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Development of Optical Pressure Sensor for Capillary Refill Time Measurement System

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Abstract: Capillary refill time (CRT) refers to the amount of time it takes for a distal capillary bed to regain its color following blanching produced by externally applied pressure. Generally, the CRT is manually observed by the naked eye of the examiner, and the applied pressure impacts it. Therefore, the results are likely to be unreliable and imprecise because of the observer-dependent measurement, and there is no standardization of the actual blanching maneuver. To overcome this problem, this project proposed a CRT with a contact pressure measurement using a flexible tube and optical fiber sensor. A light-emitting diode (LED) and phototransistor circuits were developed for transmitting and receiving light for the CRT and pressure measurement. The signals were transmitted online via a node MCU and processed by the Matlab software through the Thingspeak application. The relationship between the light intensity and the applied pressure was carried out through the experiment using a manual cuff blood pressure system. The results show a nonlinear relationship between the light intensity transmitted by the LED with the corresponding voltage of 0.59 V down to 0.02 V (bright to dimmer). The result from the volunteer's study shows that voltage detected by the POF sensor increases as pressure increases. These findings demonstrated that the proposed system could be used for a contact pressure sensor for CRT measurement. The added value of the IoT system makes it useful for online monitoring and will be beneficial to society in the future.

Keywords: Capillary Refill Time, Optical Fibre Sensor, Matlab Software

1. Introduction

The amount of time it takes for a distal capillary bed to regain its color following blanching produced by externally applied pressure is known as capillary refill time (CRT). This test has been proposed as a tool for the clinical assessment of peripheral macrovascular illness and cutaneous

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microvascular disease, and it is routinely used in clinical treatment as a basic way of cardiovascular assessment [1]. The commonly used capillary refill time (CRT) calculation is currently performed by manually applying pressure and using a stopwatch to monitor the time it takes for the skin to return to its natural color after blanching pressure is applied [2][3]. Capillary refill time (CRT) assessment is a standard clinical test conducted at the bedside by physicians and emergency medical technicians of all levels of training. The effects of underestimating or overestimating a CRT can be serious. Due to the subjective nature of CRT, there is concern that clinicians may underestimate it, resulting in undertreatment or death [4]. Due to the fact that the most commonly used method for calculating CRT is highly observer-dependent and is influenced by skin temperature, and there is no standardization of the actual blanching maneuver (for example, pressure strength, pressure duration of 3 s, 5 s, or until the capillary bed visually blanches), the results are likely to be unreliable and inaccurate [5][6][7].

Besides, the validity of CRT results can be influenced by a variety of factors, including variances in ambient conditions, patient age, skin color, the presence of nail paint or artificial nails, and even interobserver and interobserver reliability [8]. CRT increased 3.3 percent every decade of life, baseline CRT was lower in males, and doctors' interpretation of CRT as normal or abnormal differed, according to a prospective observational study of 1,000 ED patients [9]. The capillary refill arm showed a small improvement in the primary endpoint, all-cause death at 28 days (34.9 percent vs. 43.4 percent with a 95 percent confidence interval, P = 0.06) [10]. One study to increase dependability perfusion status was determined first by examiner-measured CRT and subsequently by cutaneous temperature readings [11]. According to the findings, patients with decreased perfusion were 7.4 times the risk of increasing organ failure and 4.6 times the risk of hyperlactatemia (p 0.05), according to the findings [11].

Optical fiber sensors have been developed to measure a wide variety of physical properties, such as chemical changes, strain, electric and magnetic fields, temperature, pressure, rotation, displacement (position), radiation, flow, liquid level, vibrations, light intensity, and color [10]. One study has been conducted using optical fiber technology, and a simple intensity-based optical fiber sensor was used to assess respiration rate [12]. The development of low-cost POF pressure sensor has been be applied to the mattress for vital sign monitoring [13]. The results of applied stress and sensor output demonstrate that circular diaphragms are far more efficient than alternative designs [14]. The finite element approach can be used to investigate pressure distribution in a healthy human foot [15]. These findings from the finite element approach may be used to evaluate the physical and mechanical behavior of the human foot, and can be used to analyze and construct orthotic appliances, prosthetic devices, and insoles [16].

In this project, an optical fibre sensor will be designed to assess the intensity of the blanching pressure for CRT measurements. Furthermore, the accuracy of the CRT measurement will be improved by simultaneously measuring the applied pressure at the fingertip. The circuit design and the software configuration for the system will be briefly discussed in the next section.

