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Design of Finger-vein Capture Device with Quality Assessment using Arduino Microcontroller

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***Abstract*—This paper focuses on designing and developing a finger-vein capturing device by using Arduino Microcontroller. It is a device that will capture the human finger-vein image and be controlled by Arduino Microcontroller. This device is applicable for authentication, verification and identification. It uses the concept of near-infrared light (NIR) emitted by a bank of NIR Light Emitting Diodes (LEDs). The NIR penetrates the finger and then absorbed by the haemoglobin in the blood. The areas in which the NIR rays are absorbed (i.e. Veins) thus appear as dark regions in an image conveyed by a CCD camera located on the opposite side of the finger. The brightness of the NIR will be controlled automatically using Arduino Microcontroller to obtain sufficient quality of image brightness. Although the Arduino Microcontroller is more expensive than potentiometer, it is more convenient and efficient as brightness adjuster. Besides that, it is definitely a low-cost device compares to FPGA. The image captured is analyzed by using Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR). A low cost capturing device is developed and decent quality finger-vein images are produced.**

***Index Terms*—Biometric Systems; Finger-vein; Arduino; Microcontroller; MATLAB.**

I. INTRODUCTION

This project focuses on designing and developing a low-cost and standalone finger-vein capturing device. This device, which captures finger-vein image is used for biometric security purposes such as authentication, recognition, and identification. There is a number of existing finger-vein capturing device that is available on the market. However, the devices are extremely expensive: Some devices cost more than RM2000. Besides that, most of the devices are not standalone device, where they have their own verification software to run with. Therefore, those devices are not suitable for any research development purposes.

Light reflection concept is applied in capturing the finger-vein images. A near-infrared light (NIR) emitted from a bank of NIR Light Emitting Diodes (LEDs) penetrates through the finger, and the NIR is then absorbed by the haemoglobins in the blood. The vein areas where the rays are absorbed will appear as dark areas in the image. Then the Charged-Couple Device (CCD) camera located at the opposite side of the finger captures the image. However, the body temperature of each person varies from one another. In addition, shadows may be created when the NIR pass through the finger.

Researchers have come out with a few standalone finger-vein capturing device in order to solve the mentioned problems. Different types of brightness controllers have been introduced to control the brightness of the NIR input. An FPGA-based finger-vein capturing device has been used [1] to capture the image. Although the output images in good quality, it was a high-cost device. Other than that, a low-cost potentiometer has also been used [2]; however, the output images were not good as the one using FPGA. Further, the brightness of the NIR LEDs was not adjusted very efficiently. Therefore, another brightness controller device is introduced. Arduino Uno microcontroller was used to control the output of the Pulse Width Modulation (PWM) from the light intensity of the NIR to suit different person's body temperature; thus reducing the shadows of the image being captured. The Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 Analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, In-circuit serial programming (ICSP) header and a reset button. The image captured is analyzed by using Mean Square Error (MSE) as well as Peak Signal-to-Noise Ratio (PSNR) in MATLAB in order to identify the best finger-vein image. Finally, the best image will be produced and can increase the image quality for further biometric security proposes.

The remainder of this paper is organized as follows. In Section II, we discuss the theory of biometrics, features of finger-vein biometric and vein pattern imaging methods. In Section III, we discuss the methodology of the project. In Section IV, we discuss the results of this project. Finally, we conclude this paper with a summary of work.

II. LITERATURE REVIEW

A. Theory of Biometrics

A biometric system can be defined as the science and technology of measuring and analyzing biological data. In the biometric security system, biometric traits are used for recognition and authentication of the individual. These traits have the ability to differentiate one individual from another. Biometric traits are divided into two categories; physiological and behavioral [3]. Soft biometric like gender [4] has both categories.

Physiological are related to the shape of the body. Examples include, but are not limited to fingerprint, face recognition [5], hand and palm geometry [6] and iris recognition [7].

Behavioral are related to the behavior of a person. Characteristic implemented by using biometrics are signature verification [8], keystroke dynamics [9] and voice [10].

A good biometric trait must hold a few basic parameters. The first parameter is universality [11,12]; it means that everyone who is using the system must have the same traits. The second parameter is uniqueness [3,11,12]; it means how the traits make the particular person be different between one another in the relevant population. The third parameter is permanence [3,11,12]; it means how the traits behave and varies over time. Normally, a trait with good permanence will be invariant over time with respect to particular verification algorithms. The fourth parameter is collectability and measurability [3,11,12]; it means how easy the measurement and acquisition of the trait can be. The fifth parameter is performance [3,12]; it is related to the technology's accuracy, processing speed and sturdiness. The sixth parameter is acceptability [3,11,12]; it means how well the person accepts the technology so that they are willing to have their biometric trait to be retrieved and processed. The last parameter is circumvention [3,12]; it means how easy the traits can be copied or imitated by using some methods.

