Mechanical Heart-Motion Generating System for Biomedical Applications

Jay Awale[a], Anju Gupta[b]

[a] Capgemini Technology Services India Limited, Pune

[b] Department of Electronics Design Technology, Shri Ramdeobaba College of Engineering and Management, Nagpur, Maharashtra, India

Abstract:

The pacemaker is a battery-powered medical device that Bradycardia patients use to correct their heartbeat. About 5-7 years are the maximum lifespan of the pacemaker battery. Once the battery fully discharges, a patient undergoes surgery to replace the battery, which is costly and painful. The piezoelectric energy harvesting method, which increases the life of rechargeable pacemaker batteries by capturing energy from heart action, is one approach to the problem. For testing such harvesters, animal testing is a prime concern. To get around this problem, we built a mechanical heart that replicates the anatomical motion of the human spirit. The model reproduces the movement of the four chambers of the heart. The model accurately reproduces the motion of the heartbeat with a minimal BPM (Beats per minute) error at average BPM (60–100) and an error of roughly 8.4% at high BPM (110–130). The mechanical model has a 3D- designed silicon cover/shell in the shape of the heart. The cover provides a more realistic anatomical heart movement. In addition to being utilized for medical research, this heart model is used to test pacemaker battery recharging. The flexible tiny Piezo sensor, mounted to the bottom of the heart model, transforms the mechanical stress of the heart's movement into electrical energy. This model could replace a portion of animal testing. The result demonstrates that the model simulation is error-free in a real-time operation.

Keywords *:Pacemaker; Mechanical Heart; Anatomical Heart Piezo Sensor; Rechargable batteries*

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1 Introduction

The most crucial part of our body is the heart. When the heart cannot pump enough blood, it results in bradycardia or tachycardia, which is the cause of heart failure. Such diseases are treated by surgically implanting a patient with an **electronic pacemaker.** An artificial cardiac pacemaker is a small device placed in the chest or abdomen to help control abnormal heart rhythms called arrhythmias. Without significant flaws, the batteries must be replaced typically every seven to eight years (Asri et al., (2019), Robinson (2019). Battery replacement surgeries increase overall cost, patient discomfort, recovery time, and intra-op and post-op complications. Biomedical research industries are trying to develop self-charging power cells for pacemakers. According to the operational principles of these devices, heartbeats can be converted into electrical energy to help with battery charging by utilizing piezoelectric materials [Anand and Kundu (2019), Han *et al.*, 2018, Eghbali *et al.*, 2020, Zagabathuni and Kanagaraj(2022)]. Before being used in clinical settings, the device needs evaluation. The most popular animals employed in these investigations are pigs and mice. [Gururaj *et al.*, 2018, Li *et al.*, 2019, Zhang *et al.*, 2017, Dagdeviren *et al.*, 2014, Lu *et al.*, 2015, Cheng *et al.*, 2016] the suffering, misery, and deaths that animals endured during studies have long been a source of controversy animal research has a few other drawbacks outside the main ethical issue, such as the need for trained labor and lengthy protocols and high expense. To address these concerns, we created a mechanical heart model that resembles an essential human anatomical heart on the outside. It works with internal mechanical parts to generate movement in all four sections of the heart (Right atrium, Left atrium, Right ventricle, and Left ventricle). This device will generate rhythmic heart movement based on the user's specified beats per minute value, demonstrating how our hearts will react to specific moments or situations. It enables the user to test his devices in various heart conditions. We can use this device for research instead of performing expensive and complicated surgeries. These devices have numerous applications in biomedicine research and other fields. This animal laboratory device supports *the three R's of research reduction refinement* and *replacement*. This paper shows a mechanical heart model with a silicon elastomer outer body; it is in some ways a replacement for the complex and expensive procedure for experimental animals because it lives longer than the stah model it can be tested on animals

2 Materials and Methods

Pacemaker implantation is a 2-5hrs long surgery procedure having about 97-99% success rate but performing it after every 7-12 years for battery replacement is troubling and inefficient (Shiheido, E. and Shimada (2013). The rechargeable battery used in the pacemaker can eliminate the requirement of reoperation increasing the survival rate of the patient. The new research development on the rechargeable pacemaker is at a slow pace due to little survey available as it requires at least 5-8 years of observation for any concrete review. A drawback of animal testing is that we require maintaining the heart condition of the animal for a long period to be able to perform any tests. It is expensive and unethical to perform regular animal testing.

In the study of 2017, STAH (Soft Total Artificial Heart) was developed with biomimetic heart movement. It was made of a single silicone elastomer which pumped the blood using air pressure (Cohrs *et al.*, 2018) This model has a major disadvantage in that the elastomer body of the sTAH would rupture after the 120-150 pumping cycle . It is impractical to perform a test on this model.

The main objective of the system is to give a easy, simple and errorless solution by using a mechanical heart instead of real hearts for generating rhythmic cardiac cycle movements for purpose of various testing experiments and studies.

In this project we are using a machine having similar dimensions of real heart (of adult person) with four movement generating sections operated by four servo motors. Servo works on BPM (beats per minute) value which is given by user itself. This is done by using keypad and LCD Display.

