Microcontroller-based Fetal Heart Motion Emulator

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***Abstract* - The previous fetal heart motion emulator system is operated and controlled by a computer. This system is inflexible to be transported from one place to another and requires a high cost to build. After a few years, people move toward design that is portable and cost effective. A solution to these problems is to design an embedded system that provides a portable fetal heart emulator system which can be applied to assist biomedical engineer in testing a new fetal heart rate monitoring instruments. The system uses a microcontroller to produce fetal heart valve motion. A couple of aluminum strips are used to represent mitral valve and aortic valve that are attached to electromechanical servo motors. The examination of the fetal heart emulator is done by transmitting ultrasonic waves from an amplitude-scan ultrasound device to the emulator's valve motion. The output scanned from the emulator is compared with signal waves obtained from real fetus for evaluation and improvement.**

Keywords - ***fetal heart motion; portable; microcontroller; servo motor; ultrasound.***

I. Introduction

Monitoring of fetal heart is extremely important before and during labor to provide clinicians with essential data relating to the wellbeing of the fetus. This data is used as a tool in aiding the clinicians to make decision in the management of the maternal and the fetus [1].

Fetal Heart Rate (FHR) is used in diagnosing fetal distress to determine the health status of the fetus. Basically, FHR can be obtained by electronic fetal heart rate monitoring or intensive intermittent auscultation. Electronic fetal heart rate monitoring offer more cost effective means of surveillance than does auscultation [2]. Doppler ultrasound is the method most common in electronic monitoring to indirectly record FHR.

In order to develop a working fetal monitor, an emulator is needed to examine the function of monitoring device. The emulator must be able to provide unambiguous information regarding the cardiac activities to be analyzed by using Doppler Ultrasound device. There are several methods of designing a fetal heart emulator. In the early invention, fetal heart motion was represented by using the sound of heart beat that was produced on a speaker and controlled by a computer [3].

However, an emulator controlled by a microcontroller is required since a portable system is preferred nowadays. In addition, it is more effective to produce the fetal heart beats by imitating the real motion of the heart walls and valves by using a microcontroller.

Thus, this paper describes the design and development of a microcontroller-based fetal heart motion emulator. A Peripheral Interface Controller (PIC) which is a type of microcontroller is used to produce the fetal heart valve motions. Apart from that, a couple of servo motors are used in the design to move a couple of aluminum strips which represent two fetal heart valves. The valve movements are acquired using a Doppler Ultrasound and the resulted signals were analyzed.

II. Dimension of Fetal Heart and Its Position in Maternal Abdomen

Before the fetal heart emulator can be designed, it is essential to acquire the dimension of maternal uterus, the depth of fetal heart valve from ultrasound transducer (see Fig. 1) and the dimension of mitral and aortic valves of a fetus.

The fetal breathing activity and body movement causes heart rate in response to fetal oxygenation and metabolic state. Fetal movements begin early in pregnancy; on average maternal perception of fetal movements occur at about 20 week of gestation [4]. Therefore, an ultrasound is generally performed for all maternal at 20 weeks of gestation.

The diameter of maternal uterus can be obtained from the abdominal circumference (AC) of the fetus. At 20 weeks of gestation, the average value of AC is 15 cm [5]. According to Murata et.al [6], the distance between the ultrasound transducer and fetal heart is 20 cm. They reported that the distance from the transducer to the heart was obtained by repeating different possible position relative to the abdominal transducer [7].

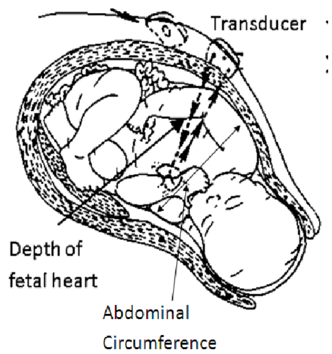

Fig. 1. Position of fetal heart in maternal abdomen

Normally, there are four components of fetal heart that being assessed by clinicians; atrial wall, ventricular wall, mitral valve and aortic valve. However, the monitor only uses mitral valve and aortic valve motions to calculate the heart rate. The position of mitral valve and aortic valve can be seen from Fig.2.