B. *Features and comparison*

Finger-vein recognition technology has several important features that make it special from other forms of biometrics. It is the most secure and convenient for personal authentication.

Table 1
Feature and comparison

No	Importance features	Explanation
1	Resistant to Criminal Tampering [2]	Since veins are hidden inside the human body, stealing the person's identity is impossible. If the thief tries to cut the finger, there will be no point since the blood is in contact with the oxygen presence in the air, the haemoglobin in the red blood cell will die off and thus no pattern image can be seen.
2	High Accuracy [2]	The authentication accuracy is less than 0.01% for the FRR (False Rejection Rate), less than 0.0001% for the FAR (False Acceptance Rate), and 0% for the FTE (Failure to Enroll). So, finger-vein pattern recognition can provide a very high accuracy in identifying a person's identity.
3	Unique and Constant [2]	Finger-vein patterns are different for every person, even among identical twins who have nearly the same DNA and will remain unchanged throughout the whole life time.
4	Contactless [2]	The use of near-infrared light allows for non-invasive, contactless imaging that ensures both convenience and cleanliness for the user experience.
5	Ease of Feature Extraction [2]	Finger-vein patterns are relatively stable and clearly captured, enabling the use of low-resolution cameras to take vein images for small-size, simple data image processing.
6	Fast Authentication Speed [2]	One-to-one authentication takes less than one second. Moreover, the authentication device can be compact due to the small size of fingers.

C. *Finger-vein Pattern Imaging Methods*

Basically, there are two finger-vein pattern imaging methods [13], which are the "light reflection" and "light transmission". Hitachi company who was the first developer of finger-vein authentication had combined the "light reflection" and "light transmission" to become "side lighting". For light reflection method, the NIR light source and the CCD camera are placed on the same side of the finger, the reflected light from the finger will be captured by the CCD camera. As for light transmission method, the finger will be placed in between the NIR light source and the CCD camera, the NIR light will penetrate through the finger and the image will be captured by the CCD camera. The combination between the light transmission method and light reflection method produces the other method side lighting where the light source are placed on both sides of the finger and CCD camera from the bottom of the finger to capture image produced.

III. METHODOLOGY

A. *Finger-vein pattern method*

The method of light transmission method can be understood where the finger will be placed in between the NIR light source and the CCD camera. The NIR lights will penetrate through the finger and the vein pattern will be captured by the CCD camera, as shown in Figure 1. When the NIR light penetrates through the finger, the lights will be absorbed by the haemoglobin in the finger-veins. Thus, the light absorbed area will appear as dark region; hence vein patterns will be visible. The pattern is then captured by the CCD camera.

The advantage of this method is that it could eliminate the effect of reflection, as high contrast vein pattern image can be produced. [2].

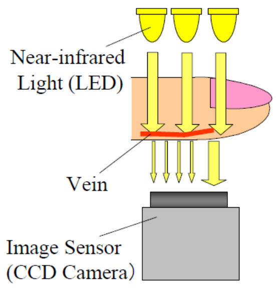

Figure 1: Light Transmission Method [13]

B. *Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR)*

Mean square error (MSE) can be defined as the measurement of Average Square of error from the estimation value. In this project, there are two error metrics had been classified to be used. The comparison of the quality of an image can be measured by using Mean Square Error (MSE) and the Peak Signal-to-Noise Ratio (PSNR). The MSE is the cumulative squared error between the sampled images and the reference image, whereas PSNR is the measure of the peak error. The mathematical equations are shown as follows:

$$MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}[I(x,y) - I'(x,y)]^2 \quad (1)$$

$$PSNR = 20\log 10\left(\frac{MaxI}{\sqrt{MSE}}\right) \quad (2)$$

where:

$I(x,y)$ = reference image
$I'(x,y)$ = sampled image
M, N = dimensions of the images
$MaxI$ = maximum pixel of the image

From the equations above, the value of MSE indicates the value of the error produced. The higher the value of MSE indicates a higher noise contained in the image and vice versa. The higher the value of MSE, the lower the value of PNSR is. Last but not least, the better image produced is the image which has the lower the MSE and higher the PSNR. The output value of MSE and PSNR were also compared to the value in [2] to see which method produces a better quality images.

