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Sphygmomanometer with Led Bar Display to Improve the Blood Pressure Reading Accuracy

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ABSTRACT Measurement of vital signs, including blood pressure measurement is very important to know the patient's condition. An instrument used for measuring blood pressure is known as a sphygmomanometer. In this case, there are several blood pressure meters used, one of which is a digital blood pressure meter and a mercury blood pressure meter. However, the use of a mercury sphygmomanometer has been prohibited by the government regulations from the Ministry of Health, so it is necessary to develop a sphygmomanometer technology that is allowed by the government and can be used easily and efficiently. The purpose of this study was to reduce the use of mercury which is harmful to humans, in addition to training the nurse's ability to take blood pressure readings on patients. This method research used pressure as a sensor input on the module that would be further detected by the MPX5050GP pressure sensor and converted into voltage. Sensor output data were then processed by ATMega 2560. The results of data processing were then displayed on the Led Bar display as blood pressure readings. In this case, the result of the research is the error value when testing the module's suitability value using the DPM (Digital Pressure Monitor) calibrator in a range of 0 to 0.67%. It was obtained that each set point had a different error value, in which the lowest error value among the six set points was 0%, while the highest error value was 0.67%. Meanwhile, in terms of the systole, the lowest error value was 0.2%, while the highest error value was 2.16%. Furthermore, in terms of diastole, the lowest error value was 0% and the highest error value was 5.55%. Based on the results of the research that has been carried out, the authors concluded that this module can replace mercury which was prohibited because it is dangerous for humans and trains nurses' abilities in determining blood pressure readings.

INDEX TERMS Sphygmomanometer, Led Bar, MPX5050GP, Microcontroller.

I. INTRODUCTION

Instruments used in the hospital environment take a role of assisting and promoting diagnoses and treatments more accurately. The general conditions of the equipment used as well as its handing are of great importance for good prognostics [1]. One of these instruments is the device used for measuring the blood pressure called sphygmomanometer, one of biomedical equipment, particularly as a daily measuring instrument [2], [3], used by the health professionals. In this case, the pressure of blood pushing against the wall of arteries is called as BP. Blood pressure (BP) is one of the basic windows to the healthy activity of the cardiovascular system. Accurate BP measurement is very essential and inevitable in the clinical diagnosis of various cardiovascular disorders. It has its own place in the diagnosis and management of hypertension, chronic kidney disease, vascular abnormalities, hormonal aberrations, etc [4]. In this case, BP can rise and fall throughout the day, where BP of 120/80 mmHg is considered normal [5].

Sphygmomanometer works by using a cuff that fits the patient (recommendations from the AHA-American Heart Association) with an appropriate cuff to the patient (recommendations of the AHA-American Heart Association) [6], air outlet control valve, pear, unidirectional air pump valve and manometer. In order for this device to measure a person's blood pressure with minimum measurement errors, some specific cares are required. Furthermore, there are several types of sphygmomanometers including Aneroid Sphygmomanometer and Mercury Sphygmomanometer. In this case, Aneroid Sphygmomanometer is an aneroid gauge replacing the mercury manometer. The aneroid gauge may be in the forms of wall or desk mounted or attached to the hand bulb. Meanwhile, Mercury Sphygmomanometer, is in the forms of an upper arm cuff and a hand inflation bulb with a pressure control valve; that requires the use of a stethoscope to listen to the Korotkoff sounds [7].

Furthermore, Digital Sphygmomanometer is in the forms of a pressure sensor and electronic display replacing the mercury manometer. The display may be a numerical display or a circular or linear bar graph with battery powered [8].

According to the European Union Health Commission, through the regulations that have been enforced since 3 April 2009, the use of medical devices containing mercury is prohibited [9]. This is due to the environmental concerns related to the disposal of medical waste contaminated with mercury and the hazardous risk of mercury spills [10]. The Ministry of Health has also issued an order through the Regulation of the Minister of Health of the Republic of Indonesia Number 41 Year 2019 concerning the Elimination and Withdrawal of Mercury Medical Devices in Health Service Facilities which states that the use of mercury medical devices in health care facilities will have an impact on environmental and public health problems, so their use needs to be stopped. Thus, through the Law Number 11 Year 2017 concerning Ratification of the Minamata Convention on Mercury and Presidential Regulation Number 21 Year 2019 concerning the National Action Plan for Mercury Reduction and Elimination, Indonesia has committed to eliminate the mercury medical devices in the form of thermometers, sphygmomanometer, and dental amalgam by 2020 [11], [12]. Moreover, mercury as a neurotoxin poses serious health hazard [13][14], thus, United Nations Environment Programme and various national governments have issued guidelines for the use of instruments that are containing mercury [15]. European Union and many other countries have also suggested a widespread ban for the use of mercury-based instruments [16].

