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Capillary Refill Time Monitoring System using Optical Fibre Sensor

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Abstract: Capillary Refill Time (CRT) assessment in healthcare plays a crucial role in evaluating perfusion and guiding treatment decisions. However, manual observation and subjective estimation of CRT using traditional counting methods are prone to human errors. Additionally, the lack of standardized blanching maneuvers further compromises measurement reliability. To address these challenges, an Optical Fibre Sensor integrated with a Force Sensitive Resistor (FSR) sensor was developed. The system employed an LED, photodetector, and Arduino Uno microcontroller for real-time data acquisition, while MATLAB processed and stored the data in Microsoft Excel. The experiment involved two conditions: one using a pulse sensor and the other utilizing the fibre optic connection, with a consistent group of 10 volunteers. The result demonstrates that the capillary refill time on the subjects for fibre optic was 0.65±0.14s (mean and standard deviation) compared to pulse sensor which is 1.38±0.46s. These results clearly demonstrate that the fibre optic connection yielded improved measurements for capillary refill time and exhibited greater consistency and precision compared to the pulse sensor. The integration of the Optical Fibre Sensor with FSR sensor enhances CRT measurement reliability, offering potential benefits in assessing tissue perfusion accurately and consistently. These findings contribute to advancing patient care and guiding appropriate treatment interventions based on reliable CRT measurements.

Keywords: Capillary Refill Time, Optical Fibre Sensor, Force Sensitive Resistor

1. Introduction

Capillary refill time (CRT) is the time it takes for a distal capillary bed to restore its colour following blanching produced by externally applied pressure. This test is extensively used in clinical care as a simple way of cardiovascular evaluation, and it has been recommended as a tool for the clinical assessment of peripheral macrovascular illness and cutaneous microvascular disease [1]. There is currently not properly defined and accepted procedure for measuring CRT [2]. The most popular way of measuring CRT is to manually record the time it takes for the skin to restore its colour after blanching [3,4]. Typically, the testing location is positioned near to the toenail or fingernail [5]. The results are

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likely to be unreliable and inaccurate because the most common method of calculating CRT is highly observer-dependent and affected by skin temperature, with a lack of standardisation of the actual blanching manoeuvre (e.g., pressure strength: light, moderate, or firm; pressure duration: 3 s, 5 s, or until the capillary bed visually blanches) [6-9].

Besides, this capillary refill time will detect the shock in patients suffering from life-threatening diseases or traumas. This capillary test will be necessary if the patient is suffering from or is in risk of suffering from shock because of Anaphylaxis, Dehydration, Hemorrhage, Hyperthermia (excessive body heat), Hypothermia (decreased body temperature), and serious burns [10]. This capillary refill test may be conducted when a person becomes medically unstable, such as disorientation or strange behaviour, chilly hands, arms, legs, or feet, dangerously low or high vital signs (blood pressure, pulse, breathing rate, and temperature), or loss of consciousness [10]. Aside from that, covert compensated shock is difficult to detect since it lacks traditional shock symptoms such as hypotension, rapid pulse, oliguria, hyperlactacidemia, and hemodynamic abnormalities [11]. If doctors do not recognise the shock in time, their patients with acute severe shock will die.

One study has been conducted using plastic optical fibre pressure sensor embedded in mattress for vital signal monitoring [12]. This development constructs a low-cost plastic optical fibre (POF) pressure sensor for monitoring vital signals. This test employs one static and two dynamic tests to evaluate sensor performance. The first static test was performed by applying weights ranging from 0-500 g (0-4.9 N) with a step of 100 g (force = 0.98 N) to the matrix's sensitive spots. The second test is a dynamic test in which a force step stimulus was provided to a location on the mattress sensor. The third test is a cyclic loading test. The force was delivered to four separate sites for the static testing, and the charge cycles were repeated three times. The results show that the sensor can detect human breathing movement in contact with the mattress sensor.