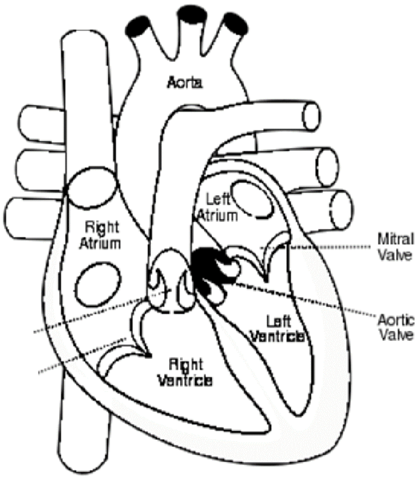

Fig. 2. Position of mitral and aortic valve in a human heart

The mitral valve lies between the left atrium and the left ventricle whereas the aortic valve lies between the left ventricle and the aorta [8]. The average aortic valve diameter of a fetal heart is 10 mm whereas the mitral valve diameter is 11 mm [10] [11].

III. Design and Development Of Fetal Heart Motion Emulator

The design of fetal heart motion emulator was divided into two parts; mechanical part and electronic circuit. The emulator system was basically designed to produce mitral and aortic valves' motions that mimic the real fetal heart valve movements after the device was switched on. Besides that, the emulator was structured in a way that it can be easily carried from one place to another.

A. Mechanical Part

The mechanical design of fetal heart motion emulator consists of two parts; the Artificial Valve Unit and the Holder. In order to obtain the most accurate results, the dimensions of the mechanical design were selected according to the dimension of maternal uterus, the depth of fetal heart valve from ultrasound transducer and the dimension of mitral and aortic valves of a fetus.

Initially, the mechanical part was designed by using Autocad software to view the overall structure before the parts were assembled. The design layouts were designed in 2D and 3D as shown in Fig. 3 and Fig. 4 respectively.

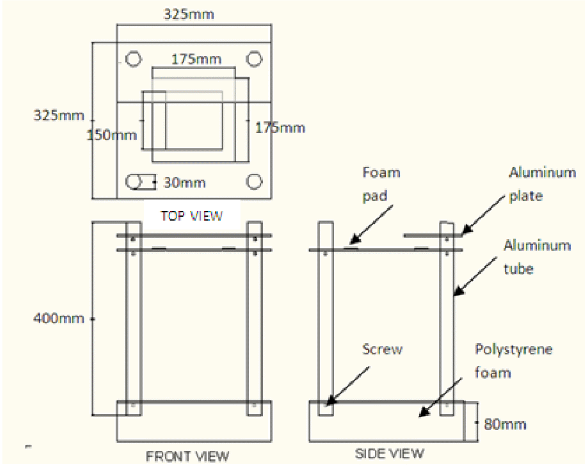

Fig. 3. 2D orthographic diagram of the Holder

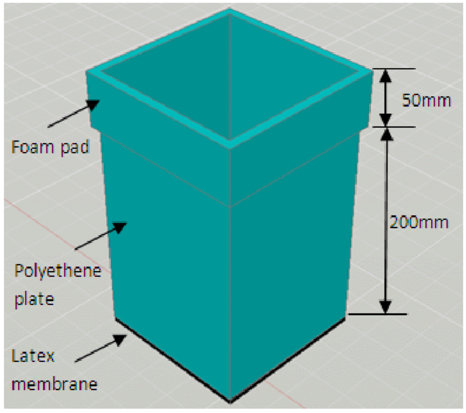

Fig. 4. 3D isometric diagram of Artificial Valve Unit

The parameters obtained from real patient data were used to develop the Artificial Valve Unit as (see Fig. 4) whereas the holder was constructed to hold the artificial valve unit during monitoring examination process. Apart from that, a latex membrane was placed at the bottom of the Artificial Valve Unit which represented mother's abdomen and as an interface for the ultrasound transducer. Latex was the most suitable material to represent human skin. The artificial valve unit was filled with water as a substitute to amniotic fluid during examination process. Note that there were foam pads in both Artificial Valve Unit and the Holder. The foam pads were used to reduce vibration of servo motor during ultrasound examination process which may lead to the occurrence of noise.

A couple of aluminum strips representing mitral and aortic valves were included in the mechanical part. The widths of the aluminum strips were taken according to the diameter of real fetal heart valves (see Fig. 5). Height of the aluminum strips were determined from the height between the servo motor and how deep the strips being immersed into the water. Only the loose part of the strip was immersed into the water which was about 3cm. This design was to ensure that the strips were flexible enough to move in the water.

