Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics
Multidisciplinary : Rapid Review : Open Access Journal Vol. 5, No. 3, August 2023, pp.151-157 e-ISSN: 2656-8624

RESEARCH ARTICLE OPEN ACCESS

Manuscript received August 17, 2022; revised August 24, 2023; accepted August 29, 2023; date of publication August 30, 2023
Digital Object Identifier (**DOI**): https://doi.org/10.35882/ijeeemi.v5i3.293

How to cite: Cantika Melinda, I Dewa Gede Hari Wisana, Andjar Pudji, Triwiyanto, "ECG and NIBP Simulator in One Device Display on TFT Nextion", Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 5, no. 3, pp.151-157, August. 2023

ECG and NIBP Simulator in One Device Display on TFT Nextion

Cantika Melinda, I Dewa Gede Hari Wisana, Andjar Pudji, and Triwiyanto
Department of Electromedical Engineering Poltekkes Kemenkes, Surabaya Jl. Pucang Jajar Timur No. 10, Surabaya, 60245, Indonesia

Corresponding author: I Dewa Gede Hari Wisana (dewa@poltekkesdepkes-sby.ac.id)

ABSTRACT Accurate monitoring of NIBP (Non-Invasive Blood Pressure) parameters using vital sign monitors is crucial for patient care. Therefore, calibration of vital sign monitors is essential to ensure their safety and reliability. A vital sign simulator was developed in this study, integrating ECG and NIBP parameters with a TFT Nextion display. The aim is to calibrate ECG and NIBP readings on vital sign monitors. The system utilized the Arduino Mega 2560 as the central controller and the MPX5050GP sensor for NIBP measurement and motor pump control. The NIBP parameters were measured at two settings: 60/30 and 80/50. The results showed a maximum systolic error of 3.5% and a diastolic error of 5.6% for the NIBP setting of 80/50. The largest standard deviation value of 2.05 was observed at the NIBP setting of 60/30. The highest uncertainty value of 0.5 was also found in the NIBP 60/30 setting. The obtained data indicated stable module readings within the acceptable threshold for vital sign monitor calibration. The developed vital sign simulator offers a reliable means of calibrating NIBP parameters, enabling accurate blood pressure measurements. Further research and refinement can be conducted to enhance the system's precision and expand its capabilities for calibration of additional vital sign parameters. By ensuring accurate calibration, healthcare professionals can rely on vital sign monitors for effective patient monitoring and diagnosis.

INDEX TERMS Calibration, Vital Sign Monitor, NIBP, MPX5050GP

I. Introduction

Hypertension is a major cardiovascular risk factor. According to the American College of Cardiology 2017 and the Definition of Hypertension according to the American Heart Association in 2017-2018 it was reported that among adults aged 18 years and older, the prevalence of hypertension was recorded at 45.4%, with a higher prevalence in men (51.0%) compared to women (39.7%). [1]. This can occur due to several factors, one of which is not checking blood pressure regularly, so that a person does not know the condition of his blood pressure. Failing to check blood pressure regularly can lead to a lack of awareness about an individual's blood pressure status, potentially delaying necessary interventions or treatment [2][3]. In the human body, there are several vital signs that indicate very important functions for the health of the body. These vital signs include several physiological parameters, such as blood pressure, body temperature, oxygen saturation, pulse, and respiratory rate. These vital signs are the basic indicators of the vital functions of the human body [4]. An important vital sign is blood pressure, which reflects the force of blood flow through the blood vessels. Regular monitoring of these vital signs is very important in monitoring health and diagnosing medical conditions. By understanding and observing changes in these vital signs, we can detect any possible health problems and immediately take the necessary steps to maintain health and prevent more serious complications [5][6].

