Accredited SINTA 2 Ranking
Decree of the Director General of Higher Education, Research, and Technology, No. 158/E/KPT/2021
Validity period from Volume 5 Number 2 of 2021 to Volume 10 Number 1 of 2026

Published online at: **http://jurnal.iaii.or.id**

JURNAL RESTI
(Rekayasa Sistem dan Teknologi Informasi)
Vol. 8 No. 5 (2024) 651 - 657 e-ISSN: 2580-0760

ESP32 and MAX30100 with Chebyshev Filter for Enhanced Heart and Oxygen Measurement

Naval Indra Waskita[1], Hizkia Menahem Tandungan[2], Ridhan Hafizh[3], Syifa Jauza Suwaendi[4], Magfirawaty Magfirawaty[5*]
[1,2,3,4,5]Cryptographic Hardware Engineering, Cryptography Department, National Cyber and Crypto Polytechnic, Bogor, Indonesia
[1]naval.indra@student.poltekssn.ac.id, [2]hizkia.menahem@student.poltekssn.ac.id, [3]ridhan.hafizh@student.poltekssn.ac.id, [4]syifa.jauza@student.poltekssn.ac.id, [5]magfirawaty@poltekssn.ac.id

Abstract

Health monitoring is important in the technology and information era. A health monitoring device must possess high accuracy in monitoring an individual's health. The MAX30100 sensor still exhibits low accuracy and requires improvements to enhance its precision. This study proposes a remote health monitoring system based on a MAX30100 sensor for heart rate and oxygen saturation detection. The digital signal processing method uses the Chebyshev II filter on PPG to reduce noise, and the RSA algorithm is employed to enhance data security. The results of testing the MAX30100 sensor value without a filter produced the lowest error value of 0.97%, the highest 6.59% for BPM, the lowest error value of 1.88%, and the highest error of 2.66% for SpO2. The MAX30100 sensor with the Chebyshev II filter that the author proposed has the highest level of accuracy with a low error value compared to previous tests, with the lowest error value of 0.23% and the highest 0.99% for BPM and the lowest error value of 0% and the highest error of 0.2% for SpO2. The RSA algorithm ensures secure data transmission from data modification by eavesdroppers. The average total time required by the system is 542.9 ms.

Keywords: *chebyshev filter; butterworth filter; heart rate; PPG signal; MAX30100 sensor*

How to Cite: M. Magfirawaty, Naval Indra Waskita, Hizkia Menahem Tandungan, Ridhan Hafizh, and Syifa Jauza Suwaendi, "ESP32 and MAX30100 with Chebyshev Filter for Enhanced Heart and Oxygen Measurement", *J. RESTI (Rekayasa Sist. Teknol. Inf.)*, vol. 8, no. 5, pp. 651 - 657, Oct. 2024.
DOI: https://doi.org/10.29207/resti.v8i5.5945

1. Introduction

Health monitoring is important in today's increasingly complex public health conditions. Patients experience health difficulties due to inadequate health monitoring systems. Monitoring heart rate and blood oxygen levels is integral to tracking a person's health and physiological parameters. Existing health monitoring cannot provide real-time patient health alerts and is constrained by the distance between the patient and the hospital. The change in health monitoring from face-to-face counselling to telemedicine has been facilitated by the emergence of Internet of Things (IoT) technology [1] - [5].

In research [1]A health monitoring tool was created to monitor patient oxygen saturation using the MAX30100 and ESP32 sensors, and it was then sent to the health worker's email for further treatment. The MAX30100 sensor measures oxygen saturation levels and heart rate with Photoplethysmography signals and transfers information to the microcontroller (ESP32) via the I2C interface. Thus, the sensor has two functions integrated into it: monitoring heart rate and measuring oxygen saturation levels simply. When compared to factory-produced oximeters, the MAX30100 sensor has a low level of accuracy [1], [6].