2. Materials and Methods

To ensure the flow of the project run smoothly, three significant steps need to be aimed at planning, implementing, and analyzing. It will be explained the activity, methodology, software system and hardware development that has been implemented to complete the project. The software used in this project was described in detail in the technical specifications. A software simulation was created in accordance with the specifications for the pressure sensor development. The flow chart of this project is shown in Figure 1.

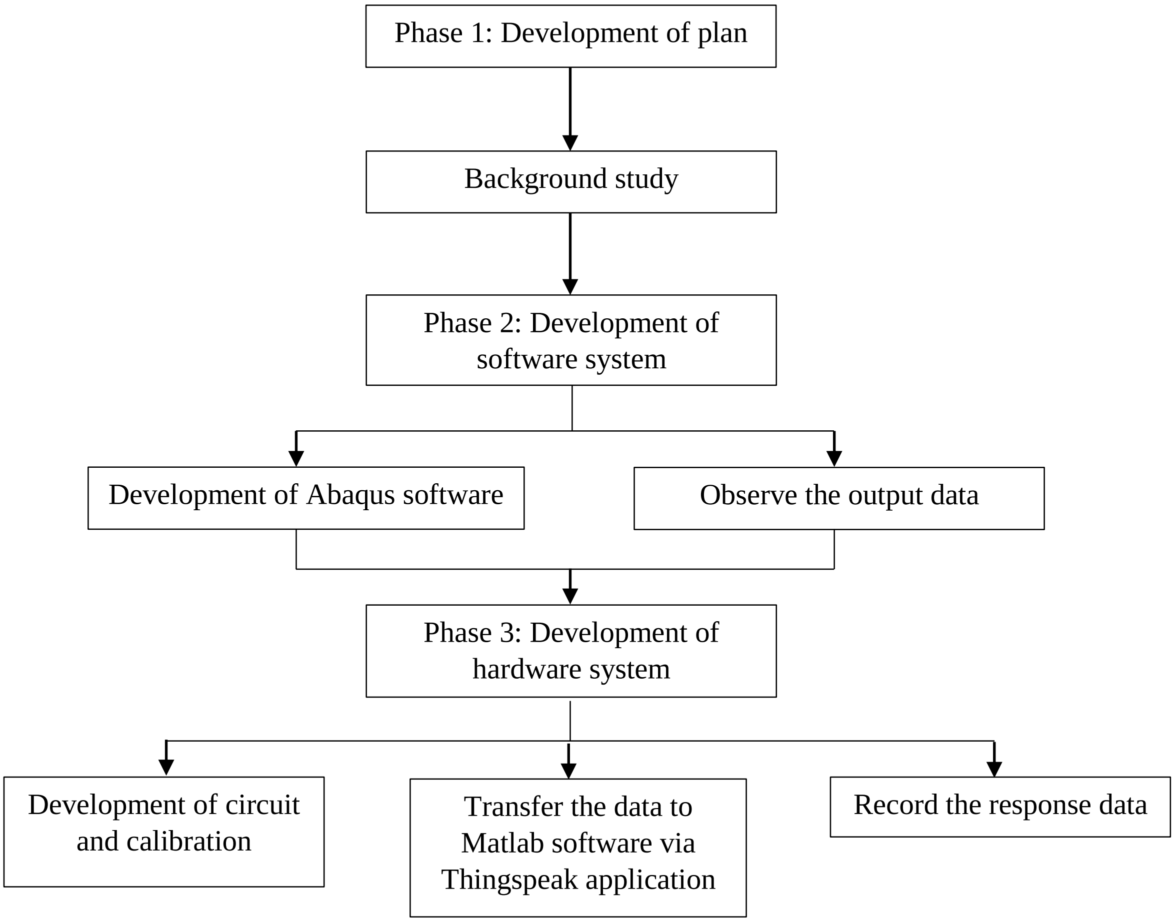


Figure 1: Flowchart of the project

2.1 Project block diagram

The block diagram of the optical pressure sensor system based on the flexible tube is shown in Figure 2.