Digital sphygmomanometers are known for their high accuracy and ease of use. However, the accuracy of the digital sphygmomanometer measurement also depends on the battery life used, how to use the tool, and movement during the inspection. Thus, the resulting accuracy is not always the same in every measurement. Some researchers found that aneroid devices performed so much better than digital devices where aneroid devices were significantly more accurate than digital devices of both arm and wrist. The measurement of systolic blood pressure on digital devices is considered excessive, so that it can affect the measurement results [16]. For more than a century, the mercury gravity sphygmomanometer has been the standard for indirect measurement of blood pressure. Indeed, the world primary standard for pressure measurement is a mercury manometer. It is a simple, gravity-based unit with easy calibration, infrequent need for repair, and has been validated in many clinical circumstances against direct intra-arterial blood pressure measurement [17]. Though the mercury sphygmomanometers are best to use but as there are technological advancements nowadays the digital sphygmomanometers have come into existence. Although the results and readings between the two equipment are different, the mercury sphygmomanometers are still much better than the digital sphygmomanometers [18]. Though the digital sphygmomanometer is easy to use and does not require any expertise but it does not reach the standard yet. There is a risk of people' hypertension getting misdiagnosed due to the use of this equipment. As far as detection, management, and treatment of hypertension are concerned, the digital sphygmomanometer may prove disastrous if used by health personnel for detecting hypertension [19].

Furthermore, measurement results are also influenced by the device users, for example, the paramedics in hospitals. The paramedics will read the results of the examination measurements to the patient, in this case, the accuracy or inaccuracy of the readings of the measurement results will be determined by the ability of the medical personnel in reading the results [20]. Previous study has found that about 70 percent of the time, these digital devices were not accurate within five mmHg compared to the mercury sphygmomanometer reading (used by medical practitioners) leading to flaws in making informed health decisions. The devices were off the mark by 10 mmHg about 30 percent of the time [21].

Clinical skills are the foundation of nursing practice (Bloomfield et al., 2010) used to implement strategies to ensure that students are clinically competent and registered which is a priority for educational providers, but often problematic to achieve [22]. This is because there is an increased trend of technology use in the past two decades, thus manual measurement preference decreased and people preferred more on automated recording [23]. On the other hand, the use of automated devices requires minimal training or skill and is often undertaken by non-registered staff [24], while manual BP measurement requires a more complex psychomotor skill with training and practice [24]. Blood pressure (BP) measurement is a fundamental clinical skill that is frequently performed by registered nurses and one considered technically challengingto master for nursing students [25]. Accuracy is imperative for patient health assessment and for informing clinical decision–making [26] and it is, therefore, essential that nursing students are taught to perform the skill correctly [27]. Besides measurement, recording is also important. Accurate blood pressure (BP) recording is an essential part of clinical decision-making. Yet, with the introduction of automated recording devices, the skill of taking a manual BP recording has been reported to have declined [28]. There are circumstances where a manual recording will be needed, for example, where an automated BP reading appears inaccurate when considered alongside a patient's clinical picture [29]. In addition, national guidelines recommend a manual BP recording if there is any doubt about the accuracy of an automated measurement or if the patient has hypotension or hypertension [30]. Manual BP recording is considered technically challenging to master (Bland and Ousey, 2012) but is an essential feature of accurate patient assessment and clinical decision-making and, as such, is taught in the pre-registration nursing curriculum [31].

Blood pressure measurement is an important clinical skill for nurses. Nurses taking blood pressure measurements to patients must be trained and follow appropriate procedures for measuring blood pressure using conventional mercury or aneroid sphygmomanometers and electronic blood pressure monitors. It is also identified as a potential source of error in blood pressure measurement (Wallymahmed, 2008) [32]. In 2016, Tri Rangga Rizqi conducted a research entitled a digital sphygmomanometer which was also designed by previous researchers using the MPX5100 sensor as a pressure sensor and a control system using a microcontroller [33]. This study revealed several advantages including the good skill in reading blood pressure which is also equipped with a hold as a marker, where the lack of marking will result in nurses not being able to train their abilities in determining the patient's blood pressure and for the sensor section to be too large in pressure readings. Furthermore, Januar Ariadhi Bhismantara carried out research in 2020 on Digital Sphygmomanometer with Bar Graph Display using the MPX5050GP pressure sensor because it has a good pressure reading ability. Therefore, the advantages of this study is the good ability to read blood pressure. However, the drawback of this tool is the size of the Bar Graph display which is expected to be shortened to make it easier to use [34].