The prototype made in the study [1] monitors oxygen saturation with an error of 1.6%. Meanwhile, the study [6] used the device to monitor oxygen saturation and heart rate. The ability to monitor oxygen saturation has an accuracy level of 98.56%, and tracking heart rate has an accuracy level of 92.947% [6]. This indicates that the MAX30100 sensor has limitations in measurement accuracy, which may affect its reliability in critical health monitoring applications. Therefore, the accuracy of the MAX30100 sensor needs to be improved. In general, there are two types of filters, namely finite

Received: 23-07-2024 | Accepted: 17-10-2024 | Published Online: 19-10-2024

impulse response (FIR) and infinite impulse response (IIR). FIR filters are often related to polynomials of shift operators. IIR filters are generally described as rational functions that outperform polynomials and have a low degree of adjusting the desired filter. IIR filters consist of Butterworth, Chebyshev, and Elliptic [7] - [10].

Butterworth filters have the advantage of a flat frequency response in the passband region without ripple but have a slower transition between the passband and stopband than Chebyshev and elliptic filters. Chebyshev filters offer a sharper transition between the passband and stopband, which can control ripples in their frequency response but produce signal distortion. Meanwhile, elliptic filters provide a sharp transition between the passband and the stopband. This allows good control of ripples in both the passband and stopband regions. However, it requires a more complex implementation. Therefore, selecting an appropriate filter must consider the trade-off between the desired frequency response, signal distortion, and implementation complexity [7], [11] - [13].

Based on the types of IIR filters available, the Chebyshev type II filter is an effective filter for performing Photoplethysmography (PPG) [8], [12], [14]. In this study, the author will develop a prototype from the study [1] by adding a Chebyshev type II filter to improve the accuracy of the MAX30100 sensor, and the data is secured using the RSA algorithm [14], [15], [16]. The data is displayed in real-time on the website using Google Firebase, as done in the study [3], [17] - [19] as a monitoring function by medical personnel. The test focuses on comparing the study's accuracy level [1], [6] with the level of accuracy after applying the Chebyshev type II filter to the MAX30100 sensor.

2. Research Methods

Research methodology to ensure that research results are valid and reliable.

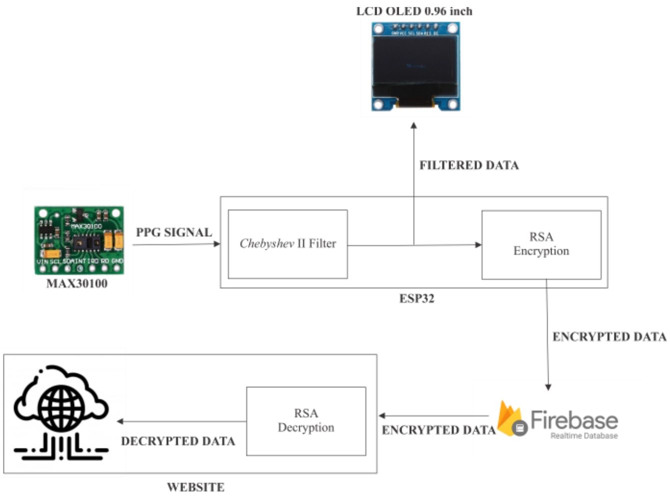

Figure 1. System Overview

The process begins with the initialization of the ESP32 as a microcontroller module. The MAX30100 sensor is initialized to measure heart rate and blood oxygen levels. Figure 1 shows the system's process. The ESP32 takes data from the MAX30100 sensor. Heart rate and oxygen level data are collected periodically and processed by the ESP32. The Chebyshev II filter is used to improve signal quality. The processed data is then encrypted using the RSA algorithm. Data processing results are displayed on a 0.96-inch OLED LCD and sent to Firebase to be displayed on the website.

The implementation of this system aims to monitor heart rate and blood oxygen levels in real-time. The ESP32 microcontroller has Wi-Fi and Bluetooth features to connect to the internet for remote data transmission.

The system is designed to connect the VCC pin of the OLED LCD and the MAX30100 sensor to the 3.3V pin on the ESP32, ensuring a stable power supply. The GND pin of both modules is connected to the ESP32 GND pin to complete the electrical circuit. Data communication between the devices is done via the I2C protocol, where the SDA pin of the OLED LCD and MAX30100 is connected in parallel to the GPIO21 (SDA) pin on the ESP32, while the SCL pin of both modules is connected to the GPIO22 (SCL) pin on the ESP32. This configuration allows simultaneous communication between the ESP32 and both modules using the same I2C bus, minimizing the use of I/O pins.

