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Mechanical Fetal Simulator for Fetal Doppler Testing

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ABSTRACT The continuous use of fetal Doppler allows for discrepancies in values that lead to misdiagnoses in patients. This study aims to determine the effect of sound source distance on the fetal simulator with the measurement point. The contribution of this research is that the mechanical fetal heart system has 4 distances so that later it can be analyzed whether there is an influence of the location of the sound source on the accuracy of measurements using a fetal simulator. To get the desired distance, a solenoid is used which ends with a pipe of 2 cm, 5 cm, 10 cm, and 50 cm respectively. The solenoid used in the fetal simulator functions as a producer of the fetal heart. There is a rotary switch that functions for solenoid selection, namely 2 cm, 5 cm, 10 cm and 50 cm solenoids. Data collection was carried out on each solenoid and by placing the Doppler probe perpendicular and tilted. On the solenoid with a distance of 50 cm all measurement results exceed the allowable tolerance limit. The results showed that the BPM value of the two Doppler brands did not have a significant difference in value. When measuring fetal Doppler, the largest error value was 2.67%. The results of this study can be used as a reference when conducting an examination

INDEX TERMS fetal simulator, solenoid, fetal doppler.

I. INTRODUCTION

Fetal Doppler is used to detect the fetal heart rate in beats per minute (BPM) [1][2][3]. Fetal well-being is usually assessed by means of monitoring the fetal heart rate (fHR) based on Doppler [4][5][6][7]. Fetal Doppler function in continuous monitoring of fHR before and during labor is performed using a Doppler ultrasound probe that is placed in the mother's abdomen [8][9][10][11]. The location to hear the fetal heart rate is in the midline area of the fundus 2 – 3 cm above the symphysis pubis and continues towards the left lower quadrant (puctum maximum) or by ensuring the position of the fetal back [12][13]. Measurement of uterine fundal height should be performed with a consistent measurement technique in each measurement and using the same instrument [14][15][16][17]. Fetal Doppler and its probe should be calibrated periodically to avoid misdiagnosis of the patient. Calibration on fetal doppler is carried out by measuring BPM at points 60, 90, 120, 150, 180, and 210 BPM, in accordance with the Decree of the Director General of Health Services Number: HK.02.02/V/5571/2018 concerning Work Methods and or Equipment Calibration Health [18]. Based on the Regulation of the Minister of Health of the Republic of Indonesia No. 54 of 2015 concerning testing and calibration of medical devices CHAPTER I Article I, what is meant by calibration is a calibration activity to determine the correctness of the value of the designation of measuring instruments and/or measuring materials [19].

The design of the fetal simulator has been carried out by several researchers. In 2013, Ahmet Mert et al conducted a study using a modified microcontroller and relay. The results of testing on several fetal heart rate monitors are known from ten measurements there are four measurements that have a maximum error of -1.4%. However, research still needs to be done to reduce the error value [20]. In 2017, Alfina Nadhirotussolikah conducted a study using a solenoid filled with a liquid to simulate the fetal heartbeat. Based on the measurement results, the largest error value is 0.2% at the setting of 240 BPM. However, this study did not use a battery so that it was not efficient in its use [21].

In 2019, Milla Kusnaindi et al conducted research using a solenoid and a DHT22 humidity sensor. Based on data collection, it is known that the deviation of the Doppler measurement is below 1%. However, the deviation of temperature measurement is 12.4% [22]. In 2019, Amrutha B et al conducted a study using a latex balloon filled with water as a simulation of the abdomen of pregnant women with amniotic fluid. This study can simulate a fetal heart rate between 80 to 180 BPM. However, in the case of a low fetal heart rate (80 to 110 BPM), it is very difficult to calculate the heart rate because the sounds captured are difficult to distinguish [23]. In 2020, Daniele Bibbo et al conducted a study designed to use a relay controlled by an electrical signal that allows switching of two different frequencies, namely the frequency of the fetal and maternal heartbeats. This prototype has an accuracy rate of $\pm$3% of the setting frequency value, so this prototype can be used to re-calibrate the fetal heart rate monitor. However, this prototype still cannot detect the frequency at a certain value [24].

Based on the description of the literature study that has been described, there are several things that need to be resolved through a study, namely in previous studies never paying attention to the distance of the sound source. While things that happen in the field, generally the distance from the sound source can affect the value of the fetal heart rate that is read on the fetal doppler. Therefore, in this study a fetal simulator will be designed with four sound source distances with the aim of knowing and analyzing whether the sound source affects the measurement results.