Based on the background of the problem above, current researchers have not found any research in designing sphygmomanometer using LED bar to replace mercury that is forbidden by the Ministry of Health. Therefore, the objective of this research is "Sphygmomanometer with LED Bar Display" tool that is designed for several reasons, including reducing the use of mercury which is prohibited by the Ministry of Health because it is harmful to humans. Furthermore, the contribution expected from this research is to train the health workers to determine the blood pressure by the use of LED bar to avoid reading error in diagnosing the blood pressure value [35].

II. MATERIALS AND METHODS

In this study, the author proposed to make a sphygmomanometer with Led Bar Displays with the following materials and methods:

A. DATA COLLECTION

In this research, the response of the five Led Bar modules was tested after the design is complete. Each Led Bar module consisted of 30 segments. The modules were then connected vertically to produce 150 Led Bar segments. During this data collection stage, there were two data collection processed conducted, namely by using a calibrator to test the suitability value and taking respondent data to make comparisons between modules and sphygmomanometer that has been traded. The first method of using a calibrator, namely DPM (Digital Pressure Monitor), data were collected six times at each set point as in accordance with the requirements of the sphygmomanometer suitability test at pressure points of 0, 50, 100, 150, 200, and 250 mmHg. Meanwhile, the second method of collecting the data on six randomly selected respondents with an average age of 20.5 years was conducted using a module with sphygmomanometer by six times as well. The results were then compared.

FIGURE 1 shows a block diagram of the entire system. The power supply provided voltage to the entire circuit block. The cuff was attached to the patient's arm and inflated using a bulb until the cuff exerted pressure. The pressure was used as a sensor input on the module, will be detected by the MPX5050GP pressure sensor and converted into voltage. Sensor output data were then processed on ATMega 2560. The results of data processing were further displayed on the Led Bar display as blood pressure readings. Each bulb in the pump then the cuff generated pressure which caused each segment on the Led Bar to light up gradually vertically, as well as when the pressure in the cuff decreased, causing each lit segment to gradually turn off.

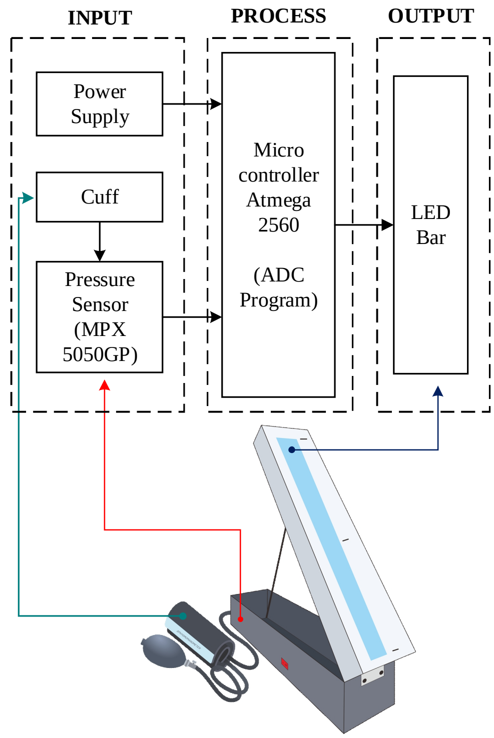

FIGURE 1. Design of Sphygmomanometer with Led Bar display to measure blood pressure in humans. The system is controlled using an Arduino MEGA module and a 10 segment Led Bar as a display of human blood pressure measurements.

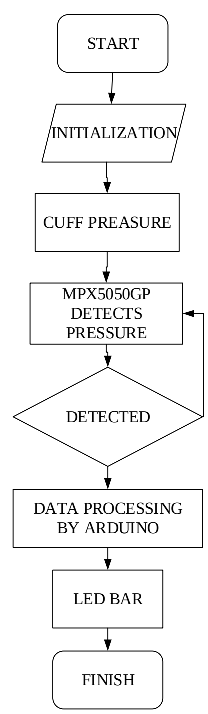

FIGURE 2. System flow chart to detect cuff pressure reading by MPX5050GP and data are processed by Arduino and displayed on the Led Bar.

