Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Finger Clip Blood Pressure Measurement using Photoplethysmogram (PPG) and Biometrics Technology

Franchesca Julia Hannah S. Jurado, Jose Victor S. Virata, Jennifer C. Dela Cruz

School of Electrical, Electronics, and Communication Engineering, Mapua University, Manila, Philippines
Email: fjhsjurado@mymail.mapua.edu.ph

This study explores the development and validation of a finger clip blood pressure measurement device utilizing Photoplethysmogram (PPG) and biometric technology, aimed at providing a more suitable alternative for children. The finger clip device integrates optical and biometric sensors, transmitting data to a smartphone app for continuous health monitoring. Methodologically, the research involves integrating these sensors into a portable prototype, processing collected data, and comparing results with conventional cuff-based devices. Testing with pediatric participants reveals the finger clip device's superior accuracy and comfort. Statistical analysis shows a significant correlation between the new device's readings and traditional methods, showing a 99.999995% accuracy rate for systolic and 99.9999975% for diastolic measurements. The findings suggest that this innovative approach not only enhances measurement accuracy but also offers a more patient-friendly solution for pediatric blood pressure monitoring.

Keywords: blood pressure, Photoplethysmogram, biometrics, biometric technology, health IoT applications.

1. Introduction

The primary tool to measure blood pressure is the sphygmomanometer, which comes in two main types: manual/aneroid and digital versions. While these devices are commonly found in hospitals and clinics, recent technological advancements have introduced electronic devices with built-in blood pressure monitors. Monitoring blood pressure is vital for all age groups, but traditional devices may not be suitable for infants and young children due to their size and the level of pressure applied. Consequently, this study focuses on building a more appropriate design of blood pressure device for children.

Studies have shown that besides the oscillometric method, blood pressure can be measured using pulse oximetry waveforms or Photoplethysmogram (PPG) sensors [1]. According to Hosanee's research, PPG records volumetric blood pulsations in tissue, correlating with arterial pressure pulse [2]. Biometric sensors, employing technologies like infrared light and pressure sensors, provide non-intrusive vital signs monitoring. Integrated into portable devices, they enable continuous health monitoring, facilitating seamless data collection [3]. The determination of blood pressure through an optical biometric sensor leverages advanced signal characterization technology. This method distinctively filters out pulsatile blood flow data from background noise for precise analysis [4]. Maxim Integrated's sensor, meeting regulatory standards, exhibits an average systolic error of 1.7 mmHg and a diastolic error of 0.1 mmHg, necessitating variability improvement [5]. Research confirms that biometric sensors, particularly when combined with PPG, effectively capture and transmit real-time blood pressure data [5]. Additionally, they proficiently capture physiological signals, enhancing blood pressure measurement accuracy when integrated with PPG technology [6].

The utilization of PPG sensors is highly significant; however, these sensors do not directly measure "pressure" but instead analyze pulse waves, without providing the exact blood pressure reading. Notably, the effectiveness of PPG technology in children is yet to be sufficiently validated, as most studies have primarily focused on adults. While most commercial blood pressure devices incorporate one or two PPG sensors, achieving accurate measurements in infants and children poses a challenge. Moreover, the conventional method of blood pressure measurement is not always suitable for infants and children, and may yield inaccurate results.

This study primarily aims on developing a finger clip device for blood pressure measurement by utilizing PPG and biometric technology. The specific objectives are to: (1) develop a compact prototype that combines optical and biometric sensors with a smartphone app, (2) employ signal processing techniques for the gathered data, (3) evaluate the device's effectiveness in acquiring blood pressure readings from children, and (4) compare the accuracy of the proposed device with traditional cuff-based measurements.

This device aims to significantly measure and monitor a child's blood pressure without the need for a cuff, recording data after each use via a smartphone app. Its finger clip design ensures convenience and user-friendliness. Additionally, this study will assist future researchers in developing or enhancing blood pressure devices with advanced technology

The primary point of this study is to create a cuffless blood pressure device for children, utilizing PPG and biometric technology to ensure precise measurements. The focus is on evaluating the device's efficacy through the use of fingertip sensors in pediatric patients. Testing will be conducted with the full consent of participants in a controlled setting. The data collected will solely consist of blood pressure readings and will not include any formal medical assessments.