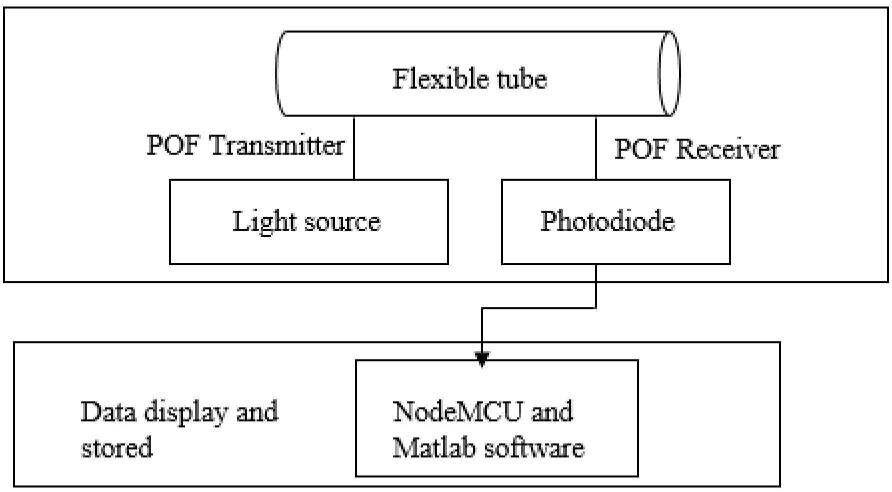


Figure 2: Block diagram of the hardware development

The output data will be produced by the light intensity of the photodiode circuit. The flexible tube with the plastic optical fibre (POF) will be responded based on the applied pressure. The flexible tube compress will change the light intensity, and the photodiode circuit detects this change. The measurement result will be analyzed for the contact pressure measurement. The light source from POF will illuminate the fingertip for the CRT measurement, and the photodiode circuit will detect the intensity of the reflected light. When pressure is applied to the skin, the light intensity changes due to the change in colour. Following that, the signals will be transferred to Node MCU, and the data will be sent to Matlab via Thingspeak apps. The Matlab software will be used to analyze the CRT signal corresponding to contact pressure applied on the fingertip.

2.2 Hardware development

2.2.1 Transmitter circuit

Green LED was used in the transmitter circuit, powered by the circuit depicted. 5 V supply voltage, 500 mA fuse, and 50 Ω variable resistance make up the circuit. The current range was controlled by a variable resistor ranging from 100 mA to 500 mA. While altering the variable resistance, the fuse was added to the driven circuit to safeguard the LED from the excess current.

2.2.2 Receiver circuit

The receiver circuit detects the reflected light intensity from the illuminated flexible tube. TEMT6000 Ambient Light Sensors were used to measure the light intensity. The sensor operates in 3.3 V using power supply module MB-V2. The NodeMcu is used to read the value from the receiver circuit to measure the capillary refill time and the applied pressure simultaneously.

2.2.3 The design of flexible tube sensor

The plastic optical fiber (POF) was attached to a flexible tube by using glue. The plastic optical fiber (POF) with a length of 50cm were cut at 45° of angle to reflect the light that goes through it. The flexible tube was located on the patient's arm to test the pressure sensor performance. Figure 3 shows the design of the CRT measurement probe, and Figure 4 shows the picture of the CRT probe. The transmitter sensor's T1 and T2 transmit light to the skin, and R1 and R2 receive the reflected light from the skin. A black tape was placed on top of the flexible tube sensor to block light from the outside and ensure the R1, and R2 received only reflected light from the skin. T1 and T3 transmit the light for the pressure measurement, and R3 and R4 will detect the reflected light from the flexible tube.

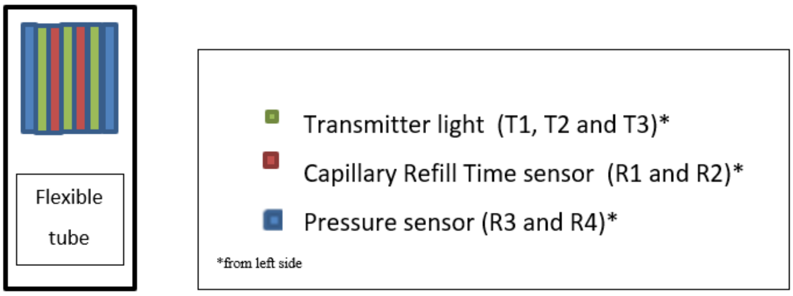
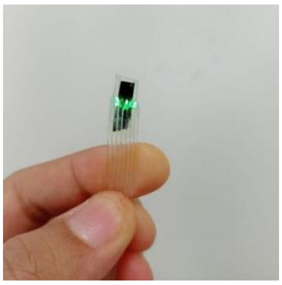
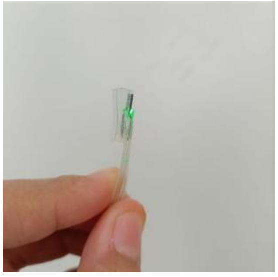


Figure 3: The design of POF on flexible tube





(a) (b)

Figure 4: (a) Front view of design; (b) Side view of design

3. Results and Discussion

The result and analysis of the CRT measurement will be discussed in this section. It included the analysis of the light intensity measurement and the applied pressure on the flexible tube on the volunteer's arm.