FIGURE 2 shows how Arduino works. When the tool is ready, AT-Mega will initialize, the cuff gets pressure by pumping the bulb to produce pressure on the cuff. The pressure will then be detected by the MPX505GP and converted into a voltage, which then enters the internal ADC on the Arduino Mega 2560 [25]. The data from the program processing will further be displayed on the Led Bar indicator.

B. DATA ANALYSIS

Systolic and diastolic measurements were repeated 6 times for each respondent. The mean value of the measurement was obtained using the following equation (1):

$$x = \frac{X_1 + X_2 \ldots\ldots\ldots\ldots + X_n}{n}$$

where x indicates the mean (average) value for n- measurement, x_1 indicates the first measurement, x_2 shows the second measurement, and xn indicates the n measurement. Furthermore, the standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard deviation from its mean. The standard deviation (SD) formula is shown in equation (2):

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

where xi indicates the amount of the desired values, x indicates the average of the measurement results, and n shows the number of measurements. Uncertainty (UA) is doubtful that appears in each measurement result. The uncertainty formula is shown in equation (3):

$$\boldsymbol{U} = \frac{\boldsymbol{s}}{\sqrt{\boldsymbol{n}}} \qquad (3)$$

where UA indicates the uncertainty value from the total measurement, SD shows the resulted standard deviation, and n shows the amount of measurement. Furthermore, the %error shows the error of the system, the lower value error is the difference between the mean of each data, and the error shows the deviation between the standard and the design or model. In this case, the error formula is shown in equation (4).

$$\%ERROR = \frac{(\boldsymbol{x_n}-\mathbf{x})}{\boldsymbol{x_n}} \times 100\% \qquad (4)$$

where xn is the value measured from the calibrator machine. The x is the value measured from the design.

III. RESULT

Based on the results of data collection that has been carried out, the authors found an error value when testing the module's suitability value using the DPM (Digital Pressure Monitor) calibrator with a range between 0 and 0.67%. Each set point had a different error value, where the lowest error value found was 0% and the highest error value was 0.67%, namely at a pressure of 100 mmHg. This can be seen in TABLE 1 and FIGURE 3. Based on Table 1 above, the lowest mean error of among measurement at each point set of 50, 100, 150, 200, and 250 mmHg were 0.1%, while the highest error was 0.67%. In this case, the error value was described in Figure 3.

TABLE 1

The data collection between the design and the calibrator unit for six setpoints including 50, 100, 150, 200, and 250 mmHg. Every setpoint data collection was carried out six times. Note: in this study, the calibrator used was the Fluke brand DPM (Digital Pressure Monitor).

NO	Point (mmHg)	Mean (mmHg)	Error %
1	0	0.1	0.1
2	50	50.1	0.1
3	100	99.3	0.67
4	150	149.3	0.4
5	200	199.5	0.25
6	250	249.67	0.13

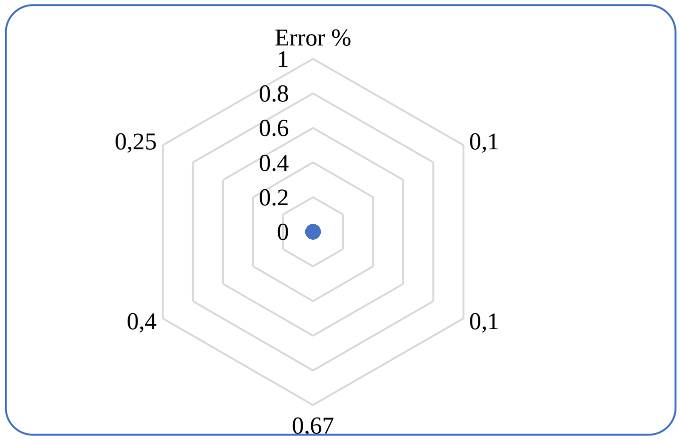

FIGURE 3. The results of data collection using a calibrator unit for six setpoints (0, 50, 100, 150, 200, and 250 mmhg) and error value.

TABLE 2

Blood pressure measurement error between the design and the calibrator unit for all set point (0, 50, 100, 150, 200, and 250 mmHg). Measurements were carried out 6 times for each set point. Note: in this study, the calibrator used was DPM (Digital Pressure Monitor) with the Fluke brand.