The diagnosis of hypertension is based on measuring Blood Pressure (BP) using the NIBP. The NIBP parameter on the vital sign monitor is an important thing that needs to be considered because checking vital signs is one way to find out changes in the body's systems [7]. Generally, checking vital signs uses a vital sign monitor, where this tool shows the presence of medical equipment that has many advanced functions and capabilities. So that in its use it will always be ready to use and meet the technical standards for the use of medical equipment. The NIBP parameter is a parameter on the vital sign monitor that detects blood pressure in patients [8][9]. Accuracy of blood pressure measurement is a key factor in the diagnosis and prevention of cardiovascular disease and hypertension [10]. There are still vital sign monitoring devices that have not been tested for their adequacy level and can result in erroneous results in the process of providing assistance and diagnosis. To ensure the suitability of medical devices requires a process called calibration [11][12]. Calibration according to the Vocabulary of International Metrology (VIM) and ISO/IEC Guide 17025:2005 is a series of activities that establish a relationship between the value expressed by a measuring instrument or measuring system, or the value expressed by the measuring material, and known values related to the quantity being measured in certain conditions [13]. Calibration of vital sign monitors using a vital sign simulator. Vital sign simulator is a medical device calibrator that has an important function to determine whether the device is appropriate for monitoring the patient's condition by utilizing the parameters in it, these parameters include blood pressure, oxygen content in the blood, temperature or body temperature, heart rate and respiration[14].

In 2017, Nico Antonio Santoso et al., with the title Control System for DC Motor Based Micro Air Pump to Simulate Oscillograph of blood Pressure In this study, a micro air pump was utilized as a pressure generator to generate oscillometric waves. The pressure sensor is used to measure the pressure readings from the NIBP monitor and to regulate the operation of the micro air pump. However, it is important to acknowledge the limitations of this study, as it still exhibited an error rate of 6.67% specifically at the preset blood pressure level of 60/30. While the use of a micro air pump and pressure sensor represents a notable advancement in the methodology, the observed error suggests the presence of inaccuracies or imprecisions in the measurement process[15][16]. Then in 2019, A Darwongso et al., conducted a study entitled Blood Pressure Simulator: Minimizing the Effects of Inflation and Deflation Rates on Oscillation Simulations. In this study, a blood pressure simulator was developed utilizing a micro air pump DC motor as a controller, which was regulated using a Pulse Width Modulation (PWM) value. The pressure sensor employed in this tool was the MPX5100GP pressure sensor. While this approach represents a significant advancement, it is important to acknowledge a weakness in the research, namely an observed error of 3 mmHg. The identified error, although relatively small, indicates the presence of minor inaccuracies in the blood pressure simulation process. It is crucial to address this error to ensure the reliability and accuracy of the simulator's output[17] [18][19] . In 2017, N. Shahid conducted research with the title Comparative Analysis and Accuracy of a Devised Automated Non Invasive Blood Pressure Monitor Based on Oscillometric Method. In this study, a comparison was conducted on blood pressure measurements using the oscillometric method. However, it is important to acknowledge a deficiency in the microcontroller component, specifically the utilization of the Arduino, which led to inaccurate results. The identified deficiency in the microcontroller system is a crucial factor that affected the accuracy of the blood pressure measurements [20][21][22]. In 2016, A. Aditya et al,. conducted research with the title Design of Automatic Blood Pressure Gauge on the Wrist Using the Arduino Mega 2560 Based Oscillometry Method This study aimed to measure blood pressure using a non-invasive approach, specifically the oscillometry method. The measurement process was automated and relied on the implementation of the Maximum Amplitude Algorithm (MAA) with a piezoresistive pressure sensor integrated into the Arduino Mega 2560 microcontroller. The designed instrument was capable of accurately measuring blood pressure within a range of 55 to 200 mmHg, accompanied by a heart rate range of 0-300 bpm [23] [24][25].

Moreover, the integration of the NIBP simulator within the same device will further enhance its functionality. This addition will enable the device to simulate blood pressure measurements, providing a comprehensive solution for calibration and testing purposes. By incorporating both ECG and NIBP simulations into a single device, researchers and healthcare professionals will have a convenient tool that offers a realistic and customizable simulation experience.

II. Materials And Methods

A. Materials And Tool

This research uses uses the MPX5050GP sensor which is used to read pressure when measuring NIBP which is generated from the vital sign monitor and as a control for the motor pump to work. The microcontroller used to process the data is the Arduino Mega 2560. The study took place at Poltekkes Surabaya's Department of Electromedical Engineering, using a device that mimics vital signs for comparison purposes. The study design for developing the module utilized a pre-test with a Post-Only Design approach. In this approach, the researcher employed a single group of participants and focused solely on observing the outcomes without evaluating or being aware of the baseline conditions. However, a comparison group was used as a reference for the study.