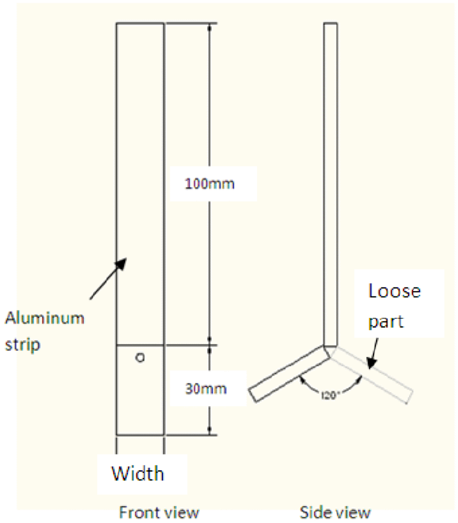

Fig. 5. Diagram showing dimension of aluminum strip

B. Electronic Circuit

The electronic circuit consists of a 16F877A Peripheral Interface Controller (PIC), a crystal clock, a power switch, a reset switch, an input switch and a couple of Power HD-1160A servo motors. The main function of the PIC was to produce a series of pulse to control the rotation angle of the servo motors and the time intervals between each motor movement. The servo motors were attached to the aluminum strips that represented the heart valves. The circuit was connected to a 5 Vdc power supply by using a DC adapter. Strip 1 represented the mitral valve whereas Strip 2 represented the aortic valve. At first, the schematic circuit was simulated by using Proteus software before it was fabricated on a Printed Circuit Board (PCB). Fig. 6 illustrates the block diagram of overall electrical system in the fetal heart emulator.

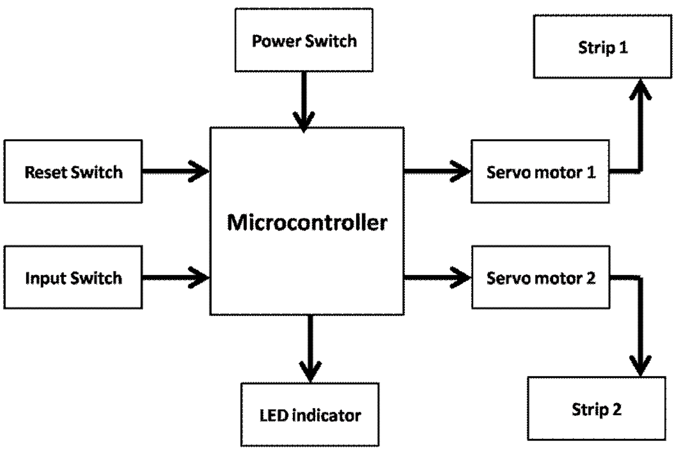

Fig. 6. Block diagram of the electrical system

The inputs of the microcontroller were Reset Switch and Input switch while the outputs were LED indicator, Servo Motor 1 and Servo Motor 2. The function of Power Switch was to deliver the 5 Vdc voltage supply to the electronic circuit.

The schematic circuit of the emulator is shown in Fig. 7. There were numbers of unused Input or Output (I/O) ports made available on the PCB for future improvement on the circuit.

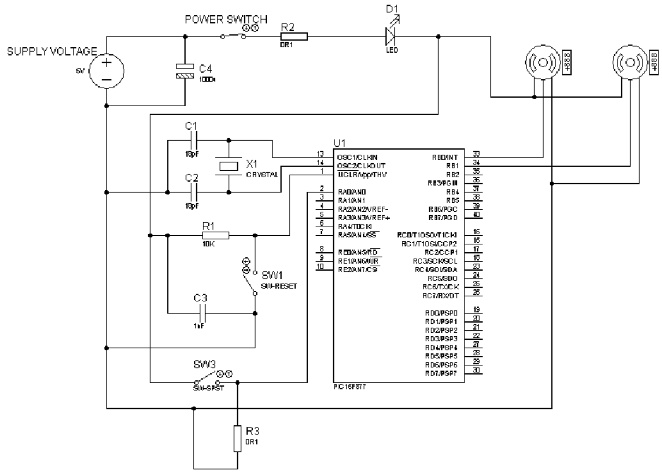

Fig. 7. Schematic diagram of the emulator

IV. CONTROLLING SYSTEM

There were four valve motions involved in the fetal heart emulator system. The motions started with mitral valve opening, and then followed by mitral valve closing, aortic valve opening and aortic valve closing. The duration and the occurrence of valve motions were taken from the valve durations (see Fig. 8) obtained from real patient data [9].