C. NIR Illuminating Intelligent Schematic Input System(ISIS) Circuit Design and Simulation

From the research, this design is based on the ISIS for the Arduino as the PWM controller as shown in Figure 2. Arduino Uno has been added into the libraries of ISIS in the Proteus Software. The 6 number of NIR LEDs located after the resistor in pin 3 will be controlled by the PWM controller. The auto adjustment is the switch located in pin12 where the brightness of the NIR LEDs can be adjusted.

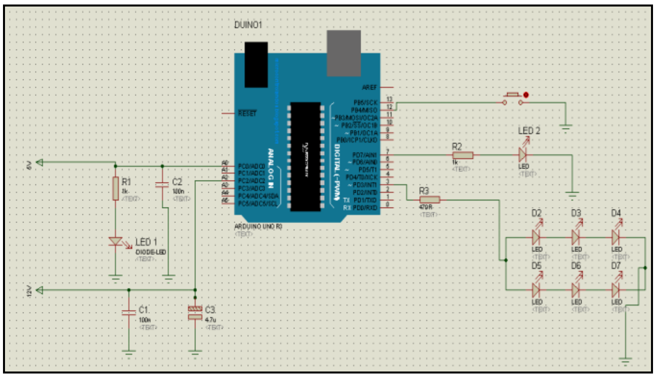

Figure 2: NIR Illuminating ISIS Circuit Design and Simulation for Arduino Microcontroller.

D. NIR Illuminating Circuit Construction and Testing on Arduino

Figure 3 shows the light of NIR LED after the push button is pushed. This is the result of the ISIS design. In order to make it visible to human eyes for the NIR LEDs, the camera of Logitech C170 is placed with a piece of black film to allow the light array from the NIR LEDs to be seen by the human eyes. This is the result of NIR LEDs circuit that proves the functionality of the circuit and can be executed for the whole day without having any damage to the component.

Figure 3: NIR LED testing.

E. The final product of Finger-vein Image Capturing Device Prototype

The final product was built completely as shown in Figure 4. There is a sponge between finger's users to place the finger during the capturing process. The finger placement has also been measured to suit the size of the user's finger. This is important to ensure that the entire user has placed his/her finger correctly, which can help to obtain a high-quality finger-vein image.

Figure 4: Finger-vein Capturing Device Prototype

F. Evaluating and Initial Capture of a Finger-vein Image

The NIR LEDs circuit and webcam modification is combined and tested with the first captured of a finger-vein image. The image shows that the functionality of combining the NIR LEDs circuit and the camera as shown in Figure 5. This is the first step of initial capture of a finger-vein image after built up the complete prototype. The first finger-vein image is taken and the grey lines in the middle of the finger shows the veins of a finger.

Figure 5: The first image of finger-vein image after building the prototype.

G. Developing the Finger-vein Capturing Device's GUI

The final step of the methodology analysis is to develop a Graphical User Interface (GUI) for the finger-vein capturing device as shown in Figure 6. The image is captured for nine times with different level and the standard image is determined and ultimately, the best image is produced by comparing them to the standard image. The GUI has one axis, two panels and two static text boxes so that there are six buttons created. Next, the box analysis result will show the standard image and the result will show the best image.

The axes 1 panel is for the preview of the stream live webcam.

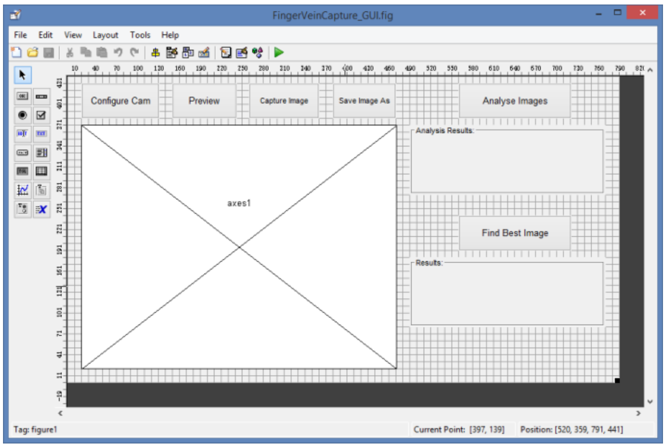

Figure 6: The six button of the finger –vein capturing device design in "guide" MATLAB.

IV. RESULT

A. Simulation of NIR Illuminating Circuit with difference level of PWM

The circuit is designed and simulated by the Proteus. This software is the Virtual System Modelling (VSM) that combine circuit simulation, component, and microprocessor model. The NIR LEDs are not visible to human eyes, hence during the simulation, the interface or Arduino will guide each step starting from level 1 until level 9 due to the value of PWM of each stage. The increase of the stage will increase the brightness of the IR LED. Figure 7 shows the result obtained during the simulation.