This article consists of 5 Parts, Part II contains methods and development conducted, Part III is the results obtained in this research, Part IV is the discussion of the findings, and Part V is the conclusion.

II. MATERIALS AND METHOD

A. EXERIMENTAL SETUP

This study uses 2 types of fetal doppler to retrieve data. Data collection was carried out five times at solenoid distances of 2 cm, 5 cm, 10 cm, and 50 cm.

B. MATERIAL AND DEVICES

This study uses solenoid (JF-0530B, China) to simulate fetal heart [25]. Microcontroller used to processing data (Arduino Nano, 3.x, Italy) [26] and using software arduino (Version 1.8.5, Italy). LCD Character Display use to show the BPM value. Digital oscilloscope (Tektronix, USA) used to check the output. The measured fetal doppler are VCOMIN (FD2208, China) and Life Dop (LD 250, USA).

C. EXPERIMENT

Data collection was carried out five times on each fetal Doppler. And for each fetal Doppler, measurements are made on the probe in an upright and oblique position. The measured BPM are 60, 90, 120, 150, 180 and 210.

D. THE DIAGRAM BLOCK

The Fetal Doppler Simulator made has several settings as input components of the tool, namely BPM settings ranging from 60 – 210 BPM and sound source distance settings of 2, 5, 10, and 50 cm. After setting the tool there is a start button to start the tool work and stop to end. The settings that have been selected will be processed on the Arduino microcontroller and produce output in the form of digital waves with a delay that matches the settings that have been selected. The output from the microcontroller will be fed to a mechanical driver circuit which is then connected to a solenoid to generate a heartbeat simulation. The result of setting the tool that has been done previously will be displayed on the LCD of the tool (FIGURE 1).

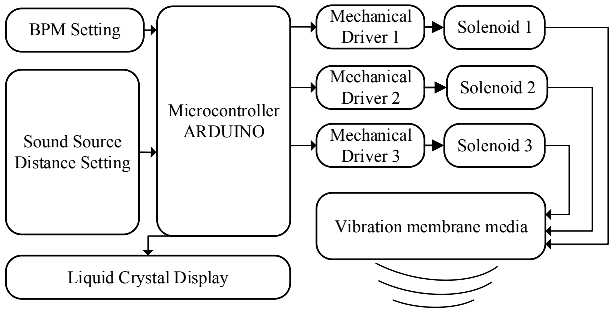

FIGURE 1. Mechanical fetal simulator diagram block

E. THE FLOWCHART

The program starts from the LCD initialization process to display the tool display, then the BPM is selected by pressing the UP button to increase the BPM and DOWN to decrease the BPM by moving 30 BPM for each selection. Followed by the selection of the sound source distance with three choices, namely 2, 5, 10, and 50 cm. After selecting some of these settings, the microcontroller produces a digital signal with a certain delay from each BPM selection and feeds the output results to the mechanical circuit on the mechanical block of the device via a connecting cable and measurements using Fetal Doppler can be performed on the mechanical block (FIGURE 2).

F. CIRCUIT

1) DISPLAY CIRCUIT

LCD is used to display the BPM value. The LCD used is a character LCD with a size of 2x16. The I2C module is used to streamline the use of pins from the LCD. So it only uses 4 pins and only needs to connect to ground, +5V voltage, pin A4, and pin A5 on Arduino.

2) SOLENOID CIRCUIT

The solenoid circuit is the core of the fetal Doppler simulator which functions as a substitute for the fetal heartbeat. By applying a voltage of 12VDC, the coil/coil of the solenoid will become a magnet so that it is able to attract the main iron from the solenoid and when no voltage is applied, the solenoid will return to its original position.

This condition will continue to repeat itself according to the desired frequency (BPM). To adjust the BPM frequency, it takes a transistor as a voltage breaker switch from the solenoid where the base will get a signal from the Arduino D6 pin. Capacitors and diodes function to prevent voltage feedback.

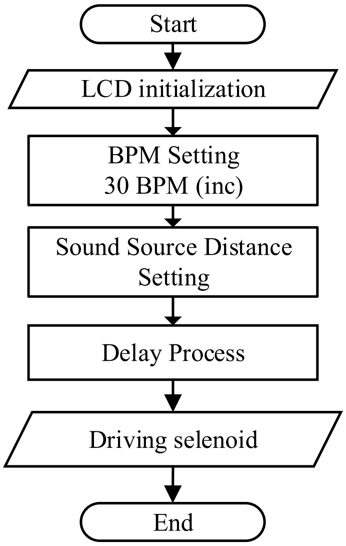

FIGURE 2. **The Flowchart.**

3) Push Button Circuit
The push button is used to adjust the BPM frequency (increase and decrease) as well as trigger the start and stop of the fetal Doppler device. Push button up is connected to pin D2, push button down is connected to pin D3, push button start is connected to pin D4 and push button reset is connected to reset pin of Arduino.