In this work, to measure the CRT, the POF and an FSR pressure sensor will be employed to detect the reflectance PPG (photoplethysmography) signal and the blanching pressure. This sensor is utilized to concurrently monitor the reflectance signals and the applied pressure signals to give a novel technique of monitoring CRT. The FSR sensor can detect a wide range of pressure from very light touch to higher force application and is better suited for measurements of skin contact.

2. Materials and Methods

Figure 1 depicts the block diagram of the proposed system. The FSR sensor responds to applied pressure, and the measurement results are utilized for calibration purposes. For Capillary Refill Time (CRT) measurement, the POF light source illuminates the fingertip area, and the photosensor monitors the intensity of the reflected light. As pressure is applied, the light intensity changes due to color variations in the skin region. The signals are then transmitted to the Arduino kit, and the data is subsequently sent to MATLAB. The MATLAB program evaluates the CRT signal corresponding to the contact pressure on the fingertip. Finally, the CRT data is saved in an Excel file.

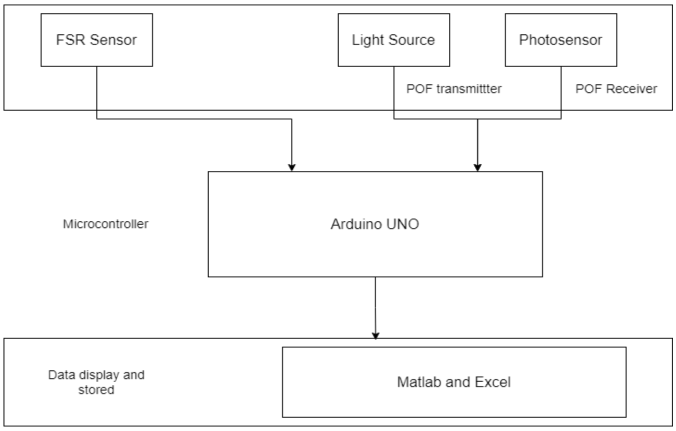

Figure 1: Block diagram Capillary Refill Time (CRT)

A prototype of the capillary refill time system was created to get data from the receiver and transmit it to MATLAB. It can also analyse the CRT signal associated with the touch pressure applied to the fingertip. The operational flow of the system is shown in Figure 2.

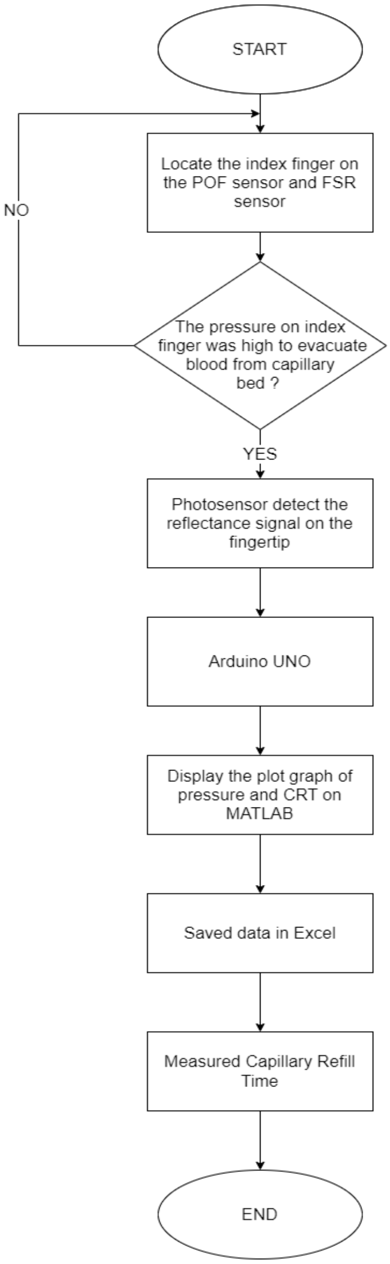

Figure 2: Operational flow of Capillary Refill Time (CRT)