B. Experiment

After completing the design phase, the study proceeded a test was conducted to measure the pressure response during Non-Invasive Blood Pressure (NIBP) measurements on a vital sign monitor set at 60/30 and 80/50. Furthermore, the vital sign monitor will display the NIBP systolic and diastolic values. Following this, the result of NIBP will be shown on the vital sign monitor. The data collected from the module will undergo analysis, considering parameters such as average value, standard deviation, error, uncertainty, and deviation.

In this research, the micro air pump in this tool is used to generate blood pressure simulation waves by generating pressure on the NIBP vital sign monitor cuff. Data processing was handled by the Arduino Mega 2560 microcontroller. The TFT Nextion display, once processed through the microcontroller, enabled the selection of settings through buttons. The accompanying FIGURE 1 illustrates the block diagram, which comprises three main parts: input, process, and output. Upon pressing the on button, the system initiates, and the TFT Nextion displays parameter options.

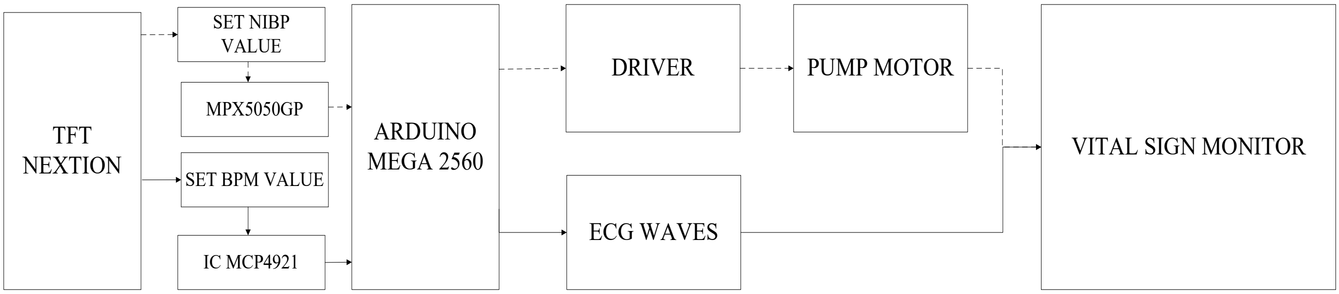

FIGURE 1. System Block Diagram in Research ECG and NIBP Simulator in One Device Display on TFT Nextion.

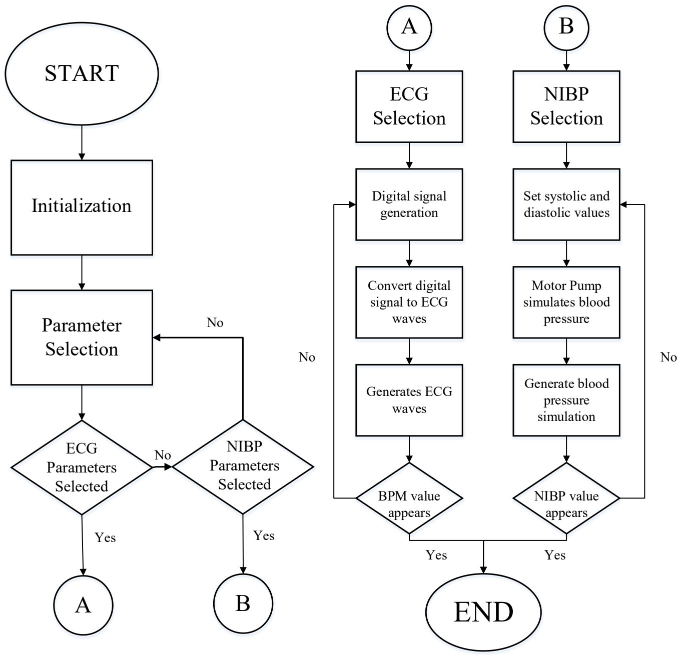

FIGURE 2. The flowchart, the temperature reading is then processed by Arduino which is then displayed on the LCD and saved to the SD Card.