2. Review of Related Literature

A. Photoplethysmography (PPG)

Utilizing photoplethysmography (PPG), pulse oximeters assess oxygen saturation and cardiovascular rates by detecting variations in light absorption by hemoglobin, depending on its oxygenation state [9]. The finger clip, sized 3.45 cm in width, 5.84 cm in height, and 3.30 cm in depth, fits finger widths of 0.3 to 1.0 inches, making it versatile for both children and adults [10].

B. Fingerprint Recognition

A blood pressure measurement using a fingertip device offers a rapid response and does not require medical instruments inside the body for assessing and monitoring blood pressure [7]. The device was tested on 26 individuals, achieving a 90% accuracy for systolic and 63% for diastolic blood pressure measurements [8].

C. Relation of Biometric to Blood Pressure

Espina's study identified the most accurate estimate of systolic blood pressure through various calibrations, as illustrated in (1). In this equation, L represents the biometric measurement, A denotes sensitivity coefficient, and B stands as a fixed quantity. The sensitivity factor applies universally to all healthy individuals, while the constant value is individually adjusted based on measurements of systolic blood pressure and pulse arrival time [6].

$$\mathrm{SBP} = \mathrm{A}\frac{\mathrm{L}}{\mathrm{PAT}} + \mathrm{B} \quad (1)$$

D. Comparison between PPG and Biometric Sensors

A new study has unveiled a small Body Sensor Network (BSN) designed for ongoing cuffless blood pressure tracking. This system calculates blood pressure levels by examining Pulse Arrival Time (PAT) through a single-lead ECG and a PPG sensor [6].

E. Smart Medical Devices

Innovative healthcare technologies embrace the latest in information technology, like IoT, cloud services, and Artificial Intelligence, to enhance the existing medical system, thus rendering healthcare more efficient, convenient, and accessible in the contemporary world [11]. Medical professionals can track patients and administer more tailored treatment by employing IoT wearable devices. The ability to continuously monitor patients with IoT could significantly enhance the quality of care and healthcare operations [12].

3. Methodology

The chapter primarily outlines the prototype design and capabilities of the finger clip blood pressure device, including its hardware components and analytical methods used in constructing the device to achieve its integrated functions. The methodology focuses on the conceptual framework, system process flow, and configuration of the finger clip blood pressure device.

A. Conceptual Framework

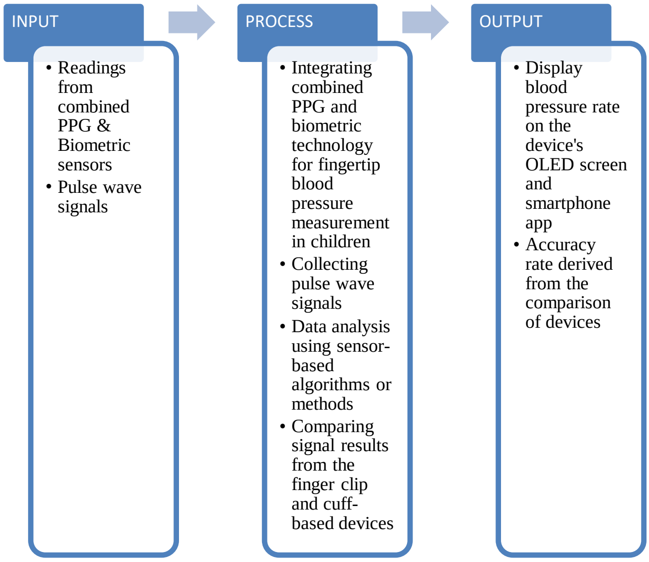

Fig. 1. Conceptual Framework

Fig. 1 illustrates the input, process, and output of the system. The system requires inputs such as PPG and biometric sensors, as well as the pulse wave signals measured by both sensors. The system's process involves four procedures: (1) Integrating the combined PPG and biometric system techniques to measure blood pressure through the child's fingertips, (2) Collecting data signals, (3) Analyzing the data, and (4) Comparing the signal results obtained from the finger clip device and cuff-based device. Finally, significant blood pressure results will be displayed on the OLED display screen of the device and the smartphone application. Moreover, accuracy rates derived from the comparison of devices shall be obtained.