2.3 Monitoring system of capillary refill time (CRT) design

The Figure 3 illustrates the design of the Capillary Refill Time (CRT) monitoring system. The system incorporates a Green LED, which emits light directed towards the plastic optical fibre (POF). The POF is responsible for receiving and reflecting the transmitted light. The reflected light is then captured and monitored by a photodiode. To measure the pressure applied to the fingertip area, an FSR sensor is positioned beneath the POF. The FSR sensor can detect a range of pressures exerted on the skin. As pressure is applied, the corresponding region experiences a change in colour, leading to variations in the intensity of the reflected light. These variations in light intensity serve as indicators of the applied pressure. The signals obtained from both the photodiode and the FSR sensor are sent to an

Arduino for processing. The Arduino acts as the central controller, receiving and analysing the data from the sensors. The processed data is then transmitted to a computer for further analysis of the CRT signal associated with fingertip contact pressure.

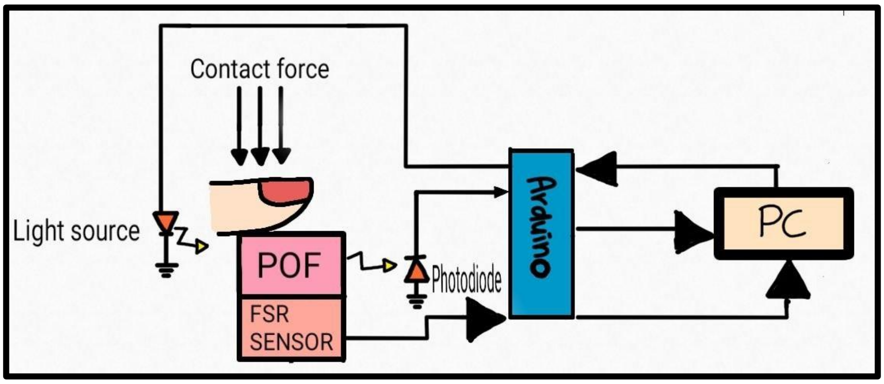

Figure 3: Monitoring system of capillary refill time (CRT) design

2.4 The design of Plastic Optical Fibre (POF) Sensors

For the connection of plastic optical fibres (POFs), adhesive was used to securely attach them. The CRT system incorporated six POFs, each with a 20 cm diameter, enabling effective transmission and reception of light. To enhance light transfer, the 20 cm POFs were cut at a 45° angle, facilitating efficient reflection of the transmitted light. Positioned on the patient's fingertip, the sensor design, as shown in Figure 4, included transmitter sensors (T1) responsible for emitting light onto the skin, and receiver sensors (R1 and R2) capturing the reflected light. This configuration enabled monitoring of variations in light intensity, providing valuable insights into the capillary refill process.

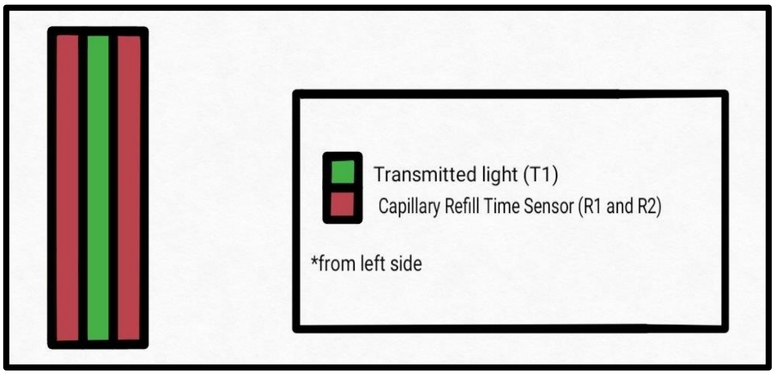

Figure 4: The design of POF for capillary refill time measurement

3. Results and Discussion

Capillary Refill Time (CRT) is determined by the time taken for capillaries to refill with blood after pressure is applied and released. Two experiments using pulse sensor and POF were utilized to measure reflected light intensity, indicating changes in tissue absorption, and an FSR sensor to record contact pressure and determine the moment of pressure release for CRT calculation. Ten volunteers participated by placing their finger on both sensors and applying sufficient pressure to evacuate blood from the capillary bed. The pulse sensor or POF captured photoplethysmography waveform, reflecting blood volume variations, while the FSR sensor measured contact pressure, enabling precise timing analysis.