No	Measurement (mmHg)	Mean	Error %	SD	UA
1	0	0	0	0	0
2	50	50	0	0	0
3	100	99.3	0.67	0.89	0.365
4	150	149.3	0.4	0.89	0.365
5	200	199.5	0.25	0.77	0.316
6	250	249.67	0.13	1	0.4

Based on TABLE 2 in determining the measurement uncertainty value at each point set of 50, 100, 150, 200, and 250 mmHg, the lowest point obtained was 0, while the highest was 0.365. Furthermore, the accuracy value of uncertainty is explained in FIGURE 4.

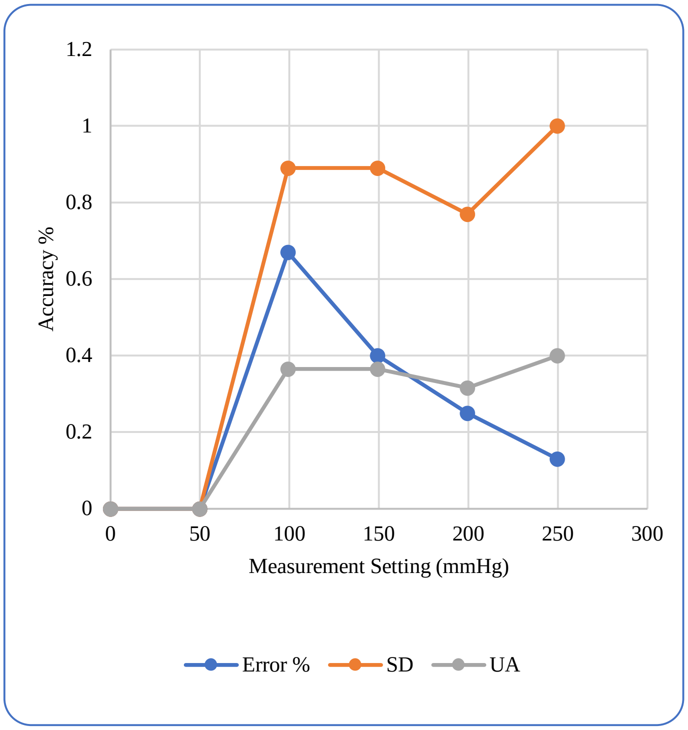

FIGURE 4. Blood pressure measurement error between the design and the calibrator unit for all set points (0, 50, 100, 150, 200, and 250 mmHg). Measurements were carried out 6 times for each setpoint. Note: in this study, the calibrator used was DPM (Digital Pressure Monitor) with the Fluke brand

The results of data collection between the module and the calibrator have been analyzed and the results were shown on TABLE 2 and FIGURE 4. In this case, the mean value, error value, standard deviation value, and uncertainty value were calculated. Each set point had a different analysis calculation results.

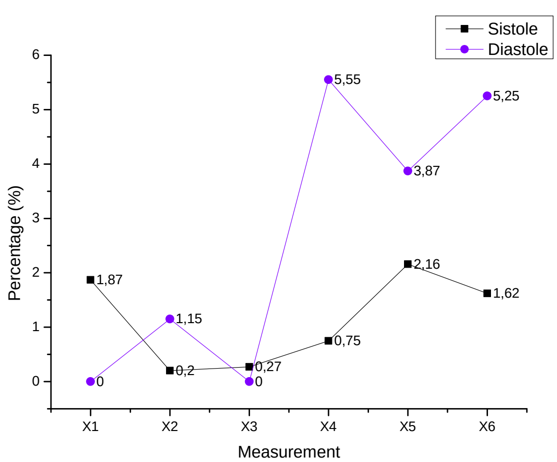

FIGURE 5. Error graph based on the results of data collection on six respondents for six times

FIGURE 5 shows the graph and table of data collection that has been carried out on 6 respondents and for 6 times for each respondent to obtain the mean value.
Based on the measurement results, mean value was obtained from the measurement results using a comparison tool in the forms of a sphygmomanometer that has been traded with the module. In this case, the final result found that the smallest error value in systole was 0.2%, while the highest error value was 2.16%. Meanwhile, the smallest diastolic error value was 0%, while the highest was 5.55%.

IV. DISCUSSION

In this study, the author made a sphygmomanometer with Led Bar Display to show the value of blood pressure in patients. This module used the MPX5050GP sensor which was used to detect pressure in the cuff. This sensor worked by pumping the bulb until the nurse found the patient's systole and diastole. From the pressure on the cuff, the MPX5050GP sensor converted the pressure into tension. The voltage was then processed by the ATMega2560 to enumerate the data and display the MPX5050GP sensor readings on the Led Bar. The use of the pressure sensor used the MPX5050GP with a relatively small error value to get more accurate results in data collection.