B. System Process Flow

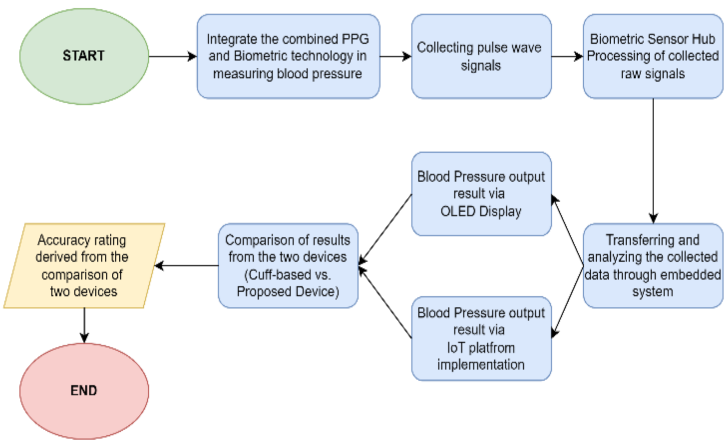

Fig. 2. System Process Flow Diagram

The system process shown in Fig. 2 involves evaluating the accuracy of blood pressure measurements by comparing the results obtained from a finger clip device and a cuff-based device. Initially, PPG and biometric technology are integrated for measurement. Pulse wave signals are then collected and analyzed using an embedded platform and discrete methods. The MAX32664 uses a built-in algorithm for digital filtering, compensation, wave detection, and auto gain control to measure blood pressure, displaying systolic and diastolic readings on a finger clip device's OLED display and through an IoT Android application. Finally, the accuracy of the results from both the finger clip and cuff-based devices is compared.

C. Block Diagram

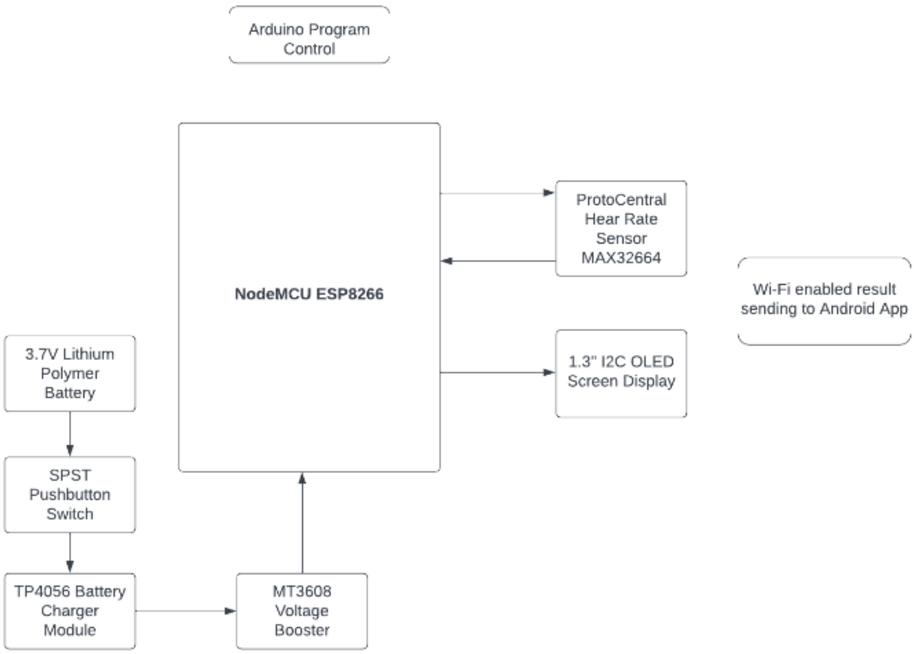

Fig. 3. Block Diagram of the Proposed Device

Fig. 3 demonstrates the component connections for the proposed device. PPG and biometric sensors are linked to a photodetector for optimal light selection. The system is powered by a 9V battery connected through a voltage regulator. All components, including the power supply and sensors, are connected to the microcontroller. The NodeMCU ESP8266 processes and analyzes data, which is then displayed on an OLED screen. An IoT platform enables access to and control of the device via a smartphone application.