3.1 Capillary Refill Time and Pressure monitoring using Pulse Sensor and FSR Sensor

The pressure and photodetector plots were based on Figure 5. During manual pressure application on the Plastic Optical Fiber (POF), the FSR sensor exhibited instability between 6.13 to 14.92 seconds. Capillary refill time was calculated by measuring the time difference between the stronger pulse signal from the photodetector graph and pressure release indicated in the pressure graph. The data revealed a capillary refill time of 1.11 seconds, falling within the normal range and considered positive. interpretation of the findings.

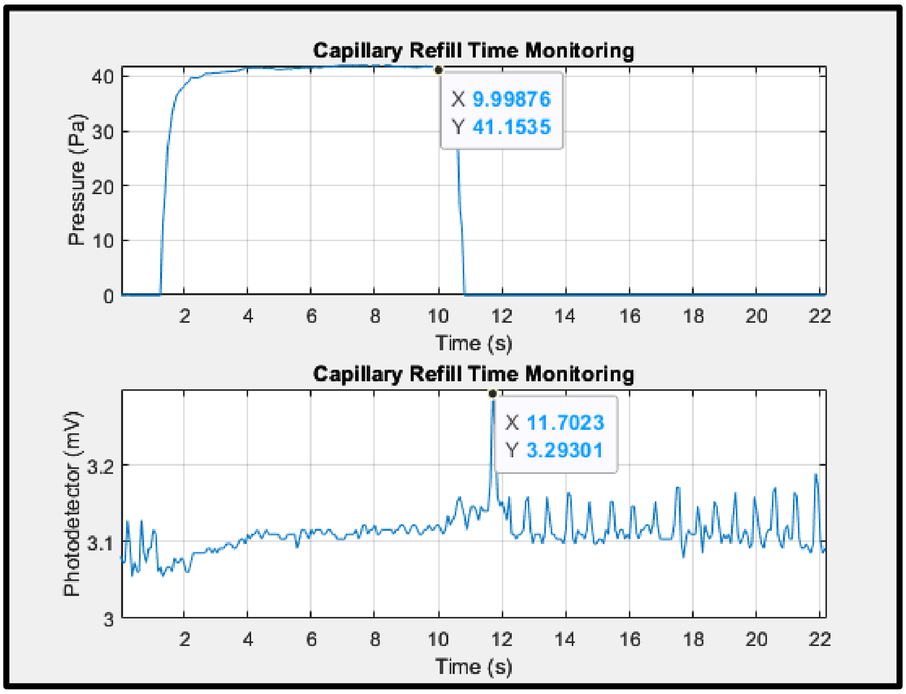

Figure 5: The plotted of pressure and photodetector to measure the capillary refill time and blanching pressure

Figure 6 demonstrates the relationship between standard deviation and capillary refill time. Table 1 provides a summary of the capillary refill time responses for all 10 volunteers. Each volunteer underwent the blanching process five times, resulting in 50 capillary refill datasets. A higher standard deviation indicates a wider range or greater inconsistency in capillary refill time measurements, suggesting fluctuations in the data. Conversely, a lower standard deviation signifies more uniformity or stability in the measurements.