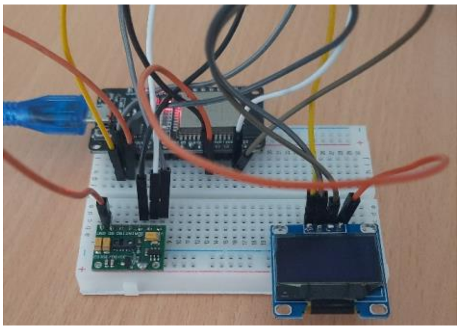

Figure 2. Hardware Configuration

Figure 2 is a system design implemented in hardware. The system proposed by the author consists of an LCD screen component to display data, an ESP32 microcontroller to control the system, and an MAX30100 sensor to measure heart rate and blood oxygen levels. All components are connected using jumper cables to maintain a stable connection between system parts.

Ten people were the subjects of data collection. Each person was given five data collection sessions for each condition without a filter, Butterworth Filter, and Chebychev Filter type II. The data from each condition was compared with the Omron Oximeter to calculate the error value.

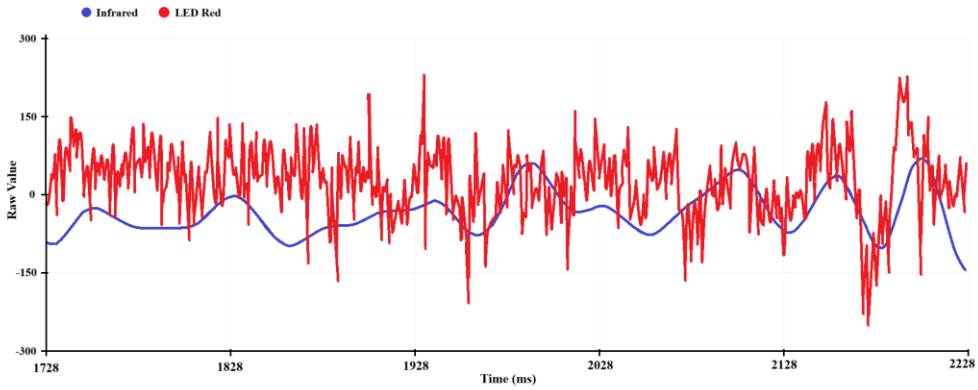

Figure 3. Infrared signal and red led signal graph

The MAX30100 sensor measures red and infrared (IR) light signals reflected from blood to detect heart rate. Changes in light absorption by blood in capillaries produce values in the Red and IR signals. These AC values reflect variations due to heart rate. A comparison graph of infrared and red LEDs is shown in Figure 3. Each measured AC value from the Red and IR signals is squared to calculate the total squared AC value ($\Sigma\sqrt{redAC}$ and $\Sigma\sqrt{irAC}$). After a certain number of heartbeats are detected, the average of the squared AC values is calculated for the Red and IR signals. The logarithmic ratio of these averaged squared values to calculated blood oxygen levels and itis calculated using Formula 1.

$$AC\ Ratio = 100 \times \frac{\log(\frac{\Sigma\sqrt{redAC}}{\text{samplesRecorded}})}{\log(\frac{\Sigma\sqrt{irAC}}{\text{samplesRecorded}})} \quad (1)$$

The heart rate (BPM) is calculated based on the detected heartbeat period using Formula 2.

$$BPM = \frac{1}{beatPeriod} \times 1000 \times 60 \quad (2)$$

Formula 2 converts the heartbeat period to a frequency in beats per millisecond, multiplied by 1000 to get beats per second and by 60 to get beats per minute (BPM) [20].

3. Results and Discussions

The proposed system's accuracy is evaluated by comparing its results with those from a standard oximeter, demonstrating excellent performance in detecting both heart rate and oxygen saturation levels. This high level of accuracy underscores the system's reliability and potential as an effective tool for precise health monitoring. The model's ability to consistently track these vital signs highlights its suitability as an alternative to traditional oximeter devices, offering reliable and accurate measurements.