D. Schematic Diagram

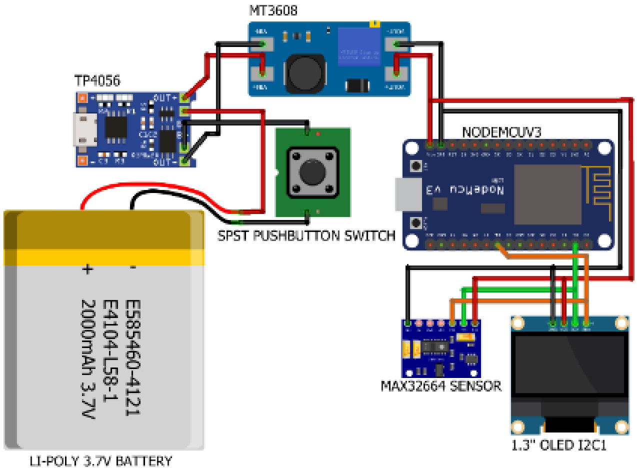

Fig. 4. Schematic Diagram

The circuit represented in Fig. 4 is based on the NodeMCUv3 environment, with I2C protocol connecting components to designated pins. A 3.7V Lithium-Polymer Battery powers the circuit, regulated by a TP4056 Battery Charging Management Board. The voltage is stepped up to 5V using an MT3608 and supplied to the NodeMCUv3, with other components connected to this power level. A Single Pole Single Throw Pushbutton Switch controls power. The MAX32664 biometric sensor integrates with the MAX30101 PPG sensor for measuring heart rate and blood pressure, with power and ground connections to the microcontroller. Communication lines (I2C) are established between the sensor and other components. Wi-Fi connectivity for IoT functionality is also ensured. Pin connections are carefully configured for correct system operation.

E. Prototype Design

Fig. 5. Prototype Design

Fig. 5 depicts the prototype design of the Finger Clip BP Device using PPG & Biometric Technology. Based on a standard finger clip pulse oximeter design, it significantly differs in function. The design includes device dimensions (73mm length, 43mm width, 35mm height) suitable for infants, children, and adults. Features comprise a storage compartment for a rechargeable battery, a power button for device control, and a USB Micro-B connector for charging and data transfer. The OLED display presents systolic and diastolic blood pressure, as well as heart rate measurements. The design aims for a casing suitable for children yet appropriate for adults if needed.

F. Data Analysis

After signal processing, the processed signals become explanatory variables, while reference blood pressure serves as the objective variable. Statistical or machine learning models establish the relationship between features and blood pressure. Principal component analysis extracts PLS factors from pulse wave signals, with the highest PLS factor point tested at a 5% significance level. Blood pressure is calculated using the PLSR approach with Arduino IDE software. As presented in (2), SEC is obtained from the standard deviation of the difference between reference and estimated blood pressure, while SEP is derived from blood pressure calculation using the calibration curve.

$$\mathrm{SEC} = \sigma(\mathrm{BP_{ref}} - \mathrm{BP_{est}}) \tag{2}$$

G. Data Gathering

Testing of the proposed device will commence with 30 selected children. Blood pressure and heart rate of children will be measured using a new finger clip device and compared with a traditional cuff device. Each subject will undergo testing with both devices, comprising 5 trials for calibration curve determination and sensor efficiency verification. Anticipated calibration results will be compared between the proposed device and the pulse oximeter.

H. Statistical Tools

All gathered data will be compared using paired t-tests, which can be conducted through mathematical software such as MS Excel with a statistical significance of $p < 0.05$. This is done to reject the null hypothesis, aiming to demonstrate that the proposed device is superior in obtaining blood pressure measurements of children compared to the standard cuff-based device. Obtaining the accuracy rate percentage is crucial for validating the accuracy of the finger clip BP device compared to the cuff-based BP device. Accuracy percentage can be acquired by using the equation shown in (3). It provides objective evidence of the device's performance, guides clinical decision-making, ensures quality assurance, and ultimately enhances patient safety and care.

$$\text{Accuracy (\%)} = (1 - \mathrm{p}) * 100$$

The Pearson correlation method will be used to assess the relationship between variables. The Pearson correlation coefficient, denoted by (r), spans from -1 to 1. Values near 1 signify a robust positive correlation, those approaching -1 denote a strong negative correlation, and values around 0 imply little to no linear relationship. Correlation results aligned with expectations support the validity of the results. SEC is determined by calculating the standard deviation of the differences between the reference and estimated blood pressure values obtained through calibration. A lower SEC indicates a more precise calibration process.

4. Results and Discussion

This chapter outlines each testing procedure conducted with the prototype, along with the resulting findings. In terms of its capabilities, the results demonstrate the reliability and effectiveness of the finger clip blood pressure device for use with children compared to the traditional cuff-based device.