3.1 Light intensity measurement

For this project, the resistor value of 50 Ω with dimmer light to 350 Ω with brighter light on the transmitter circuit was used to control the light intensity. Figure 5 illustrates the measurement of light intensity (voltage) in conjunction with the resistance. The results indicate that as resistance increases, the light intensity (voltage) decreases from 0.59 V down to 0.02 V (bright to dimmer). The optical response will give high sensitivity with the brighter light compare to the dimmer light. Therefore, the resistance is set to 50 Ω that correspondent to 0.59 V for the transmitter circuit.

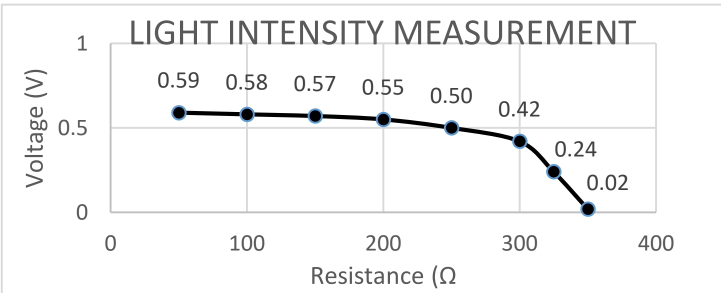


Figure 5: Comparison between resistance and voltage

3.2 Voltage and contact pressure measurement

The measurement of contact pressure based on flexible tube was performed on the volunteer's upper arm (Figure 6). The flexible tube was placed under the cuff blood pressure and squeezed a bulb to inflate the cuff around the upper arm up to 180 mmHg. Then, the voltage readings from the multimeter were taken to investigate the pressure distribution around the upper arm during the cuff deflation. The measurement was taken on three volunteers (A, B, and C) as shown in Figure 7, Figure 8, and Figure 9, respectively.