The value of PWM started with 30 pulses for step 1, 60 for the step 2, 90 for the step 3, 120 for step 4, 150 for the step 5, 180 for the step 6, 210 for the step 7, 240 for the step 8 and lastly 255 for the step 9. The NIR LEDs was set to the first stage or level.

B. Total of First 9 Finger-vein Images of Different Brightness were Captured and Saved

The first nine images of the finger-vein image are saved with the different stage or brightness level for each image. The image has to follow the value of PWM in the Arduino. The image is saved into a folder name capture with name "Cap_User_x_y.jpg", where variable "*x*" refer to which user in number and variable "*y*" refer to which PWM level. Figure 7 shows all the image of finger-vein image with the different PWM's level.

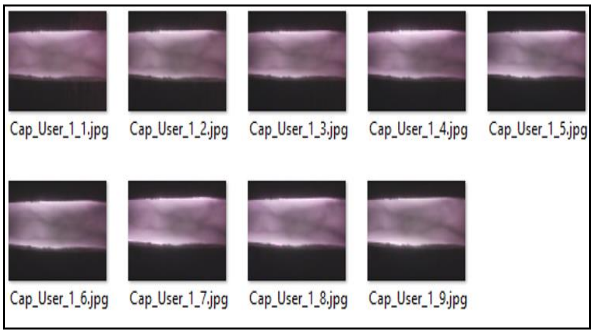

Figure 7: First ten captured image of the User.

The reference point is the image of MSE and PSNR value in which the lowest point of MSE and the highest value of PSNR are choosen. The image which had been chosen as standard image was image at 5th for user 1. The arduino level was set to the level of 5 and then MSE and PSNR between the standard image and second nine captured images are determined to find the best image as shown in Figure 8 and Table 1.

Table 1
The MSE and PSNR for the reference point of the standard image of User 1

MSE	MSE Values	PSNR	PSNR Values
1	0.0024787	1	26.0578
2	0.0018507	2	17.4540
3	0.0028151	3	28.6723
4	0.0004346	4	44.4328
5	0.0001088	5	46.3728
6	0.0026838	6	38.7342
7	0.0038146	7	26.4389
8	0.0061431	8	29.4327
9	0.0087210	9	28.3248

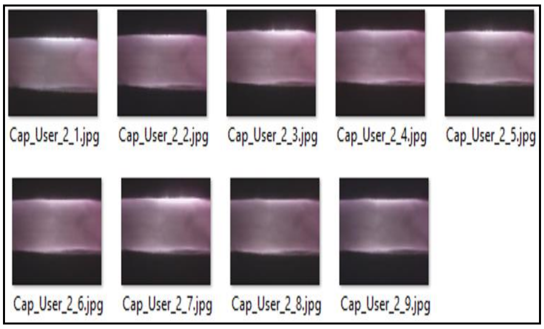

Figure 8: First ten captured image of the User

This is the last part of the analysis of the result, the finger-vein image with the lowest value of MSE and the highest value of PSNR is determined from Table 2. The result of the analysis will be shown in the GUI in Figure 9.

Table 2
The MSE and PSNR for the standard image and second nine captured Finger-vein image of User 1.

MSE	MSE Values	PSNR	PSNR Values
1	0.0030257	1	25.1917
2	0.0072309	2	21.4081
3	0.0156490	3	18.0553
4	0.0061242	4	22.1295
5	0.0058401	5	22.3358
6	0.0100060	6	19.9973
7	0.0073686	7	21.3261
8	0.0053408	8	22.7240
9	0.0079665	9	20.9873

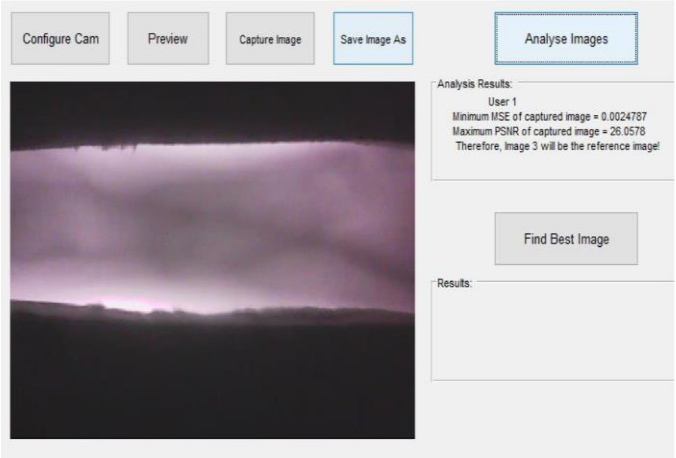

Figure 9 : The analysis result of the standard image and best image is shown in GUI.