A. Actual Prototype Design

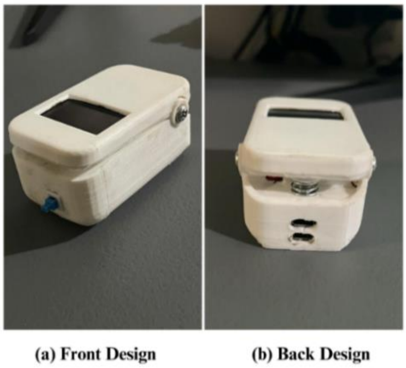

Fig. 6. Actual Finger Clip Blood Pressure Device integrated with PPG and Biometrics Technology

Fig. 6 displays the front and back designs of the finger clip blood pressure device, integrating PPG and Biometrics technology. The left image shows the device's front when off, featuring a blue push button below the OLED display, which serves as the main switch. On the right, the back design includes USB Micro-B connectors for charging and data transfer. While Fig. 7 proves that when the device is on, it shows parameters like systolic and diastolic BP measurements and heart rate on the screen. A battery level indicator is also present. The connected "Heart Care" smartphone app, as presented in Fig. 8, displays the same values as the device, along with a waveform sketch illustrating signal curves.

Fig. 7. Finger clip Blood Pressure Device (sample when turned ON)

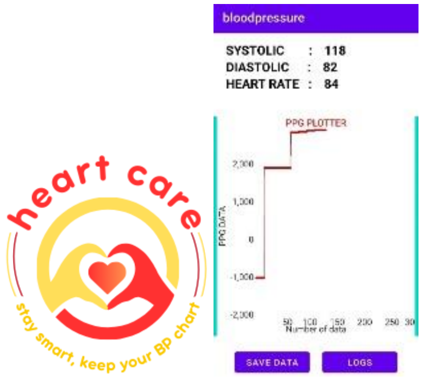

Fig. 8. Heart Care Smartphone Application

B. Data Collection and Processing

There is a sequence of stages in signal processing within the system to further obtain blood pressure results at the end using the combined optical and biometric technology in MAX32664 sensor. Fig. 9 depicts the initial photoplethysmogram (PPG) signal or raw signal recorded by the sensor labeled MAX32664. The waveform displays a fluctuating signal with notable amplitude variations, representing the unprocessed data acquired from the sensor.

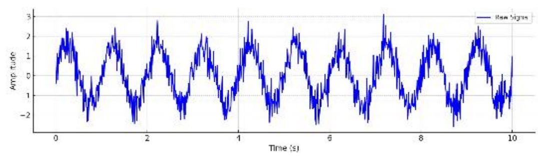

Fig. 9. Raw Signal

In Fig. 10, the filtered signal (green) is overlaid on the raw signal (light blue), showing a cleaner and more distinguishable waveform which retains the essential physiological information.

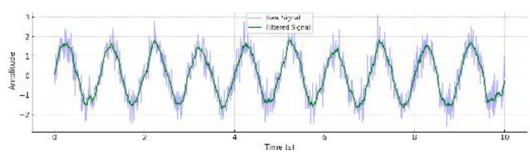

Fig. 10. Digital Filtering

Advanced wave detection shown in Fig. 11, includes the identification of crucial points in the PPG signal, such as systolic peaks and diastolic troughs. For the final step of signal processing, this stage involves applying mathematical and computational techniques to the extracted features to derive meaningful data. This final stage is represented in Fig. 12. One approach is the Partial Least Squares Regression (PLSR) method, which helps in simulating the relationship between the identified features and the BP values.

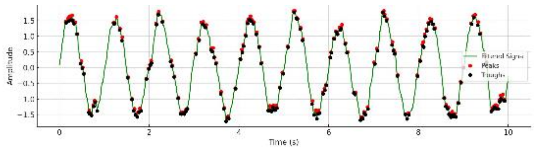

Fig. 11. Advanced Wave Detection

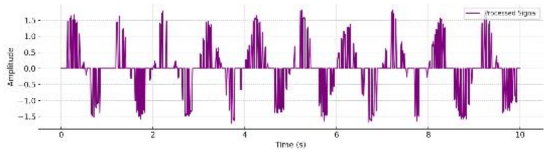

Fig. 12. Final Data Processing via PLSR method

C. Calibration Results

Referring in Fig. 13, the left waveform represents the calibration curve of measured systolic blood pressure values from 15 subjects, while the right waveform represents the calibration curve for diastolic blood pressure from the same subjects. These values are in reference to the normal blood pressure range for 3-7 years old children.