In this study, there were 2 data collection carried out, those are using a calibrator and comparing the module with other sphygmomanometer using several respondents. After data collection was carried out using a calibrator for six times at each set point (0, 50, 100, 150, 200, and 250), the results were further compared it with other sphygmomanometers six times for six respondents. Different error values were found in each data collection. When testing the suitability value using a calibrator, the error value obtained at each set point was different, where the lowest error value was 0% at pressures of 0 and 50 mmHg. Meanwhile, the highest largest error value was 0.67% at a pressure of 100 mmHg.

The results of data collection from the respondents involved are shown in FIGURE 5 which is the systolic and diastolic error values from six different respondents and as many as six times data collection for each respondent. Each error value has been found in systole and diastole. The lowest error value in systole was 0.2% and the highest error value was 2.16%. Meanwhile, the lowest error value in diastole was 0%, while the highest error value was 5.55%.

Y. W. Kusumaningtyas et al [33] conducted a study on digital reading equipment where nurses did not need to manually determine the patient's blood pressure. This causes nurses not to train their ability to determine blood pressure in patients. Meanwhile in this author's research, the tool used was not equipped with digital reading. It aimed to train nurses' ability in determining blood pressure in patients because it is very important for nurses in determining blood pressure in patients.

In this study, there were limitations in the manufacture of modules including that this module still used Arduino ATMega 2560 to regulate the working system of the module and was less accurate in setting pressure because it used a non-standard Led Bar as the substitute for mercury. Based on these limitations, there was a weakness in the module that has been made, namely an error value in blood pressure readings so it is necessary to minimize the error value to be more accurate in reading blood pressure in patients. However, there were also benefits in making this module, namely replacing the use of mercury which is harmful to humans and train nurses' abilities in determining blood pressure readings of the patients.

V. CONCLUSION

In this study, the author has a purpose to be carried out. This purpose is divided into two, namely the general and specific goal. The general goal is to make a "Sphygmomanometer with Led Bar Display" as a substitute for a mercury indicator. Meanwhile, the specific goal is to make a pressure gauge circuit using a sensor and Arduino ATMega as programming. Furthermore, the results of pressure measurements are analyzed and displayed in the form of a bar graph.

Furthermore, this study also involves calculations that aim to assist the data analysis. These calculations are used to analyze the results of data collection on the DPM, consisting of mean value, standard deviation, and uncertainty value in each set point. The calculation of each value in each set point further produces different result.

Based on the calculations obtained, the calculation of the mean value, standard deviation, and uncertainty value of the six data are conducted at specified set point, namely 0, 50, 100, 150, 200, and 250 mmHg. At a pressure of 0 mmHg, the mean value is 0 mmHg, the standard deviation value is 0, and the uncertainty value is 0. At a pressure of 50 mmHg, the mean value is 50 mmHg, the standard deviation value is 0, and the uncertainty value is 0. At a pressure of 100 mmHg, the mean value is 99.3 mmHg, the standard deviation value is 0.89, and the uncertainty value is 0.365. At a pressure of 150 mmHg, the mean value is 149.3 mmHg, the standard deviation value is 0.89, and the uncertainty value is 0.365. At a pressure of 200 mmHg, the mean value is 199.5 mmHg, the standard deviation value is 0.77, and the uncertainty value is 0.316. Finally, at a pressure of 250 mmHg, the mean value is 249.67 mmHg, the standard deviation value is 1, and the uncertainty value is 0.4.

Based on the results of the research that has been done, there are some limitations experienced, thus the shortcomings of the author's tool can be analyzed. The followings are some suggestions that can be considered for further refinement of research namely minimizing the presentation of error values so that the results are more precise during the reading, minimizing or changing the appearance of the Led Bar as a substitute for mercury to make it easier to use, adding a stethoscope to the device to make it easier for nurses to find systole and diastole.

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ATTACHMENTS

Schematic :

https://drive.google.com/drive/folders/1EkMPZ5QI-m-JByQuvbRm_enb6cCGDAXp?usp=sharing

Arduino Program Listing :

https://drive.google.com/drive/u/0/folders/1hwIBE7076Ea8I0BlqYeGd7-2VwKnPHzC