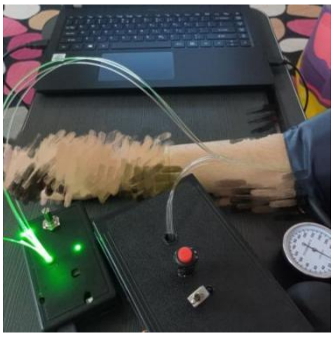


Figure 6: The setup of contact pressure measurement on the volunteer's upper arm

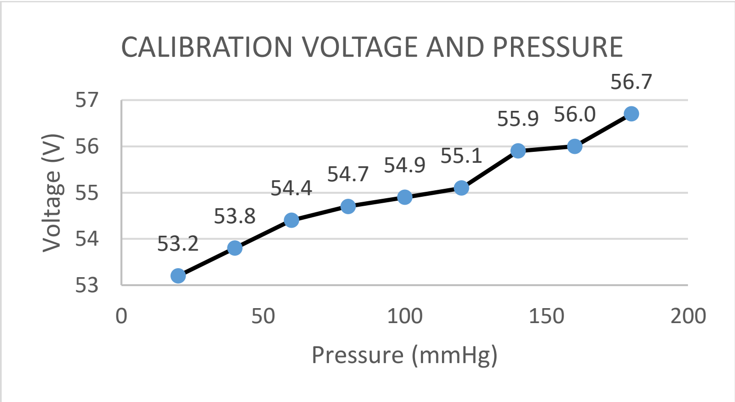


Figure 7: Measurement of voltage and pressure for Volunteer A

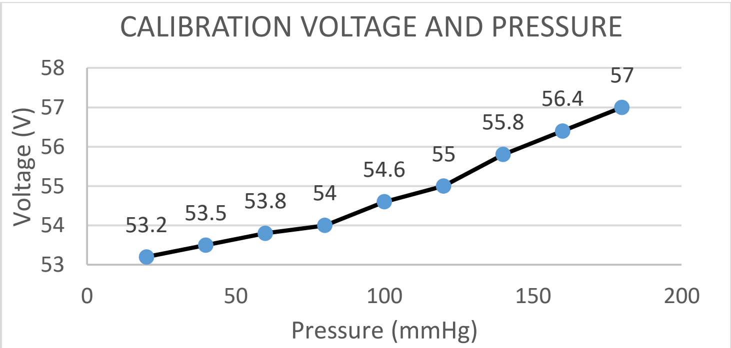


Figure 8: Measurement of voltage and pressure for Volunteer B

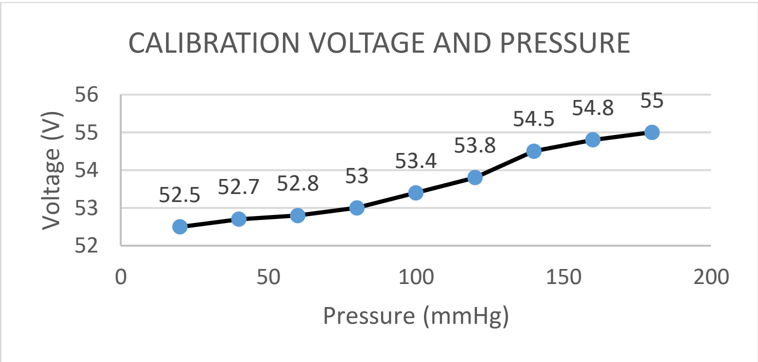


Figure 9: Measurement of voltage and pressure for Volunteer C

The applied pressure measurement shows that the voltage decreases from 56.7 mV to 53.2 mV (Volunteer A), 57.0 mV to 53.2 mV (Volunteer B), and 55.0 mV to 52.5 mV (Volunteer C), as the applied pressure reduces from 180 mmHg down to 20 mmHg. As the cuff inflates, it will compress the flexible tube, and more light will be reflected due to the shortage of flexible tube surface, thus increasing the voltage response at the photodetector.

3.3 System interfacing with Thingspeak

The responses of the flexible tube sensor on the pressure applied were shown on Arduino IDE software. The linear equation of voltage is placed in the coding on Arduino IDE. The signal was transferred to Node MCU, and the data send to Matlab via Thingspeak apps. The Matlab software will analyze the CRT signal corresponding to contact pressure applied on the fingertip. Figure 10 shows the POF pressure signal sent by the Thinkspeak apps to the Matlab software. When no external pressure is applied to the finger, the pressure sensor output and reflected light remain stable. When the pressure changes, as it does when blanching, the light intensity rapidly increases.

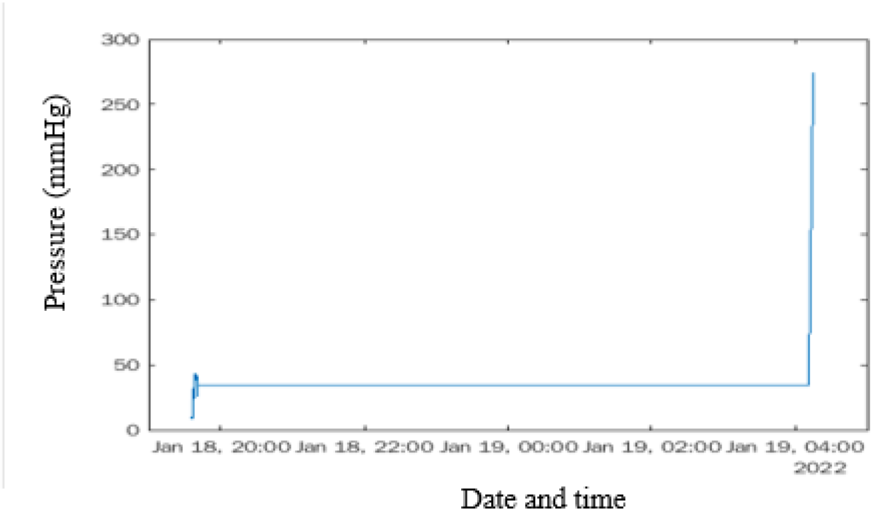


Figure 10: Contact pressure measurement on MATLAB software

4. Conclusion

This project proposed a design method for measuring Capillary Refill Time (CRT) and contact pressure simultaneously using plastic optical fibre. The LED light source and photodiode circuit were successfully developed to measure the light intensity. The results show that the resistance has an impact on the light intensity. Reducing the transmitter circuit's resistance will increase the voltage, thus increasing the light intensity. Meanwhile, the flexible tube can be used as a pressure sensor and improve the CRT measurement accuracy. The volunteer arm experiment shows that POF pressure sensors voltage increase as the cuff pressure rises. The pressure signals can be sent to the Thingspeak apps and visualized through Matlab software for further analysis. In future, the CRT measurement with the applied pressure will be analyzed through this system.

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