III. RESULT

A. FETAL SIMULATOR DESIGN

In this study, fetal simulator was tested using fetal doppler. On the front of the fetal maternal there is an LCD that functions to display the selected BPM value, up and down buttons that function to select the BPM value, rotary selector to select one of the solenoids to be used (setting the sound source distance), and 2 buttons to start and resets. While on the side of the fetal maternal there is a port that serves to connect the fetal maternal with the mechanical fetal heart. In the mechanical fetal heart, there are 3 solenoids placed in different positions (2 cm, 5 cm, and 10 cm) (FIGURE 3). The figure above is the result of the circuits and microcontroller that every circuit connected by cable (Fig. 7). The solenoid circuit is the core of the fetal Doppler simulator which functions as a substitute for the baby's heartbeat. By applying a voltage of 12VDC, the coil/coil of the solenoid will become a magnet so that it is able to attract the main iron from the solenoid and when no voltage is applied, the solenoid will return to its original position. This condition will continue to repeat itself according to the desired frequency (BPM). To adjust the BPM frequency, it takes a transistor as a voltage breaker switch from the solenoid where the base will get a signal from the Arduino D6 pin. Capacitors and diodes function to prevent feedback voltage. In this module there are 4 solenoids, namely 2 cm, 5 cm, 10 cm and 50 cm solenoids.

(a) (b)

FIGURE 3. **(a) Fetal Simulator Design and (b) Circuit**

B. ANALYSYS AND MEASUREMENT RESULT

According to the data above, the settings of 60, 90, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable. While the setting of 120 has an UA of 0.2 so that it can be said that BPM 120 has an unstable or changing value. This is because in five times of data collection, the resulting value is not stable. According to the data above, the settings of 60, 90, 120, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable. According to the data above, the settings of 60, 90, 120, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable (TABLE 1).

TABLE 1
Error Measurement on VCOMIN Brand Doppler with Probe Position Perpendicular with difference Distance

Setting	D=2cm	D=5cm	D=10cm	D=50cm
60	1.67%	1.67%	1.67%	-12,67%
90	1.11%	1.11%	1.11%	6,00%
120	2.67%	2.50%	2.50%	4,33%
150	2.67%	2.67%	2.67%	5,33%
180	2.22%	2.22%	2.22%	7,89%
210	0.00%	0.00%	0.00%	3,90%

According to the data above, setting 150 has an UA of 0 so it can be said that the BPM value is stable. While the 60 and 90 settings have an UA of 0.24 and the 120, 180 and 210 settings each have an uncertainty value of 0.2, 0.49 and 0.73 so that it can be said that BPM 60, 90, 120 , 180, and 210 have unstable or variable values. This is because in five times of data collection, the resulting value is not stable. According to the data above, the settings of 60, 90, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable (TABLE 2). While the setting of 120 has an UA of 0.2 so that it can be said that BPM 120 has an unstable or changing value. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings of 60, 90, 120, 150, 180, and

210 have an uncertainty value UA of 0 so it can be said that the BPM value is stable.

TABLE 2
Measurement on VCOMIN Brand Doppler with Probe Position tilt with difference Distance

Setting	D=2cm	D=5cm	D=10cm	D=50cm
60	1.67%	1.67%	1.67%	-12,67%
90	1.11%	1.11%	1.11%	6,00%
120	2.67%	2.50%	2.50%	4,33%
150	2.67%	2.67%	2.67%	5,33%
180	2.22%	2.22%	2.22%	7,89%
210	0.00%	0.00%	0.00%	4,10%

According to the data above, the settings of 60, 90, 120, 150, 180, and 210 have an uncertainty value UA of 0 so it can be said that the BPM value is stable. According to the data above, the settings of 120 and 150 have an uncertainty value (UA) of 0 so it can be said that the BPM value is stable. While at settings 60 and 90 have an uncertainty value (UA) of 0.24 and at settings 180 and 210 each have an uncertainty value of 0.49 and 0.6 so it can be said that BPM 60, 90, 180, and 210 have a value of unstable or volatile. This is because in five times of data collection, the resulting value is not stable.