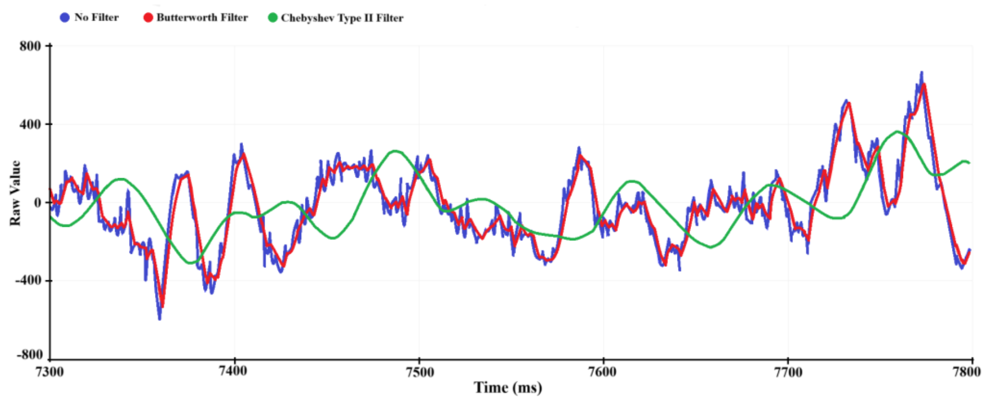

Figure 4. Digital filter comparison graph

Figure 4 compares raw data from the MAX30100 sensor without a filter (blue), with a 1st-order Butterworth filter (red) and a 4th-order Chebyshev type 2 filter (green). The unfiltered raw data shows sharp fluctuations and significant noise, while the 1st-order Butterworth filter can reduce some noise but still leaves fluctuations. The 4th-order Chebyshev type 2 filter significantly reduces noise, resulting in a smoother and more stable signal.

However, the 4th-order Chebyshev type 2 filter introduces a delay to the signal, as seen in the green signal's phase shift compared to the blue and red signals. Although this delay is a common characteristic of higher-order filters, it still significantly improves signal quality, making it more representative and reliable for further analysis, with the caveat that delay should be considered in applications that require real-time response or high timing precision.

On the other hand, using filters impacts noise reduction and affects the shape and characteristics of the resulting signal. Further analysis is needed to understand how each filter type and order affects the signal under various conditions and applications.

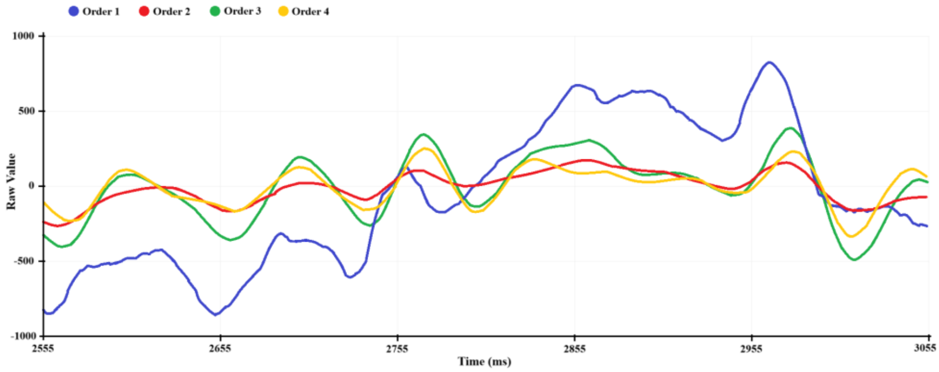

Figure 5. Chebychev filter comparison graph

Figure 5 compares the response of a Chebyshev type 2 filter with various orders (1, 2, 3, and 4) to an input signal in the time domain. The blue color shows the response of a 1st order filter, red for 2nd order, green for 3rd order, and yellow for 4th order. The graph shows that the reaction of higher order filters (3rd and 4th orders) has a smaller amplitude than the lower order filters (1st and 2nd orders). In addition, the response of higher-order filters tends to have more oscillations and is more complex than the response of lower-order filters. The 1st-order filter (blue) shows more significant and rougher fluctuations, while the 4th-order filter (yellow) shows smoother and more controlled volatility. This indicates that the effect becomes stronger as the filter order increases, resulting in a smoother output signal less susceptible to high-frequency interference. This comparison is important in the design of signal processing systems, where the selection of filter orders can affect the quality and characteristics of the output signal according to specific application needs.