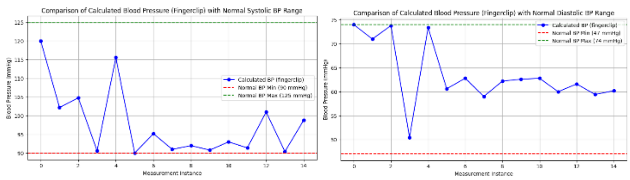

Fig. 13. Comparison Curve

D. Statistical Results

1) Systolic BP Measurements of the Standard Device and Finger clip Device

TABLE I. SYSTOLIC BP MEASUREMENTS OF THE STANDARD DEVICE AND FINGER CLIP DEVICE

	Cuff-based Device	Finger clip Device
Mean	66.56	98.61
Standard Deviation	8.90	5.76
T-statistics	10.53	
p-value (whereas p < 0.05)	0.00000005	

In Table I, standard deviations indicate variability: 8.90 for the cuff-based device and 5.76 for the finger clip device. A t-statistic of 10.53 and a p-value of 0.00000005 (less than 0.05) indicate a significant difference between the devices, leading to the rejection of the null hypothesis. A figure illustrates this comparison. The accuracy percentage, calculated from the p-value, is 99.999995%, demonstrating the precision and reliability of the finger clip device in measuring systolic blood pressure.

2) Diastolic BP Measurements of the Standard Device and Finger clip Device

TABLE II. DIASTOLIC BP MEASUREMENTS OF THE STANDARD DEVICE AND FINGER CLIP DEVICE

	Cuff-based Device	Finger clip Device
Mean	38.24	65.65
Standard Deviation	7.49	4.21
T-statistics	11.12	
p-value (whereas p < 0.05)	0.000000025	

The standard deviation is higher for the cuff-based device (7.49) compared to the finger clip device (4.21), indicating more variability as proven in Table II. A T-statistic of 11.12 and a p-value of 0.000000025 highlight significant differences between the devices. The accuracy rate of the finger clip device is 99.9999975%, showing its exceptional precision in measuring diastolic blood pressure in children compared to the conventional cuff-based device.

3) Heart Rate Measurements of the Standard Device and Finger clip Device

TABLE III. HEART RATE MEASUREMENTS OF THE STANDARD DEVICE AND FINGER CLIP DEVICE

	Cuff-based Device	Finger clip Device
Mean	90.28	92.61
Standard Deviation	10.70	4.12
T-statistics	0.84	
p-value (whereas p < 0.05)	0.4	

With a T-statistic of 0.84 and a p-value of 0.4, the data presented in Table III indicates that there is no substantial difference between the two devices in measuring heart rate. This indicates that both devices are accurate and reliable. Because the p-value exceeds 0.05, determining the accuracy rate is not meaningful, as there is no significant difference in heart rate measurements between the devices.

4) Relationship Assessment using Pearson Correlation

TABLE IV. PEARSON CORRELATION ASSESSMENT

Parameter	Method	Pearson Correlation, r
Systolic	Cuff-based Finger clip	-0.3
Diastolic	Cuff-based Finger clip	0.02
Heart Rate	Cuff-based Finger clip	0.5

As shown in Table IV, systolic blood pressure shows a weak negative correlation with -0.3, suggesting a slight decrease in one device's measurements when the other's increase. The diastolic pressure shows a negligible positive correlation of 0.02, suggesting minimal correlation between the devices. However, heart rate demonstrates a moderate positive correlation of 0.5 implying a more substantial relationship between the measurements. This underscores differences between the two devices in testing children, despite both yielding positive results.

5) Standard Error for Validation

TABLE V. STANDARD ERROR FOR VALIDATION

	Standard Error
Systolic Blood Pressure	3.14
Diastolic Blood Pressure	3.28

These low and similar standard errors in Table V suggest the reliability and reproducibility of the finger clip device's readings compared to the cuff-based method, particularly for children. This is critical in pediatric care, where accurate blood pressure measurements are vital for diagnosis and treatment. Therefore, the data implies that the proposed finger clip device is both accurate and precise for measuring blood pressure in children, offering a potentially more convenient alternative to traditional cuff-based devices.