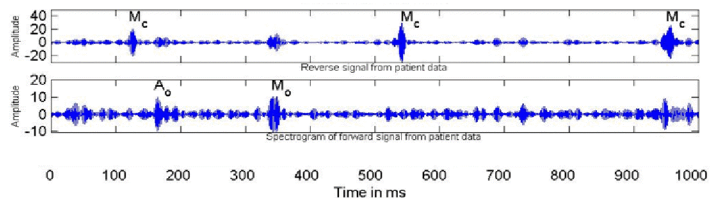

Fig. 8. Mitral and aortic valves' signals obtained from real patient. Note: Mo – mitral valve opening, Mc - mitral valve closure, Ao - aortic valve opening and Ac - aortic valve closure

The valve motions were represented by different position of servo motors (see Fig. 9). However, the rotational angle of servo motors was fixed to 5 degree but either in clockwise direction or counter clockwise direction. The position was controlled by sending pulses of variable width where they were produced and adjusted by programming the PIC. For a degree of rotation, the servo motor must be sent with 11 µs pulse width signal. The period of the pulse must be 20 ms because the typical operating frequency for the servo motor to operate was 50 Hz.

Fig. 9 shows different positions of servo motor according to the valve movements that they represented in the emulator. The movements were programmed to change in sequence as referred to the real patent data (refer Fig. 8). Table 1 shows the pulse widths needed to move the servo motor to the required angles and directions.

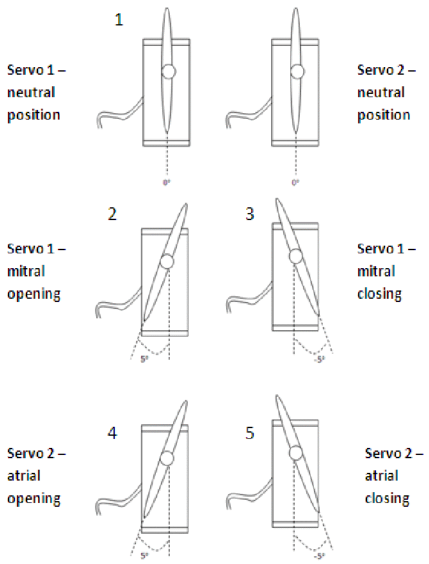

Fig. 9. Diagram showing different positions of servo motor used in the fetal heart emulator.

TABLE 1. PULSE WIDTHS REQUIRED FOR SERVO MOTOR TO ROTATE AT DIFFERENT ANGLES AND DIRECTIONS

Pulse Width (ms)	Rotation angle (degree)	Direction
1.500	0	Neutral
1.445	5	Clockwise
1.555	5	Counter clockwise

In order to control the movements of aluminum strips, a controlling software was developed. The software was written in C language which was then converted to PIC assembly language using CCS C Compiler. The program flow of the controlling software is shown in Fig. 10.

The process started by initializing all input and output ports that were used in the program. Then, the microcontroller will read the input switch to determine whether it was on or off. When the switch was on, the microcontroller will produce 1.5 ms of pulse width to set both servo motors in neutral position (90 degree). After certain amount of delay, Servo Motor 1 started to rotate 5 degree to the left (from front view) indicating the movement of mitral valve opening. The motor was then stayed at the position for 160 ms. After that, the same servo motor started to rotate 10 degree to the right and stayed at the position for 100 ms. This movement indicated the mitral valve closing. Then, Servo Motor 2 started to rotate 5 degree to the left indicating the movement of aortic valve opening. It stayed at the position for 150 ms. Lastly, the motor rotated 10 degree to the right. The process will loop back to the point where Servo Motor 1 rotated 5 degree to the left if the switch was still on.