Below are tables of heart rate and blood oxygen levels (SpO2) measurements using a device made with a MAX30100 sensor without a filter, with a Butterworth filter, and a Chebyshev type 2 filter where each measurement will be compared with a measurement using an oximeter that was carried out simultaneously. The percentage error is calculated for each measurement to evaluate the accuracy of the MAX30100 device compared to a standard oximeter. These tables include columns for respondents, average (Mean), standard deviation (STD), and percentage error (Error). The research was conducted using 10 individuals as samples for each measurement, referring to research [1], [19].

Table 1. Data measurements of SpO2 using MAX30100 with no filter

Respondent	Mean (%)	STD	Error (%)
1	95	0,54	2,66
2	94,6	0,44	2,27
3	96	0,54	2,63
4	93,8	0,44	1,88
5	95	0,54	2,66
6	94,6	0,70	2,07
7	97	0,54	2,61
8	96	0,54	2,63
9	93,8	0.44	1,88
10	95	0,54	2,66

Table 1 shows SpO2 measurement data using the MAX30100 sensor without a filter. The data show that the average SpO2 value ranges from 93% to 96%, with the error percentage varying between 1.88% and 2.66%. This indicates a significant difference between the measurements of the MAX30100 sensor without a filter and a standard oximeter.

Table 2. Data measurements of SpO2 using MAX30100 with Butterworth

Respondent	Mean (%)	STD	Error (%)
1	96,6	0,77	1,02
2	95,6	0,44	1,23
3	97,6	0,70	1,01
4	94,6	0,70	1,04
5	96,6	0,70	1,02
6	95,6	0,70	1,03
7	98,2	0,89	1,40
8	97,6	0,70	1,01
9	94,6	0,70	1,04
10	96,6	0,70	1,02

Table 2 presents SpO2 measurement data using the MAX30100 sensor with a Butterworth filter. The measurement results show increased accuracy compared to without a filter, with a slightly higher average SpO2 value and a standard deviation within an acceptable range. The percentage error also decreased between 1.02% and 1.43%, indicating that using a Butterworth filter can improve the accuracy of the MAX30100 sensor measurement.

Table 3. Data measurements of SpO2 using MAX30100 with Chebychev II

Respondent	Mean (%)	STD	Error (%)
1	97,8	0,44	0,20
2	96,6	0,44	0,20
3	98,8	0,44	0,20
4	95,8	0,44	0,20
5	97,8	0,44	0,20
6	96,6	0,70	0
7	99,2	0,89	0,40
8	98,8	0,44	0,20
9	95,8	0,44	0,20
10	97,8	0,44	0,20

Table 3 shows SpO2 measurement data using the MAX30100 sensor with a Chebyshev type II filter. The average SpO2 value ranges from 95.8% to 99.2%. The error percentage for 8 out of 10 measurements is 0.20%, one measurement is 0.40%, and 1 has no error. This shows that using a Chebyshev type II filter significantly improves measurement accuracy compared to not using a filter and a Butterworth filter.

Table 4. Data measurements of heart rate using MAX30100 with no filter

Respondent	Mean (%)	STD	Error (%)
1	77,2	1,64	6,31
2	76,6	2,19	6,59
3	79	0,55	5,28
4	76,2	3,27	5,22
5	83,2	2,86	0,97
6	78,2	2,39	3,93
7	81	1,95	4,03
8	79	0,55	5,5
9	83,6	0,84	3,98
10	78	0,55	5,34

Table 4 shows that heart rate measurements using the MAX30100 sensor without a filter show an average heart rate ranging from 76.2 to 83.6 beats per minute. The recorded standard deviation varies between 0.55 and 3.27. The percentage error in these measurements ranges from 0.97% to 6.31%, with high error values indicating a significant difference between the sensor and oximeter measurement results.

Table 5 shows the heart rate measurements using the MAX30100 sensor with a Butterworth filter. The average heart rate was recorded between 78.2 and 82.8 beats per minute, with the percentage error in this measurement ranging from 1.72% to 3.41%. This indicates a significant improvement in measurement accuracy when using a Butterworth filter compared to without a filter.