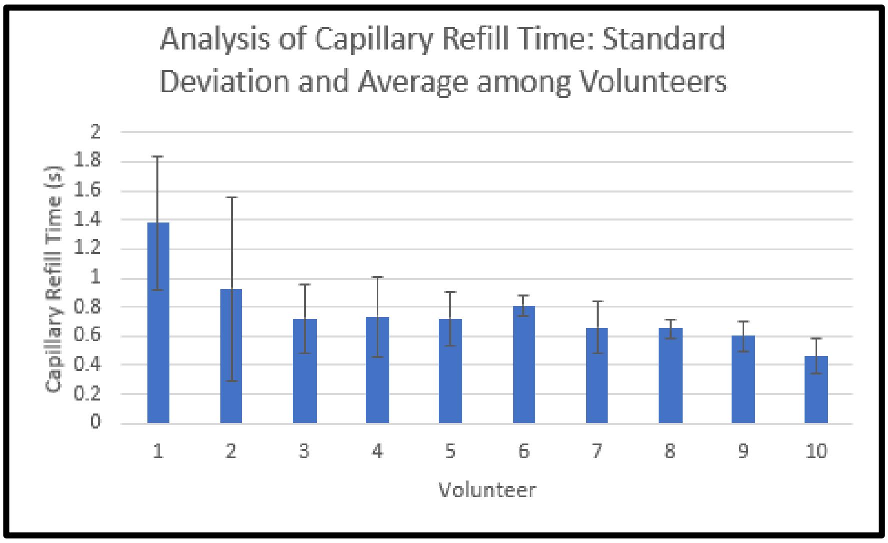

Figure 6: The average CRT and the corresponding standard deviation for CRT measurement using pulse sensor

Table 1: The capillary refill time responses for 10 volunteers using pulse sensor.

Volunteer	CRT 1 (s)	CRT 2 (s)	CRT 3 (s)	CRT 4 (s)	CRT 5 (s)	Average CRT	Standard deviation of CRT
1	1.4671	1.4501	1.9435	0.6704	1.3646	1.37914	0.456562781
2	0.5789	0.814	1.7035	0.1314	1.4134	0.92824	0.633729337
3	0.6341	0.8946	0.4193	0.6279	1.0256	0.7203	0.239873811
4	0.3803	0.8249	1.1276	0.7032	0.6261	0.73242	0.27425628
5	0.9509	0.5622	0.6349	0.5637	0.8941	0.72116	0.187210732
6	0.8885	0.8196	0.6951	0.8333	0.8254	0.81238	0.071077683
7	0.5086	0.7008	0.8905	0.759	0.44316	0.660412	0.183396147
8	0.7616	0.5767	0.6375	0.6375	0.6401	0.65068	0.067519716
9	0.6311	0.7644	0.5141	0.5748	0.5051	0.5979	0.106057037
10	0.3787	0.5263	0.3775	0.6408	0.3785	0.46036	0.119521831

3.2 Capillary Refill Time and Pressure monitoring through POF condition

The capillary refill time monitoring utilizing fiber optics was assessed on a consistent sample of 10 participants. The pressure and photodetector plots were based on Figure 7. During manual pressure application on the Plastic Optical Fiber (POF), the FSR sensor exhibited instability between 6.13 to 14.92 seconds. Capillary refill time was calculated by measuring the time difference between the stronger pulse signal from the photodetector graph and pressure release indicated in the pressure graph. The data revealed a capillary refill time of 1.11 seconds, falling within the normal range and considered positive.