Once ECG parameters are chosen, additional settings can be adjusted, and the system will commence operation based on the selected settings. The buttons on the input are used with the TFT Nextion for selecting settings in NIBP with values of 60/30 and 80/50. In the processing phase, a microcontroller is utilized to control the operation of all devices. Then when the NIBP parameter is pressed, it is followed by selecting settings and the system will start working according to the settings. Arduino Mega 2560 will process and send commands. The output of the tool will appear on the vital sign monitor.

C. The Flowchart

In FIGURE 2 show the flowchat of the system. Turn on the ON Button, after the module is activated the process begins with initialization after completion it will continue with selecting settings to calibrate the ECG or NIBP. If the user selects ECG calibration, there will be a selection of BPM settings starting from 30, 60, 120 and 180. Then it will continue with signal conversion into ECG waves. If the user selects NIBP calibration, there will be a choice of settings starting from 120/80, 150/100, 60/30 and 80/50. Then the tool will work to simulate blood pressure by producing a blood pressure simulation wave according to the setting. Furthermore, the data is in the form of a signal and the value will be displayed on the vital sign monitor.

D. Data Analysis

By applying Eq. (1) for each parameter measurement, the average value is derived using the mean or average. The average is calculated by dividing the sum of values by the number of data points in the set.:

$$\bar{x} = \frac{x1+x2...+xn}{n} \quad (1)$$

Representing the measurements, let x1 be the first measurement, x2 be the second measurement, and xn be the nth measurement. x represents the mean for the n measurements. The standard deviation is a measure indicating the extent of variation in a dataset, or the standard deviation of the mean. The formula for standard deviation (SD) is expressed as shown in Eq. (2) :

$$SD = \sqrt{\frac{\sum(xi-\bar{x})^2}{(n-1)}} \quad (2)$$

In the formula's context, x represents the average of the measurement results, xi represents the individual desired values, and n denotes the total number of measurements. Each measurement result gives rise to uncertainty (UA), signifying doubt or uncertainty. The formula depicting uncertainty is shown as Eq. (3) :

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

The total measurement uncertainty value is represented by UA, resulting standard deviation is denoted by SD, and the number of measurements is signified by n. Deviation refers to the difference between the average measurement results on the module and the average measurement results on the measuring instrument. The formula for deviation is displayed as Eq. (4) :

$$Deviation = \bar{x}module - \bar{x}measuring\ tool \quad (4)$$

In this context, the average value is represented by x. Error denotes a system error, and the lower error value corresponds to the average difference of each data point. Disparities between the standard and the design or model can be indicated by errors. The formula for error is presented as Eq. (5) :

$$\%error = \frac{(xn-x)}{xn} \times 100\% \quad (5)$$

In this scenario, x denotes the measured value of the design, while xn represents the measured value of the machine calibrator.

III. Result

In this study, vital sign monitors were tested using standard vital sign simulators and modules. The following are the results of the study

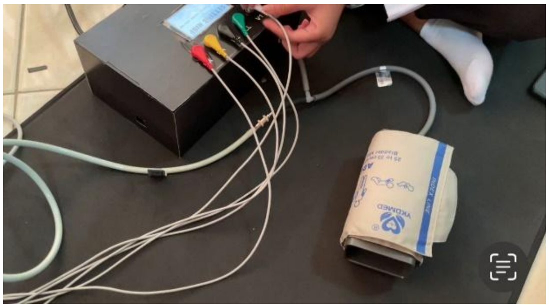

FIGURE 4. Installation of ecg and NIBP cables to the monitor module and patient

FIGURE 4 Show the results of the tool. The tool described in this study utilizes a 5V voltage supply to power various components, including the Arduino Mega 2560, DAC circuit, TFT Nextion display, motor pump, and pressure sensor. The Arduino Mega 2560 serves as the microprocessor responsible for controlling the overall system, with support from the DAC circuit and pump motor for ECG and NIBP calibration on patient monitors. The program will save the data in the In the ECG calibration process, the Arduino generates waveform data that represents the ECG signal. This data is then processed by the MCP4921 IC, which functions as a digital-to-analog converter, converting the digital signals into analog voltages to generate the ECG waveform. The output from the MCP4921 IC is subsequently passed through a voltage reduction circuit, which lowers the voltage of the ECG waves. After voltage reduction using a voltage divider circuit, the signal enters the resistor network circuit, which further refines the ECG waveform. Finally, the ECG lead connector is connected to the patient monitor to transmit the calibrated ECG signal.

