime cause an effect to the imaging process. The change in spectrum by the effect of the light in the system can also affect the perspective of the image, which can be calibrated by using gray color pad before testing [11]. The more noises can be removed from the scene; the better result can be obtained.

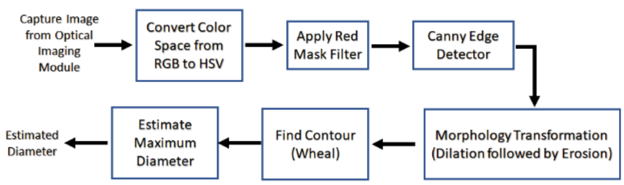


Fig. 5 The flowchart of image processing module

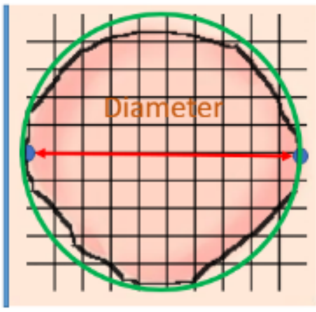


Fig. 6 Drawn circle and diameter used to estimate the size of mark

4. Experiment Setup

The experimental setup is shown in Fig. 7. It is designed to investigate how system is function under different conditions of background color and mark shapes. To create a sample used in the test, four shapes are drawn in Adobe Photoshop for the most accurate size and color. The size of the shapes created are all 10.00 mm. For the arbitrary shape, it is drawn in random size. The proposed system is tested by varying the background colors and mark shapes as shown in Table 3 and Table 4.

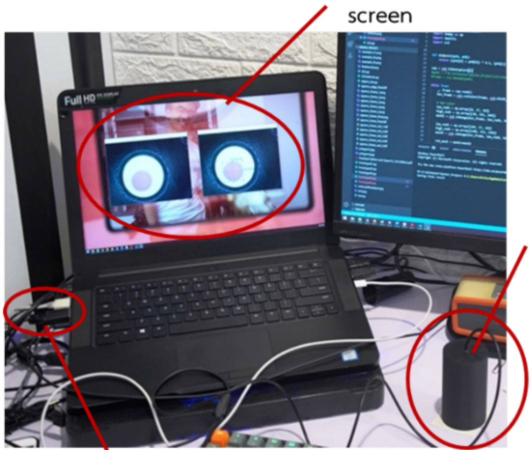


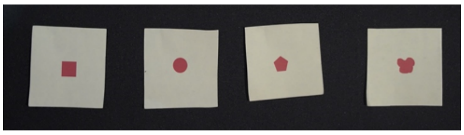
Fig. 7 Experimental Setup

Table 3 Testing sample shape and color

Square	Circle	Heptagon	Arbitrary
			
			

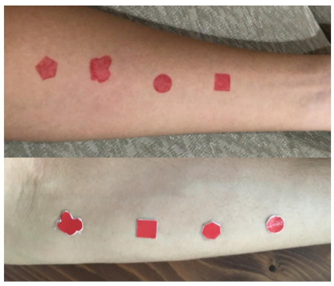
Table 4 Testing Sample Color and Background

Background	Sample Color
White (white paper)	Black
Yellow (green-read paper)	Black
	Red
Human Skin	Red



Testing Sample Cards

(a)



Testing Samples on Skin

(b)

Fig. 8 a) Testing sample on yellow background (green-read paper) and b) Test sample and on human skin

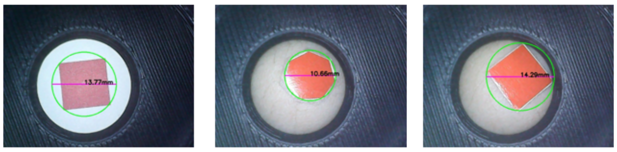


Fig. 9 Actual captured image from optical imaging module

When doing the test, the shape sample is place on the background subject, i.e., green-read paper for yellow background, or human skin as seen in Fig. 8.

5. Experimental Results

The examples of captured image from optical image module are shown in below in Fig. 9. The drawn circle and measured diameter from the program are also shown in Fig. 9

Results of measured diameter from the proposed system, denoted by D_m, are obtained after the recalibration for each experiment. All samples are tested 5 times per sample. Results are reported in average value. Note that the maximum difference, denoted by ΔD_{max}, is calculated from the largest size measured subtract with smallest size measured of each sample. D_{true} is true size of sample. All results are shown in Table 5.

For the black samples on white background, most of the measurements show slight difference of size results when repeatedly measure for square, circle, and heptagon samples. For arbitrary shape, the measurement varies the most. The maximum difference of the measurement is 0.360 mm. The measurement results of black samples on yellow background set are comparable with black sample on white background. When the samples are repeatedly measured the size of square varied the most, and the maximum difference of size is 0.350 mm. For circle, heptagon, and arbitrary sample the measured sizes are not differ much throughout repeating measurements.

On yellow background and red samples, the measurements with small variation throughout each repeated measurement are observed. When repeatedly measure, the maximum difference of all shapes is similar. The shape with least variation throughout repeating the experiment is heptagon.