Table 5. Data measurements of heart rate using MAX30100 with Butterworth

Respondent	Mean (%)	STD	Error (%)
1	80,2	1,1	2,67
2	79,2	1,48	3,41
3	81,4	0,71	2,4
4	78,2	0,45	2,74
5	80	0,55	2,91
6	80	1,95	1,72
7	82,8	0,89	1,9
8	81,8	1,1	2,15
9	79	1,95	1,74
10	80,2	1,1	2,67

Table 6. Data measurements of heart rate using MAX30100 with ChebyshevII

Respondent	Mean (%)	STD	Error (%)
1	82	0,55	0,48
2	81,8	1,1	0,24
3	83	0,89	0,48
4	80,6	0,84	0,24
5	82,8	0,89	0,48
6	82	0,55	0,73
7	84,6	0,45	0,23
8	83,8	1,1	0,23
9	81,2	1,1	0,99
10	82	1,14	0,48

Table 6 shows heart rate measurements using the MAX30100 sensor with a Chebyshev type II filter. The average heart rate is between 80.6 and 84.6 beats per minute, with a standard deviation between 0.45 and 1.14. The percentage error in this measurement is 0.24% to 0.73%. These results prove that the Chebyshev type II filter effectively reduces noise.

Table 7. System performance test

Experiment	Encryption (ms)	Decryption (ms)	Total (ms)
1	16	7	549
2	17	6	544
3	16	7	542
4	16	7	539
5	17	5	545
6	17	7	548
7	16	5	544
8	16	6	533
9	16	6	541
10	16	6	544

Table 7 shows the system's performance, measuring the time duration, including encryption, decryption, and total time from the sensor reading process to displaying data on the website. The average time required for encryption is 16.3 ms, and the average time for decryption is 6.2 ms. The average total time needed for the system is 542.9 ms.

Figure 6 shows the interface of the patient health monitoring website. The website contains patient information, including name, age, and identification number. Monitoring data includes heart rate and blood oxygen saturation (SpO2) in graphs based on time. The website also provides a notification section to warn if the patient's condition is outside the standard.

Figure 6. Displaying data value of monitoring on the website

3.2 Discussions

In a previous study entitled "Monitoring SpO2, Heart Rate, and Body Temperature on Smartband with Data Sending Using IoT Displayed on Android", this device uses the MLX90614 sensor to measure body temperature and the MAX30100 sensor to measure oxygen saturation levels and heart rate on the index finger. The measurement results from this device can be displayed in real-time and remotely, and notifications can be provided on the user's smartphone if the patient's condition is abnormal [3]. However, the oxygen saturation and heart rate values produced using the MAX30100 sensor without additional filters have the lowest error value of 0.2% and the most significant 1.6% with an average error of 0.84%, where a high level of accuracy is required in a health monitoring system, especially the monitoring system for long-distance purposes.

Based on the study's results, test data showed that using the Chebyshev II filter successfully reduced interference in the PPG signal from the MAX30100 sensor measurement results. The test results showed that the MAX30100 sensor without a filter had the lowest BPM error value of 0.97%, the highest of 6.59%, the lowest SpO2 error value of 1.88%, and the highest of 2.66%. After using the Butterworth filter, the lowest and highest BPM error values were 1.72% and 3.41%, respectively, while the lowest and highest SpO2 error values were 1.01% and 1.40%. The MAX30100 sensor with the Chebyshev II filter showed a high increase in accuracy with the lowest BPM error value of 0.23%, the highest of 0.99%, and the lowest SpO2 error value of 0% and the highest of 0.4%. The average error in taking SpO2 data with the Chebyshev II filter was 0.2%. Thus, compared to the study [3], the error value in this study had a lower average value with a difference of 0.64%.

The Chebyshev II filter has been shown to reduce noise and produce more accurate values compared to no filter and using the Butterworth filter. The RSA algorithm added to the health monitoring system adds an important layer of data security in remote health monitoring, where patient data privacy and security are critical. The proposed system performs 542.9 ms, with an average encryption time of 16.3 ms and a decryption time of 6.2 ms.

Overall, this study has successfully demonstrated that using ESP32 with the MAX30100 sensor, adding the Chebyshev II filter, and implementing the RSA algorithm can improve detection accuracy and data security in the health monitoring system. This study can provide the basis and knowledge for further research in developing a more effective and secure health monitoring system.