TABLE 3
Measurement on Life Dop Brand Doppler with Probe Position Perpendicular with difference Distance

Setting	D=2cm	D=5cm	D=10cm	D=50cm
60	1.00%	0.67%	0.67%	-11,67%
90	1.11%	1.11%	1.11%	8,44%
120	1.33%	0.83%	1.17%	5,33%
150	2.00%	2.00%	2.00%	6,67%
180	1.67%	1.67%	1.67%	10,11%
210	2.38%	2.38%	2.38%	4,76%

According to the data above, the settings of 90, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable (TABLE 3). Meanwhile, the settings of 60 and 120 have an UA of 0.24 so that it can be said that BPM 60 and 120 have unstable or changing values. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings of 90, 120, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable. While the setting 60 has an UA of 0.24 so it can be said that BPM 60 has an unstable or changing value. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings of 90, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable. Meanwhile, the settings of 60 and 120 have an UA of 0.24 so that it can be said that BPM 60 and 120 have unstable or changing values. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings for 60, 150 and 210 have an UA of 0 so it can be said that the BPM value is stable. While at settings 60 and 90 have an UA of 0.24 and at settings 180 have an uncertainty value of 0.2 so that it can be said that BPM 60, 90, and 180 have unstable or changing values. This is because in five times of data collection, the resulting value is not stable.

TABLE 4
Measurement on Life Dop Brand Doppler with Probe TILT Position with difference Distance

Setting	D=2cm	D=5cm	D=10cm	D=50cm
60	1.00%	1.00%	1.00%	-11,67%
90	1.11%	1.11%	1.11%	8,44%
120	0.83%	0.50%	0.83%	5,33%
150	2.00%	2.00%	2.00%	6,67%
180	1.67%	1.67%	1.67%	10,22%
210	2.38%	2.38%	2.29%	4,76%

According to the data above, the settings of 90, 120, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable (TABLE 4). While the setting 60 has an UA of 0.24 so it can be said that BPM 60 has an unstable or changing value. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings of 90, 150, 180, and 210 have an UA of 0 so it can be said that the BPM value is stable. Meanwhile, the settings of 60 and 120 have an UA of 0.24 so that it can be said that BPM 60 and 120 have unstable or changing values. This is because in six times of data collection, the resulting value is unstable. According to the data above, the settings of 90, 120, 150, and 180 have an UA of 0 so it can be said that the BPM value is stable. While in setting 60 has an UA of 0.24 and at setting 210 it has an UA of 0.2 so that it can be said that BPM 60 and 120 have unstable or changing values. This is because in six times of data collection, the resulting value is not stable. According to the data above, the settings for 60, 150 and 210 have an UA of 0 so it can be said that the BPM value is stable. While the 90, 180, and 210 settings have an UA of 0.24 so it can be said that BPM 90, 180, and 210 have unstable or changing values. This is because in five times of data collection, the resulting value is not stable.

IV. DISCUSSION

In this module there are four solenoids with different distances, namely the distance of 2 cm, 5 cm, 10 cm, and 50 cm. The solenoid with a distance of 50 cm is filled with +150 cc of water, the water is filled to a length of 45 cm so that there is 5 cm of space for the solenoid. It can be seen that measurements on each solenoid with the same BPM using two brands of fetal Doppler obtained the same results. At solenoid distances of 2 cm, 5 cm, and 10 cm with the probe position perpendicular or tilted, the BPM values of the two fetal Dopplers did not deviate from the allowable tolerance limits. However, the largest error value is still 2.67%. Meanwhile, at the solenoid distance of 50 cm with the probe position perpendicular and tilted, the BPM values of the two fetal Dopplers deviate from the allowable tolerance limit, which is ±5% of the setting. In previous studies the research using relay controlled by an electrical signal that allows switching of two different frequencies, namely the frequency of the fetal and maternal heartbeats. This prototype has an accuracy rate of ±3% of the setting frequency value and this prototype still cannot detect the frequency at a certain value.

V. CONCLUSION

The purpose of the current study was to analysis is there any effect from difference distance of mechanical fetal simulator. From this study can be presented Fetal Simulator using low-cost materials and have high accuracy in BPM and the value displayed is accurate when compared to the oscilloscope. This research still needs to be developed to be more perfect. In future work needed to make more the vatious distance of solenoid so the analysis of the data is more.

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