For NIBP calibration with the Arduino Mega 2560, the pressure generated by the patient monitor is read using the MPX5050GP pressure sensor. The Arduino Mega 2560 then instructs the motor pump to simulate pulses by pumping for a specified period of time. When the tool's setting matches the pressure value detected by the sensor, the pump motor operates for a longer duration to simulate pressures beyond the set value. The TFT Nextion display is utilized to present the tool's settings and provide visual feedback during the calibration process.

In summary, this study presents a tool powered by a 5V voltage supply and controlled by the Arduino Mega 2560. The tool incorporates a DAC circuit, TFT Nextion display, motor pump, and pressure sensor for ECG and NIBP calibration on patient monitors. The Arduino Mega 2560 performs ECG calibration by generating waveform data and utilizing the MCP4921 IC, while NIBP calibration involves reading pressures from the patient monitor and controlling the motor pump accordingly. The TFT Nextion display serves as a user interface to visualize and adjust the tool's settings.

Here is the result of a comparison of errors in the Design with the comparison device at tool at 60/30 and 80/50 settings in the calibration laboratory. the measurement results on the Standard are taken fifteen times on the vital sign monitor.

FIGURE 3. Measurement Results at 60/30 on patient monitor

The data taken is in the form of the number of values resulting from NIBP readings from the TA module tool which has been set to NIBP 60/30 and the comparison module in the form of prosim 4 from Fluke. The measurement results taken were 15 data. One of the NIBP test results with a 60/30 setting using a patient monitor can be seen in FIGURE 5

TABLE 1
The results of Design and the Standard at setting 60/30

No	Sistole (60)		Diastole (30)	
	Module (mmHg)	Comparison (mmHg)	Module (mmHg)	Comparison (mmHg)
(X)	62.4	59.06	35.93	33.6
SD	1.45	0.68	4.9	1.66
UA	0.37	0.16	1.27	0.43
Dev	3.3		2.3	
Error	5.64%		6.94%	

TABLE 1 explains that with the results of calculating the average value and the setting standard value of 60/30, it can be seen that the measurement results obtained the average TA module for systolic is 62.4 and diastolic is 35.93 while module compared mean systolic was 59.06 and diastolic was 33.6. For the standard deviation value of the TA module, the systolic value is 1.45 and the diastolic value is 4.9, while for the comparison module, the systolic value is 0.68 and the diastolic value is 1.66. The systolic BP module uncertainty values are 0.37 and 1.27 for diastolic, while the comparative systolic module uncertainty is 0.16 and 0.43 for diastole. The systolic error values were 3.3 and 2.3 diastolic with a systolic error rate of 5.64% and 6.94% diastolic compared with the comparison module. Based on the comparison results between the TA instrument and the comparator, there is a sizable error rate, which can occur because the pressure detection sensor of the patient monitor is not optimal for systole and comparator. The diastolic value exceeds the specified parameter.

FIGURE 6 explains that the blue color is a temperature sensor compared to the orange comparison toll with an average error value of 5.64% for sistole and 6.94% for diastole.

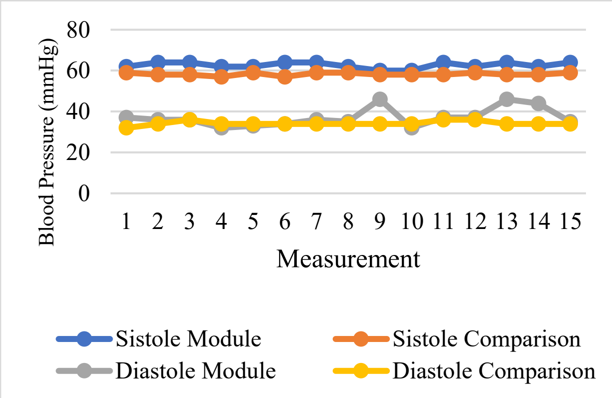

FIGURE 6. The comparison of the average results of Design and the Standard at setting 60/30