4. Conclusions

Based on the system we proposed, the test results of the MAX30100 sensor value without using a filter produced the lowest error value of 0.97%, the highest of 6.59% for BPM, and the lowest error value of 1.88% and the highest error of 2.66% for SpO2. The BPM error value for the MAX30100 sensor equipped with a

Butterworth filter was 1.72% for the lowest error and 3.41% for the highest error; the lowest error value for SpO2 was 1.01%, and the highest error value was 1.40%. The MAX30100 sensor with the Chebyshev II filter that the author proposed had the highest level of accuracy with the lowest error value compared to previous tests, with the lowest error value of 0.23% and the highest 0.99% for BPM and the lowest error value of 0% and the highest error of 0.4% for SpO2. System performance testing was also carried out by calculating the duration of time from taking sensor data to displaying data on the website. The RSA algorithm ensures secure data transmission from data modification by eavesdroppers. The average total time required by the system, from reading the sensor to displaying the data on the website, is 542.9 ms. In conclusion, this study shows that the MAX30100 sensor device equipped with the Chebyshev II filter produces accurate heart rate and oxygen saturation detection values with low error values.

References

[1] N. A. Anggraini, B. G. Irianto, I. D. G. H. Wisana, and A. Kumbhare, “Monitoring SpO2, Heart Rate, and Body Temperature on Smartband with Data Sending Use IoT Displayed on Android (SpO2),” *Jurnal Teknokes*, vol. 16, no. 4, Nov. 2023, doi: 10.35882/teknokes.v16i4.615.

[2] J. Heaney, J. Buick, M. U. Hadi, and N. Soin, “Internet of Things-Based ECG and Vitals Healthcare Monitoring System,” *Micromachines (Basel)*, vol. 13, no. 12, Dec. 2022, doi: 10.3390/mi13122153.

[3] Ameyshafida Mihat, Norhashimah Mohd Saad, Ezreen Farina Shair, Rohana Abdul Rahim, and Achmad Bayhaqi Nasir Aslam, “Smart Health Monitoring System Utilizing Internet Of Things (Iot) and Arduino,” *Asian Journal of Medical Technology (AJMedTech)* , vol. 2, no. 1, 2022.

[4] Izhangghani, I. Hikmah, and Slamet Indriyanto, “Prototype of Body Temperature and Oxygen Saturation Monitoring System Using DS18B20 and MAX30100 Sensors based on IOT,” *Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi)*, vol. 6, no. 5, pp. 810–817, Oct. 2022, doi: 10.29207/resti.v6i5.4385.

[5] A. N. Costrada, A. G. Arifah, I. D. Putri, I. K. A. Sara Sawita, H. Harmadi, and M. Djamal, “Design of Heart Rate, Oxygen Saturation, and Temperature Monitoring System for Covid-19 Patient Based on Internet of Things (IoT),” *Jurnal Ilmu Fisika | Universitas Andalas*, vol. 14, no. 1, pp. 54–63, Mar. 2022, doi: 10.25077/jif.14.1.54-63.2022.

[6] Adam Fauzan Ahmad, Bambang Setia Nugroho, and Bagus Aditya, “Deteksi Saturasi Oksigen dalam Darah Menggunakan Sensor MAX30100 Berbasis ESP8266,” *e-Proceeding of Engineering*, vol. 10, no. 4, pp. 3740–3747, 2023.

[7] P. Kannan, S. Maheswari, A. Pon Bharathi, and A. J. Wilson, “Spectral And Performance Measures Analysis Of Ecg Signal Using Various Transforms And Different Types Of Iir And Fir Filters With Different Orders,” *International Journal Of Electrical Engineering And Technology*, vol. 12, no. 5, May 2021, doi: 10.34218/ijeet.12.5.2021.009.

[8] D. G. Lapitan, D. A. Rogatkin, E. A. Molchanova, and A. P. Tarasov, “Estimation of phase distortions of the photoplethysmographic signal in digital IIR filtering,” *Sci Rep*, vol. 14, no. 1, Dec. 2024, doi: 10.1038/s41598-024-57297-3.