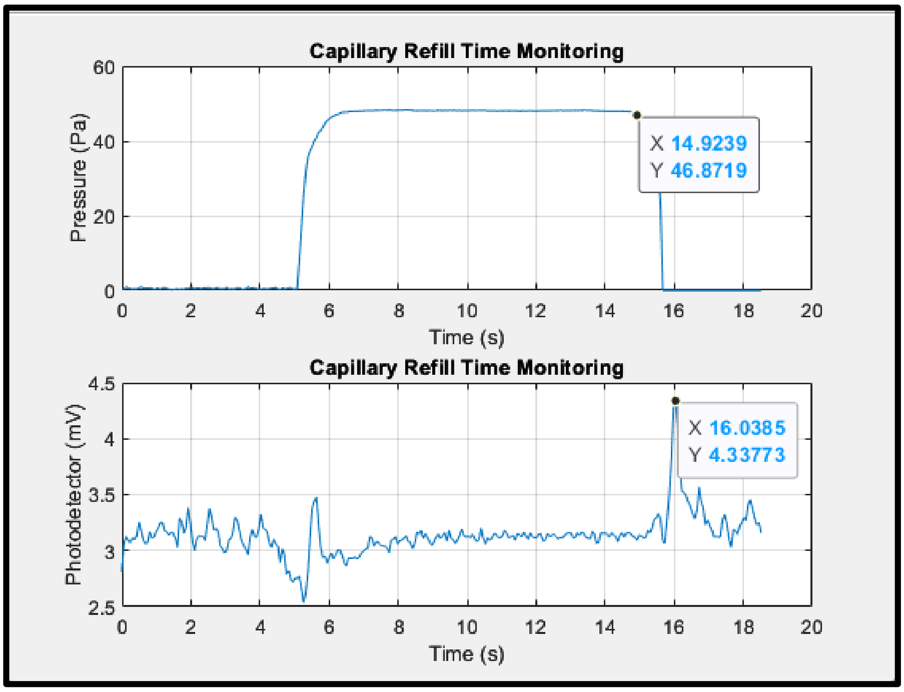

Figure 7: The plotted of graph of capillary refill time using POF

Table 2 summarized capillary refill time responses for all 10 volunteers using POF. Each volunteer underwent the blanching process five times, resulting in 50 capillary refill datasets. All volunteers demonstrated capillary refill times within the normal range, indicating positive results. Figure 8 depict A higher standard deviation indicates wider spread and inconsistency, reflecting significant variations and fluctuations. A lower standard deviation suggests uniformity and stability, with less variability among data points, providing insights into dispersion and consistency in capillary refill time data.

Table 2: The capillary refill time responses for 10 volunteers using POF

volunteer (POF)	CRT POF (1)	CRT POF (2)	CRT POF (3)	CRT POF (4)	CRT POF (5)	Average CRT	Standard deviation of CRT
1	0.7471	0.6379	0.4789	0.8282	0.5747	0.65336	0.138038864
2	1.1146	0.7740	0.4493	0.3798	0.4494	0.63342	0.309589877
3	0.4531	0.3238	0.6456	0.7099	0.8315	0.59278	0.203319347
4	0.6380	0.5142	0.4497	0.5123	0.4518	0.5132	0.076451063
5	0.4546	0.5168	0.5765	0.9650	0.3844	0.57946	0.227054262
6	0.5785	0.3815	0.2594	0.39	0.5128	0.42444	0.124308218
7	0.3811	0.5758	0.3226	0.3197	0.3225	0.38434	0.110092884
8	0.3870	0.3232	0.5185	0.5178	0.3195	0.4132	0.099492939
9	0.3260	0.4519	0.2678	0.5779	0.6376	0.45224	0.158195711
10	0.2597	0.3794	0.2557	0.1932	0.5108	0.31976	0.126275029