TABLE 2 explains that The average and standard values calculated for the 60/30 setting show interesting results. The module had a mean systolic value of 84.7 and a diastolic value of 54.47, while the comparison module had a mean systolic value of 81.87 and a diastolic value of 51, 6. The standard deviation of the module is 2.05 for systolic and 2.28 for diastole, while the comparison module has a standard deviation of 1.2 for systole and 1.02 for diastole. The uncertainty value for systolic module is 0.5 and for diastolic module is 0.6, while the uncertainty for comparator systolic module is 0.31 and for with a diastolic module of 0.26. The deviation values for the systolic and diastolic measurements are 2.87 and 2.87, respectively. The systolic error rate was 3.5% and the diastolic error rate was 5.6% compared with the values obtained from the comparison module. When analyzing the results and comparing tools, a remarkable error rate is evident. This event may be due to suboptimal sensor performance, affecting the patient monitor's ability to accurately detect pressure. therefore, this results in systolic and diastolic values exceeding the specified parameters. Overall, these results suggest that more attention and optimization of the sensor's capabilities are needed to improve measurement accuracy and reduce errors in the vital signs simulator.

FIGURE 7. Measurement Results at 80/50 on patient monitor

The data taken is in the form of the number of values resulting from NIBP readings from the TA module tool which has been set to NIBP 60/30 and the comparison module in the form of prosim 4 from Fluke. The measurement results taken were 15 data. One of the NIBP test results with a 60/30 setting using a patient monitor can be seen in FIGURE 7

TABLE 2
The results of Design and the Standard at setting 80/50

No	Sistole (80)		Diastole (50)	
	Module (mmHg)	Comparison (mmHg)	Module (mmHg)	Comparison (mmHg)
(X)	84.7	81.87	54.47	51.6
SD	2.05	1.2	2.28	1.02
UA	0.5	0.31	0.6	0.26
Dev	2.87		2.87	
Error	3.5%		5.6%	

FIGURE 8 explains that the blue color is a temperature sensor compared to the orange comparison toll with an average error value of 3,5% for sistole and 5,6% for diastole.

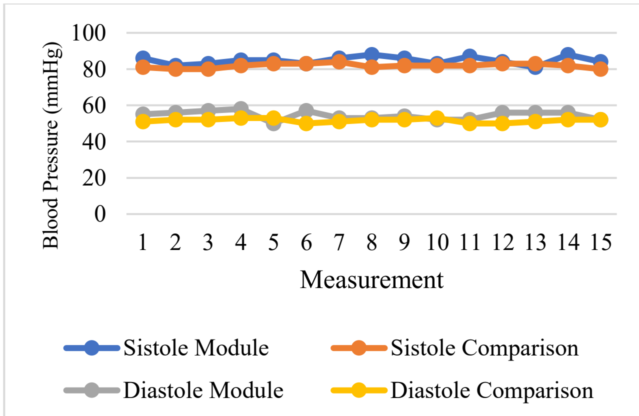

FIGURE 8. The comparison of the average results of Module and the Standard at setting 80/50

IV. Discussion

The design was scrutinized and tested extensively in this study. Therefore, the sensor reading program for each channel in the design works smoothly and works normally without any problems. TFT Nextion plays a crucial role in guiding the pre-programmed microcontroller to accurately measure Non-Invasive Blood Pressure (NIBP) using the MPX5050GP sensor. The ultimate objective is to generate and display the NIBP value on the vital sign monitor, ensuring reliable readings. During the NIBP measurement at the setting of 60/30, an error value of 7.55% was observed for systolic pressure, while the error value for diastolic pressure was 8.17%. At the 80/50 setting, the error values reduced to 3.5% for systolic pressure and 5.6% for diastolic pressure. Smaller percentage errors indicate better accuracy of the module readings. It is important to note that these error values include the calibration tolerance threshold of the vital sign monitor, which is ±5%.