[9] Z. Ge, H. Guo, T. Wang, and Z. Yang, “Universal Graph Filter Design based on Butterworth, Chebyshev and Elliptic Functions,” Mar. 2022, [Online]. Available: http://arxiv.org/abs/2203.14748

[10] H. Amhia and A. K. Wadhwani, “Stability and Phase Response Analysis of Optimum Reduced-Order IIR Filter Designs for ECG R-Peak Detection,” *J Healthc Eng*, vol. 2022, 2022, doi: 10.1155/2022/9899899.

[11] M. B. Prakash, V. Sowmya, E. A. Gopalakrishnan, and K. P. Soman, “Noise Reduction of ECG using Chebyshev filter and Classification using Machine Learning Algorithms,” in *Proceedings - IEEE 2021 International Conference on Computing, Communication, and Intelligent Systems, ICCCIS 2021*, Institute of Electrical and Electronics Engineers Inc., Feb. 2021, pp. 434–441. doi: 10.1109/ICCCIS51004.2021.9397163.

[12] N. Mangathayaru, B. P. Rani, V. Janaki, L. S. Kotturi, M. Vallabhapurapu, and G. Vikas, “Heart rate variability for predicting coronary heart disease using photoplethysmography,” in *Proceedings of the 4th International Conference on IoT in Social, Mobile, Analytics and Cloud, ISMAC 2020*, Institute of Electrical and Electronics Engineers Inc., Oct. 2020, pp. 664–671. doi: 10.1109/I-SMAC49090.2020.9243316.

[13] G. Sun, X. Ren, Z. Wang, and F. Liu, “Adaptive low-power wrist SpO2 monitoring system design using a multi-filtering scheme,” *Biomed Signal Process Control*, vol. 81, Mar. 2023, doi: 10.1016/j.bspc.2022.104432.

[14] B. Mishra and N. S. Nirala, “A Survey on Denoising Techniques of PPG Signal,” in *2020 IEEE International Conference for Innovation in Technology, INOCON 2020*, Institute of Electrical and Electronics Engineers Inc., Nov. 2020. doi: 10.1109/INOCON50539.2020.9298358.

[15] R. Imam, Q. M. Areeb, A. Alturki, and F. Anwer, “Systematic and Critical Review of RSA Based Public Key Cryptographic Schemes: Past and Present Status,” 2021, *Institute of Electrical and Electronics Engineers Inc.* doi: 10.1109/ACCESS.2021.3129224.

[16] A. Nandanavanam, I. Upasana, and N. Nandanavanam, “NTRU and RSA Cryptosystems for Data Security in IoT Environment,” in *2020 International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE)*, IEEE, Oct. 2020, pp. 371–376. doi: 10.1109/ICSTCEE49637.2020.9277159.

[17] N. N. Sari, M. N. Gani, R. A. Maharani Yusuf, and R. Firmando, “Telemedicine for silent hypoxia: Improving the reliability and accuracy of Max30100-based system,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 22, no. 3, pp. 1419–1426, Jun. 2021, doi: 10.11591/ijeecs.v22.i3.pp1419-1426.

[18] O. Y. Tham, M. A. Markom, A. H. A. Bakar, E. S. M. M. Tan, and A. M. Markom, “IoT Health Monitoring Device of Oxygen Saturation (SpO2) and Heart Rate Level,” in *Proceeding - 1st International Conference on Information Technology, Advanced Mechanical and Electrical Engineering, ICITAMEE 2020*, Institute of Electrical and Electronics Engineers Inc., Oct. 2020, pp. 128–133. doi: 10.1109/ICITAMEE50454.2020.9398455.

[19] Izhangghani, I. Hikmah, and Slamet Indriyanto, “Prototype of Body Temperature and Oxygen Saturation Monitoring System Using DS18B20 and MAX30100 Sensors based on IOT,” *Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi)*, vol. 6, no. 5, pp. 810–817, Oct. 2022, doi: 10.29207/resti.v6i5.4385.

[20] Oxullo, *Oxullo/Arduino-Max30100: Arduino Library for MAX30100, integrated oximeter and Heart Rate Sensor, GitHub*. Available: https://github.com/oxullo/Arduino-MAX30100.git (Accessed: 20 June 2024).