There were two methods to instruct the servo motor to stay in a position before rotating to another position. First, the same pulse width must be repeated according to the required duration. It must be considered that each pulse cycle took 20 ms. Therefore, if the motor needed to stay at a position for160 ms, 8 cycle of pulses were required. Another method was by sending only one cycle of pulse to the motor. Then set the motor to off for certain amount of time. This method was suitable for delay time that cannot be factored by 20. If a motor needed to stay at a position for 150 ms, a pulse cycle (20 ms) must be sent followed by 130 ms of off time.

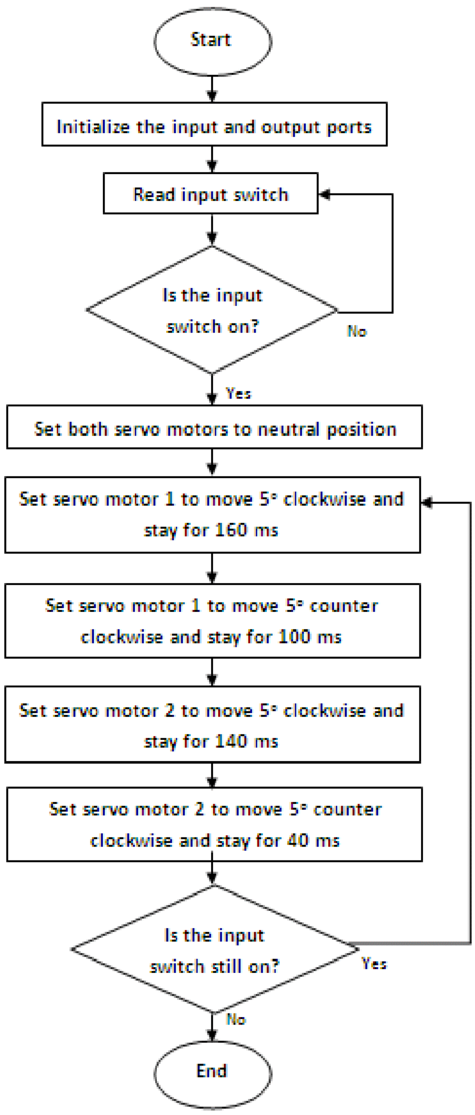

Fig. 10. Process of controlling the servo motors to generate emulated signals

V. Experiments

Before the pulse width signals driven from PIC was passed to the servo motors, the signals were tested and monitored by using an oscilloscope. This was done to avoid the servo motor from any damage due to incorrect range of pulse. Besides monitoring the pulse width and period, the oscilloscope was used to validate the duration of each motion as programmed in the PIC.

After the emulator model was completely assembled and ready to be operated, it was examined by transmitting ultrasonic waves to the emulator from a GAMPT-Scan ultrasonic measurement device. The scan was conducted in Amplitude-Scan (A-Scan) mode with 2 MHz transducer connected to the receiver. The transmitter was able to transmit and receive ultrasound signals at the same time. In order to run the examination by using this device, the transducer probe was dipped into the water and perpendicularly directed to the aluminum strips' movement (see Fig. 11).

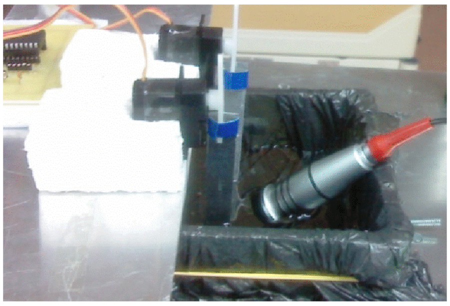

Fig. 11. Diagram showing how the ultrasound transducer being applied to the fetal heart emulator

At first, the emulator was run with one servo motor at a time. This was conducted to examine the Doppler Ultrasound Signals (DUS) produced for each motion and to detect any expected noise. During examination, the gain of transmitter, the gain of receiver, the distance between the transducer and the aluminum strips were varied to obtain the most accurate reading. However, the time gain control of the ultrasonic device including start point, slope, width and threshold was set to a constant value along the examination. In order to improve the results from time to time, every reading obtained from the emulator was compared to the reading obtained from real patient. After all single readings were evaluated; the emulator was run with both mitral and aortic valves moving simultaneously to acquire full cycle of valve motions.