The standard deviation values provide further insights into the measurement consistency. At the 80/50 setting, the largest standard deviation recorded was 2.05, while the smallest standard deviation was 1.44 at the 60/30 setting. No standard deviation values exceed the mean of the module measurements. This indicates that the mean of the modulus measurements can be considered representative of the population data. However, it is worth noting that the measurement accuracy still falls short, as the deviation value for systolic and diastolic pressures was 4.4 and 2.8, respectively, at the 60/30 setting, and 2.87 for both systolic and diastolic pressures at the 80/50 setting. These findings highlight an inherent problem with the NIBP results obtained at the 60/30 setting, as the values exceed the calibration tolerance limit of the vital sign monitor. This suggests that further adjustments or improvements are required to ensure accurate measurements within an acceptable range.To evaluate the stability of the results, the uncertainty values are taken into account. At the 60/30 setting, the uncertainty is 0.36 for systole and 1.15 for diastole. On the other hand, at the 80/50 setting, the uncertainty is 0.5 for systolic pressure and 0.6 for diastolic pressure. An uncertainty value of 0 indicates good result stability, indicating no variation in measurements. However, when the uncertainty value of the module exceeds 0, it signifies insufficient stability in the module readings.

This research was compared with the research of Nico Antonio Santoso et al who conducted research on the NIBP simulator which had a deficiency in the 60/30 setting with an error of 6.67%, whereas in this study at the 60/30 setting the resulting error was 5.64% which is smaller than Antonio's research[15]. According the research by A Darwongso et al., a blood pressure simulator was developed using the MPX5100 pressure sensor, while in my research using the MPX5050 pressure sensor where the resulting values are more accurate[17]. Similar to research conducted by A. Aditya et al. This study aims to measure blood pressure using a non-invasive approach, particularly the oscillometry method[23].

While the module provides measurements for NIBP, there are still issues with accuracy and stability, particularly at the 60/30 setting. The results obtained surpass the calibration tolerance limit of the vital sign monitor, emphasizing the need for further refinement to ensure precise and reliable NIBP measurements. The author's vision for the outcomes of this research is to make significant contributions towards the development of advanced vital sign monitoring systems. These advancements are expected to have a transformative impact on healthcare by empowering professionals with more accurate and dependable measurements. With the integration of precise and reliable measurements, the proposed advancements have the potential to revolutionize healthcare practices, leading to increased patient safety, better diagnoses, and more tailored treatment plans.

V. Conclusion

This study aimed to design a Vital Sign Simulator incorporating ECG and NIBP parameters, utilizing the MPX5050GP sensor to measure pressure during NIBP readings on a vital sign monitor. The simulator's design encompasses a comprehensive system capable of accurately simulating vital signs, including ECG waveforms and NIBP measurements. The crucial role of the MPX5050GP sensor lies in obtaining precise pressure readings required for NIBP measurement on the vital sign monitor. In summary, the study has undergone comprehensive testing, confirming that the designed simulator works as intended, successfully measuring ECG and NIBP on the vital sign monitor. When tested at the NIBP setting 60/30, an error value of 7.55% was obtained for systolic and 8.17% for diastolic. At the setting 80/50, the error values were 3.5% for systolic and 5.6% for diastolic. Smaller percentage errors indicate more accurate readings from the module. The standard deviation values ranged from 1.44 at the 60/30 setting to 2.05 at the 80/50 setting. None of the standard deviation values exceeded the average value of the module measurements, indicating that the average value can effectively represent the entire dataset. Furthermore, the study revealed an uncertainty of 0.36 for systolic and 1.15 for diastolic at the 60/30 setting, and an uncertainty of 0.5 for systolic and 0.6 for diastolic at the 80/50 setting. The data obtained from the study suggested that the vital sign monitor readings produced by the simulator are stable and fall within the specified calibration threshold for these devices. The developed vital sign simulator equipped with the TFT Nextion display serves as a valuable tool for calibrating ECG and NIBP parameters on vital sign monitors, ensuring accuracy and reliability in monitoring patients' vital signs. Future experiments may involve using other types of pressure sensors to enhance the accuracy of pressure readings. Additionally, standardization with similar sensors and making the tools portable could further facilitate their usage.

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