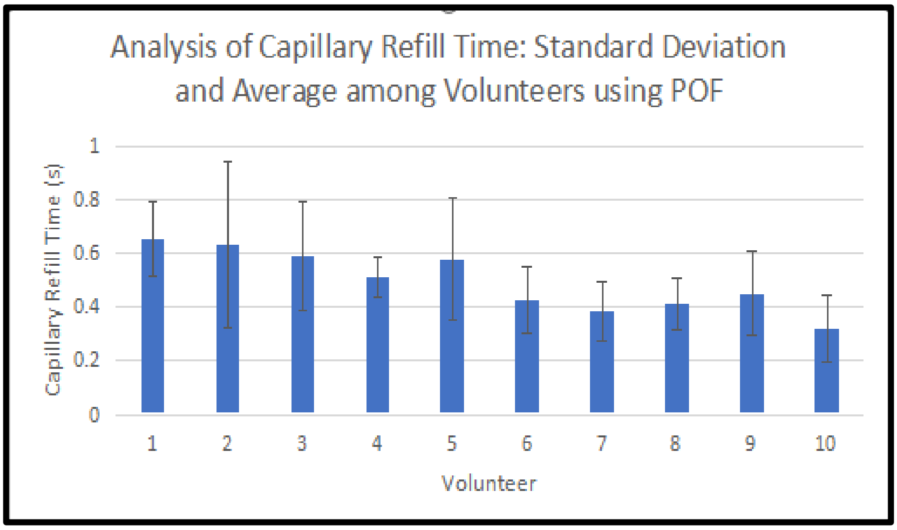

Figure 8: The average CRT and the corresponding standard deviation for CRT measurement

3.3 Comparison Capillary Refill Time measurement dataset using the pulse sensor and POF

Based on figure 9, the data obtained for capillary refill time using a pulse sensor directly and through a fiber optic connection were analyzed. The data acquired through the fiber optic connection exhibited a lower average and smaller standard deviation compared to the data from the pulse sensor. A lower average indicates a potentially shorter capillary refill time, while a smaller standard deviation suggests greater consistency in the measurements. Therefore, the data obtained through the fiber optic connection is considered more favorable, indicating a potentially shorter capillary refill time and higher precision in the measurements.

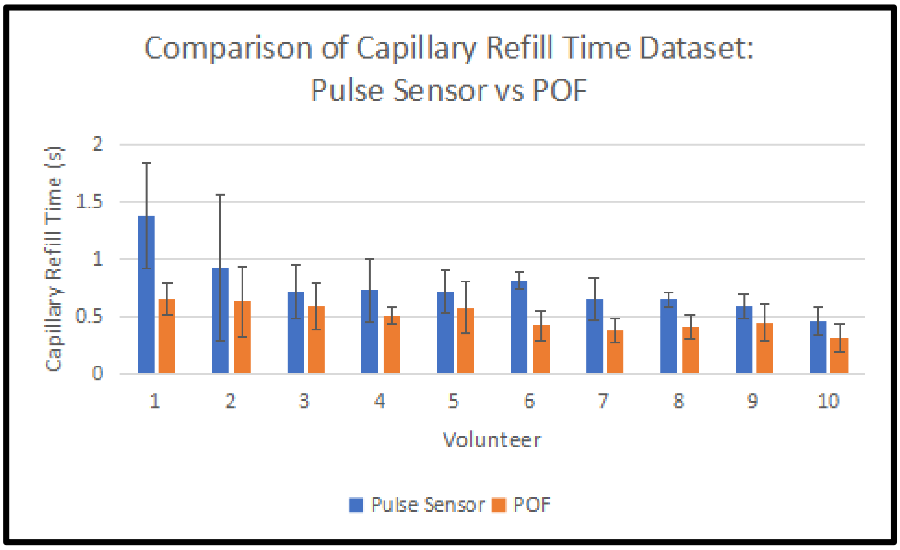

Figure 9: Comparison of Capillary Refill Time Dataset

4. Conclusion

The integration of a POF (Plastic Optical Fiber) sensor with an FSR (Force-Sensing Resistor) sensor proved to be promising in enhancing Capillary Refill Time (CRT) measurements. Through two separate experiments involving 10 healthy volunteers and a total of 50 capillary refill datasets, it was observed that all volunteers had capillary refill times within the normal range, indicating sufficient peripheral perfusion and blood flow. A comparison between the POF sensor connection and direct pulse sensor measurement showed superior performance with the POF connection, resulting in quicker capillary refill times. The POF sensor facilitated efficient light transmission, leading to more precise measurements, while also providing a more stable and consistent signal. This advancement holds potential for improved healthcare monitoring.

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