VI. Results and Discussion

Fig. 12 shows the pulse signals obtained at Port B0 of microcontroller that was connected to Servo Motor 1. The pulse width measured from the digital oscilloscope was 1.6 ms whereas the pulse cycle was 20 ms. It was found that the pulse width obtained from oscilloscope was not the same as the pulse width programmed in the PIC which was 1.555 ms for 5 degree rotation in counter clockwise direction. This happened due to the limitation on resolution of the digital oscilloscope. It can only display the duration value until 1 decimal number in ms. As a result, 1.555 ms is being rounded to 1.6 ms.

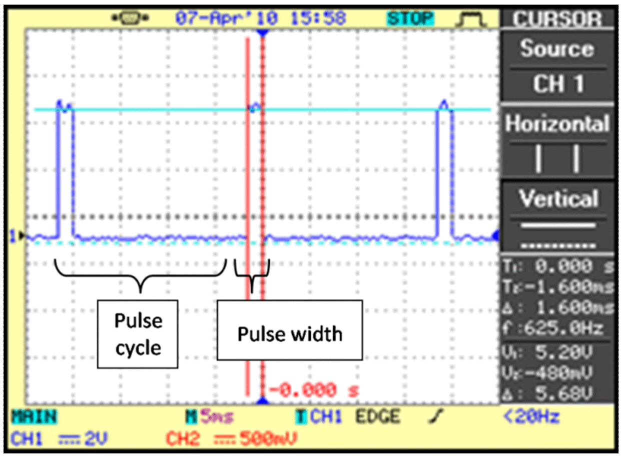

Fig. 12. Pulse signals obtained at the output of microcontroller that was connected to Servo Motor 1

Fig. 13 and Fig. 14 shows the pulse signals driven out from Port B0 and Port B1 of the PIC that were connected to Servo Motor 1 and Servo Motor 2 respectively as output ports. The blue signal was the signal used to drive Servo Motor 1 while the red signal was used to drive Servo Motor 2. When both signals were monitored at the same time, the duration between each motor movement was able to be measured. On the top signal in Fig. 13, 8 pulse cycles on the left shows the duration between first position to second position of Servo Motor 1 indicating the duration between mitral valve opening to mitral valve closing. The value measured was 160 ms, same as what it was programmed in the controlling software. The following 5 cycles on the right shows the duration between second position of Servo Motor 1 to first position of Servo Motor 2 indicating the duration between mitral valve closing to aortic valve opening. The value obtained was 100 ms, same as what it was programmed.

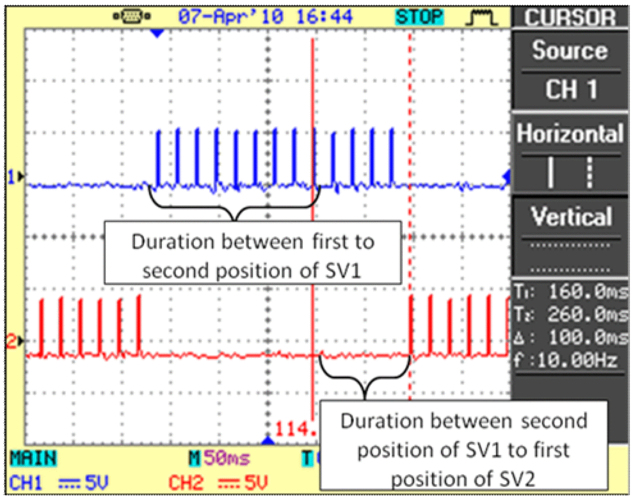

Fig. 13. Pulse signals obtained at outputs of microcontroller that are connected to Servo Motor 1 (signal above) and Servo Motor 2 (signal below) part 1

On the bottom signal in Fig. 14, 7 pulse cycles on the left shows the duration between first position to second position of

Servo Motor 2 indicating the duration between aortic valve opening to aortic valve closing. The value measured was 150 ms, same as what it is programmed in the PIC. The following 2 cycles shows the duration between second position of Servo Motor 2 to first position of Servo Motor 1 indicating the duration between aortic valve closing to mitral valve opening. The value obtained was 30 ms, same as what it was programmed in the software.