5. Conclusion and Recommendations

Fig. 14. Actual Testing Setup

The study successfully developed a finger clip device for blood pressure measurement using PPG and Biometric technology, creating a portable prototype with optical and biometric sensors integrated with a smartphone app. Testing on children demonstrated the device's comfort, consistency, appropriateness, and accuracy compared to standard cuff-based devices. Statistical analyses showed significant differences in systolic and diastolic blood pressure measurements, with high accuracy rates of 99.999995% and 99.9999975%, respectively. The finger clip device offers a precise, non-invasive, and comfortable alternative to conventional methods, with potential for widespread use in portable and non-invasive blood pressure monitoring. The actual testing setup done during data gathering can be seen in Fig. 14.

For future work, refining signal processing algorithms, increasing the sample size, and including diverse age groups could improve the device's accuracy and usefulness. Despite challenges, this research represents a significant advancement in healthcare technology, with potential for further innovation in diagnostics.

References

1. F. Riaz, M. A. Azad, J. Arshad, M. Imran, A. Hassan, and S. Rehman, “Pervasive blood pressure monitoring using Photoplethysmogram (PPG) sensor,” Futur. Gener. Comput. Syst., vol. 98, no. 2019, pp. 120–130, 2019, doi: 10.1016/j.future.2019.02.032.
2. M. Hosanee et al., “Cuffless single-site photoplethysmography for blood pressure monitoring,” J. Clin. Med., vol. 9, no. 3, 2020, doi: 10.3390/jcm9030723.
3. M. Frąckiewicz, “The Impact of Biometric Sensor Technology on Healthcare and Medical Diagnosis,” TS2 SPACE, Mar. 23, 2023. https://ts2.space/en/the-impact-of-biometric-sensor-technology-on-healthcare-and-medical-diagnosis/#:~:text=Biometric%20sensors%20are%20small%2C%20unobtrusive (accessed Sep. 15, 2023).
4. L. Dormehl, “No Cuffs Necessary! This Sensor Can Read Blood Pressure From Your Fingertip,” Digital Trends, May 24, 2017. https://www.digitaltrends.com/cool-tech/blood-pressure-sensor-phone/ (accessed Sep. 15, 2023).
5. PR Newswire, “Maxim Unveils Cuffless Blood-Pressure Measurement Solution Meeting Class-II Regulatory Accuracy Limits,” markets.businessinsider.com, Nov. 20, 2019. https://markets.businessinsider.com/news/stocks/maxim-unveils-cuffless-blood-pressure-measurement-solution-meeting-class-ii-regulatory-accuracy-limits-1028704405 (accessed Sep. 15, 2023).
6. J. Espina, T. Falck, J. Muehlsteff, and X. Aubert, “Wireless Body Sensor Network for Continuous Cuff-less Blood Pressure Monitoring,” IEEE Xplore, Sep. 01, 2006. https://ieeexplore.ieee.org/abstract/document/4201254 (accessed Sep. 15, 2023).
7. R. Narasimhan, T. Parlikar, G. Verghese, and M. V Mcconnell, “Finger-Wearable Blood Pressure Monitor,” pp. 3792–3795, 2018.
8. “Custom finger CLIP offers a new way to measure blood pressure, other vitals,” ScienceDaily, 04-Jan-2022. [Online]. Available: https://www.sciencedaily.com/releases/2022/01/220104123559.htm. [Accessed: 13-Jul-2022].
9. J. Vourvoulakis and L. Bilalis, “Real-time pulse oximetry extraction using a lightweight algorithm and a task pipeline scheme,” 2021 10th Int. Conf. Mod. Circuits Syst. Technol. MOCAST 2021, pp. 8–12, 2021, doi: 10.1109/MOCAST52088.2021.9493400.
10. O. Saturation and R. Spo, “Onyx (9500) Specifications,” no. 9500, p. 9500.
11. S. Tian, W. Yang, J. M. Le Grange, P. Wang, W. Huang, and Z. Ye, “Smart healthcare: making medical care more intelligent,” J. Glob. Health, vol. 3, no. 3, pp. 62–65, 2019, doi: 10.1016/j.glohj.2019.07.001.
12. T. E. K. T. E. L. I. C. C. Inc., “Benefits of IOT wearable devices in Healthcare,” IoT For All, 31-Mar-2022. [Online]. Available: https://www.iotforall.com/benefits-iot-wearable-devices-healthcare. [Accessed: 13-Jul-2022].