At last, on human skin and red samples, the variation of measured size is large comparing to that of yellow paper done earlier. The highest maximum difference was found in heptagon sample while the lowest was observed in circle sample. The large size-variation of this test might result from glossiness of the sample that reflects the LED light.

From the results of the whole experiment, all of the samples show a slight difference in measured size result. Although it is not significantly high, more improvement will need to be done in the future.

There are several possible reasons that can cause error in calculating for the size of an object. First is the problem with the optical imaging module. From the taken images, we can observe that some area, mostly the upper left corner of the picture, is not sharp and clear. This can possibly come from the alignment of camera. The camera might not align straight enough since the camera is not completely fixed with the model. Another possible error is about the LED brightness. The brightness might not stable enough. There is still a small difference in brightness throughout the experiment, although the brightness was made fix.

For the program and algorithm, the edge detection might not give out the more accurate edge of the sample. This can be due to differences in the color of the sample as well as the background which makes the filter become unstable or give out error. This can later be possibly improved by using more elaborate algorithms, for example, active contour, level set, or machine learning algorithms, to help distinguish the sample out of the skin and get a better result.

Table 5 Experimental results, D_{true}, D_m and ΔD_{max}

Background	Sample		D_m (mm.)	ΔD_{max} (mm.)
	Color	Mark		
White (white-paper)	Black	Square (D_{true} = 14.14 mm.)	14.132	0.120
		Circle (D_{true} = 10 mm.)	10.138	0.110
		Heptagon (D_{true} = 10 mm.)	10.328	0.120
		Arbitrary shape	13.096	0.360
Yellow (green-read paper)	Black	Square (D_{true} = 14.14 mm.)	14.158	0.350
		Circle (D_{true} = 10 mm.)	10.116	0.066
		Heptagon (D_{true} = 10 mm.)	10.424	0.096
		Arbitrary shape	13.168	0.120
	Red	Square (D_{true} = 14.14 mm.)	13.722	0.120
		Circle (D_{true} = 10 mm.)	10.028	0.130
		Heptagon (D_{true} = 10 mm.)	10.226	0.130
		Arbitrary shape	13.114	0.130
Human Skin	Red	Square (D_{true} = 14.14 mm.)	14.492	0.380
		Circle (D_{true} = 10 mm.)	10.232	0.120
		Heptagon (D_{true} = 10 mm.)	10.660	0.500
		Arbitrary shape	13.634	0.480

6. Conclusion

Tuberculin (TB) skin test is a common preliminary method for diagnosing Tuberculosis. Normal practice in clinical use interpret data using ruler and bare eyes. To standardize the test, image processing has been implemented into a prototype that helps measuring the size of the skin test wheal. The prototypes contain 2 parts: 1) the optical module consists of a low-lost USB camera embedded inside the 3D printed case that is design to helps the camera performing better in capturing an image and 2) the processing module running on PC is design to be able to measure out the size of the redness test wheal and to save the results for later use. The proposed system is compact and easy to implement with low-cost camera available widely in market. Moreover, the performance of proposed system is sufficient for preliminary Tuberculosis diagnosis.

7. References

[1] San Pedro, J.M.M. and D.P.Y. Barfeh, “Tuberculin skin test checker using digital image processing,” *IEEE International Conference on Control and Robotics Engineering (ICCRE)*, 2018.

[2] Sabliov, C.M., et al., “Image Processing Method to Determine Surface Area and Volume of Axi-Symmetric Agricultural Products,” *International Journal of Food Properties, 2002, 5(3)*, pp. 641-653.

[3] Easlon, H.M. and A.J. Bloom, “Easy Leaf Area: Automated digital image analysis for rapid and accurate measurement of leaf area,” *Appl Plant Sci*, 2014, 2(7).

[4] Lymperis, D., et al., “Image processing algorithms for a computer assisted allergy testing system,” *International Conference on Computational Intelligence in Medicine and Healthcare (3rd CIMED)*, 2007.

[5] *OpenCV: Open Source Computer Vision Library*. [Online] Available: https://github.com/opencv/opencv.

[6] A. P. Pentland, "A new sense for depth of field." *IEEE transactions on pattern analysis and machine intelligence*, no. 4 (1987): 523-531.

[7] R. C. Gonzalez, *Digital Image Processing*, Pearson, 4th ed., 2017.

[8] J. Canny, “A computational approach to edge detection,” *IEEE Transaction on Pattern Analysis and Machine Intelligence,* (6):679–698, 1986.

[9] S. Suzuki, et.al., “Topological structural analysis of digitized binary images by border following,” *Computer Vision, Graphics, and Image Processing*, 30(1):32–46, 1985.

[10] Chen, K. and L.E. Banta, “Image profile area calculation based on circular sample measurement calibration,” *Journal of Electronics (China)*, 2005, 22(5), pp. 528-533.

[11] Lamminen, H. and V. Voipio, “Computer-aided skin prick test,” *Experimental dermatology*, 2008, 17(11), pp. 975-976.