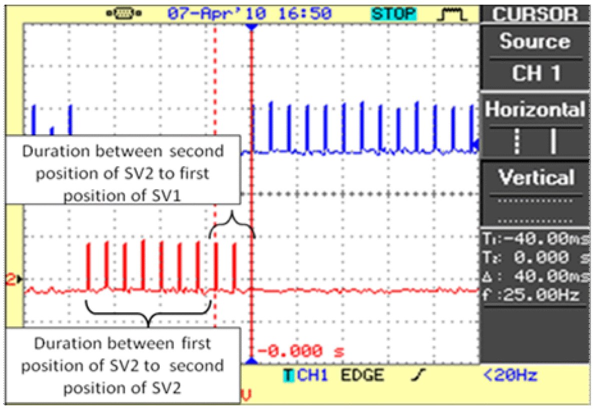

Fig. 14. Pulse signals obtained at outputs of microcontroller that are connected to Servo Motor 1 (signal above) and Servo Motor 2 (signal below) part 2

By using the GAMPT-Scan equipment, a one cycle of emulated signal can be produced due to memory storage limitation of the equipment (see Fig. 16). Fig. 15 shows the Doppler Ultrasound obtained from each valve movements separately. The shape of emulated signal was almost the same as that obtained from patient data (refer Fig. 8).

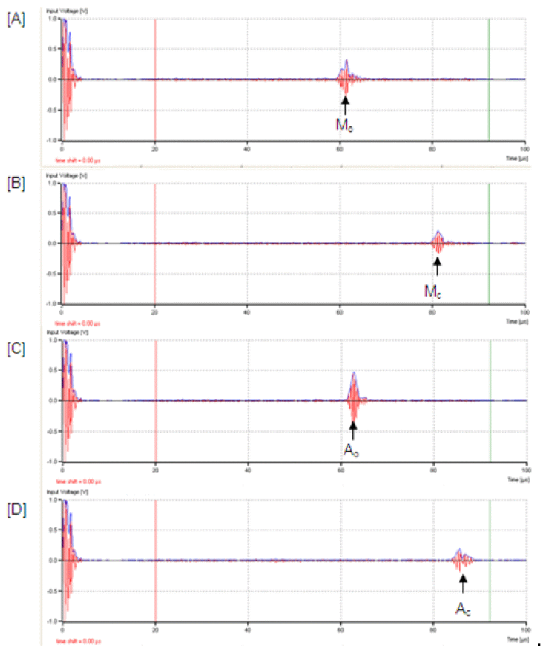

Fig. 15. Diagram showing emulated signals obtained from each valve movement separately. [A] The mitral valve opening signal [B] The mitral valve closure signal [C] The atrial valve opening signal [D] The atrial valve closure signal at a time.

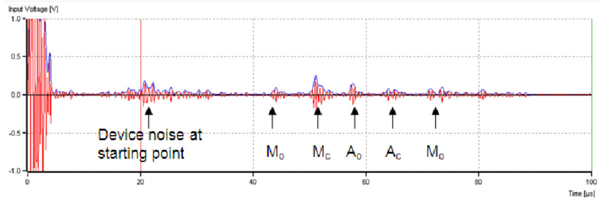

Fig. 16. Diagram showing one cycle of emulated signal obtained when both servo motors move simultaneously.

The amplitude of emulated Doppler Ultrasound Signal (DUS) was not the same as DUS obtained from real patient. Factor that can affect the amplitude reading was the angle between the sound beam and direction of valve motion. The transducer should be placed at the right angle to the direction of valve movements to get high amplitude of DUS. This was difficult to achieve using GAMPT-Scan equipment. In real practice, this was a common problem that was encountered using fetal heart monitor. Since there was a limitation with the GAMPT-Scan equipment, the long emulated data will be captured with other ultrasound equipment and further analysis will be carried out.

VII. Conclusion

In conclusion, the design and development of the microcontroller-based fetal heart emulator have been discussed in this paper. The system has the capability to produce fetal heart motion for mitral and aortic valves with the advantage of being portable.

Modification and advancement can be made to the emulator in the future to vary the heart valve motion according to different cases of fetal health condition. The emulator can be improved to receive input from user by displaying menu on a Liquid Crystal Display providing choices to change the rotation angle of the servo motor or speed of the valves motion. Apart from that, the fetal heart emulator can be expanded to include other motions in heart such as atrial wall and ventricular wall movements.

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