The standard image and the best image with their histograms were plotted in Figure 10. The histogram is labelled with the pixel count versus grey level. The reason of displaying histograms of both images is to show that this finger-vein capturing device is able to produce a finger-vein image of high quality. For User 1, the shapes of the histograms for both standard finger-vein image and best finger-vein image are almost the same even though the pixel count versus grey level is slightly different. Besides, the best finger-vein image for User 1 is clearer and high quality as compared to the standard finger-vein image.

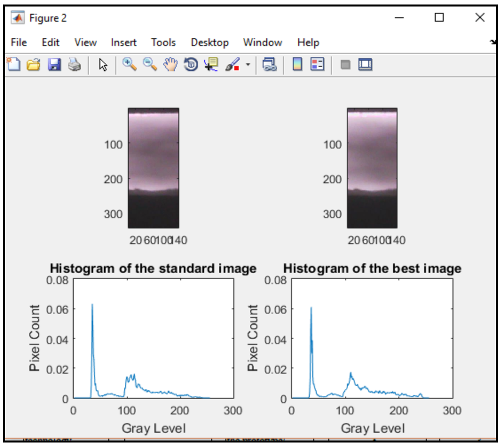

Figure 10: The standard and the best Finger-vein image displayed together with their Histogram.

C. Performance Comparison

The performance of the proposed device was measured based on the comparison of the lowest MSE value and the highest PSNR value obtained and the values obtained by Kwan et al., in [2]. Table 3 shows the comparison of the lowest value of MSE and the highest value PSNR of a finger-vein image of different brightness level. Table 4 shows the comparison of the lowest value of MSE and the highest value PSNR of a finger-vein image of the same brightness level, in determining the best image. Both comparisons prove that the proposed device produced the best images.

Table 3
Comparison of the lowest MSE and highest PSNR values of different brightness level

Device	Lowest MSE Values	Highest PSNR Values
Proposed device	0.0001088	46.3728
Kwan et al., device	0.0002080	36.8194

Table 4
Comparison of the lowest MSE and highest PSNR values of the same brightness level to find the best image

Device	Lowest MSE Values	Highest PSNR Values
Proposed device	0.0030257	25.1917
Kwan et al., device	0.0046468	23.3284

Last but not least, the comparison between the histogram of the threshold image and the best image of the proposed device displayed a more similar pattern than of the device in [2]. Figure 11 shows the histogram comparison of both devices.

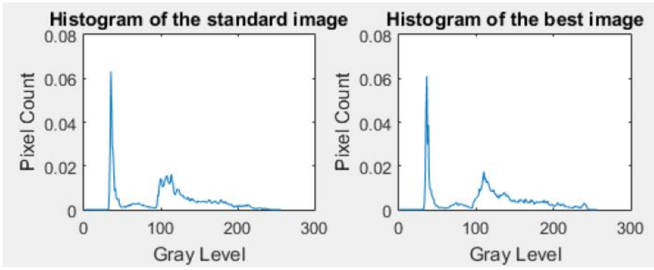

Figure 11(a): The comparison between the histogram of the threshold image and the best image of the proposed device

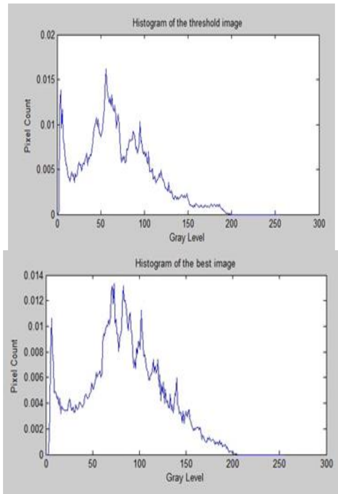

Figure 11(b): The comparison between the histogram of the threshold image and the best image of Kwan device [2]

V. Conclusion

In conclusion, the standalone finger-vein capturing device controlled by Arduino microcontroller has been designed and developed. The developed device is definitely low cost compared to FPGA-based finger-vein capturing device. Furthermore, the quality of the image, when measured based on the MSE and PSNR, proved that it is better in comparison with the image produced by potentiometer. The correct adjustment of the push button will lead to the desired level of the suitable image for a particular user. In addition, the shadow of the image can be reduced by increasing the level of PWM which had been controlled by the Arduino. The cost of the project is low and this can be done by selecting the suitable and lower cost equipment such as CCD camera Logitech and Arduino Uno.

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