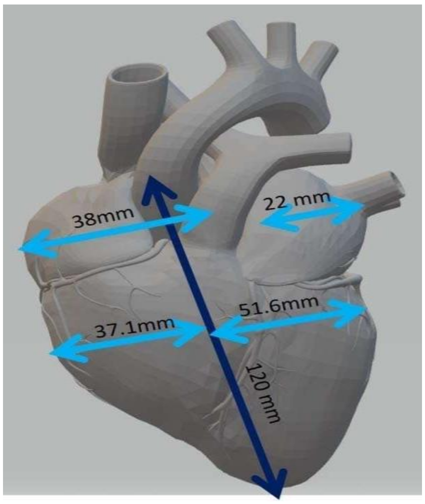

Figure 1. *The dimension of heart [*Asri et al., 2019*]*

In normal condition left atrium has a width of up to 38 ±3mm although it will increase to 41 to 46 mm in mild state, in moderate it will increase to 47 to 51 mm and in sever it increase further to 52 mm to so on. Right atrium is quite smaller in size than left atrium having height of 55 mm and width of 22 mm in normal condition, while in mild enlargement it will increase to 26 mm then up to 32 mm in moderate and in severe state it tends to greater than 32 mm (Fig.1).

In Addition, outer jacket must be of perfect size and shape. Printing of outer jacket is possible using 3D printing technique. The technology of 3D printing has allowed the production of complex geometry of outer surface of human heart using silicon material. 3D printing is possible but it takes

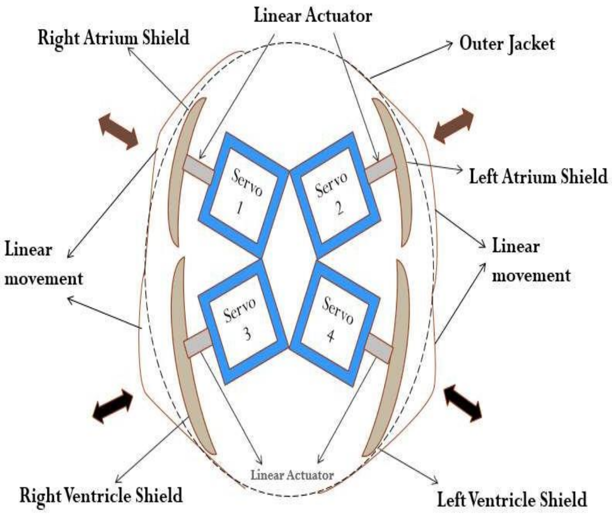

Figure.2. Heart internal hardware model

There are four servo motors placed inside the heart jacket whose shafts are connected to shields, four shields for four sections of heart. Each shield can move jacket for specific distance which is predefined. Shields are fixed with shaft called as linear actuator of servo motor, this shaft is able to move in forward and reverse direction. These shields are designed using 3D technique. When shield moves in forward and reverse outer jacket also move and give realistic movement of jacket like an actual human heart shown in Fig 2.

Linear actuators are designed in such a manner so that it can generate forward and reverse movement of shaft. This hardware is placed on a stand for freely movement of jacket and other components LCD, Keypad and power supply are placed outside it. Detailed design shows the mechanism and components used in system. Operation of this system is briefly shown by below block diagram Fig. 3.

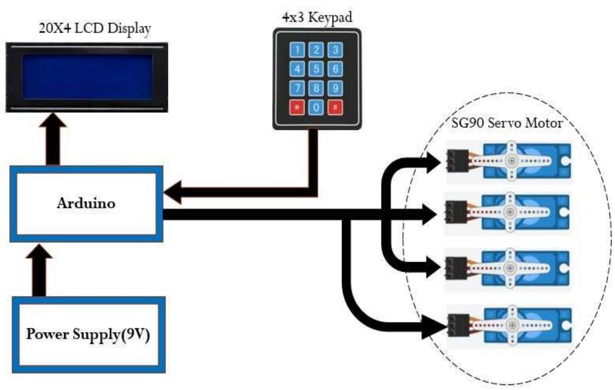

Figure 3. Block Diagram of the hardware model of the System

After turning on power supply, system starts to show basic introductory information on LCD display. Switch is used for turning on and off movement of this system. But before starting beats processor must know how many BPM it needs to generate, initially at the start of system BPM is automatically set to 30. System has range of BPM up to 130, it will automatically show state of heart during specific BPM such up to it will show 'Bradycardia' from 60 to 100 it will show normal condition and for 100 to 130 it will show 'Tachycardia'. User can change BPM manually using following steps.

Steps to change BPM manually:

1. Turn off the switch
2. Press # on keyboard (Give command to processor for manual change of BPM)
3. Enter required BPM using keyboard
4. Press # for confirming
5. Turn on the switch (To start the movement of system at required BPM)

System uses four servo motors for four sections of heart (RV- Right Ventricle, RA- Right Atrium, LA- Left Atrium and LV- Left Ventricle), cardiac cycle is done by these servos. The only thing required is user defined beats per minute. After entering number of beats processor calculates required delay in each beat.

The complete process of refilling of blood in heart and pumping blood from heart to whole body this process is called as cardiac cycle. Cardiac cycle consists of two periods; refilling of blood called diastole and pumping of blood is called systole.

Delay calculation:

Assume an adult healthy heart having beats per minute (BPM) of 75.

The cardiac cycle for normal healthy heart requires 0.8 seconds to complete one cycle (0.3 seconds in Ventricular systole and 0.5 seconds in dilation of atrium).

It means that, 0.8 second (One complete cycle) = (0.5 seconds of dilation) + (0.3 seconds of ventricular systole)

Processor calculates delay on given information and performs operation. During dilation servos of atrium work for 0.5 seconds and during ventricular systole servos of ventricles work for 0.3 seconds.

1 minute = 60 seconds = 60000 milliseconds

One cycle delay = 60000 / Beats per Minute given by user

(Required one complete cardiac cycle is obtained by dividing 60,000millisecond by number of beats given by user, one cycle delay is in millisecond)

Ventricular systole needs 37.5% duration of one complete cycle delay and dilation of atrium requires 62.5% duration of one complete cycle delay.

Therefore,

Dilation of atrium delay = (0.625* one cycle delay)

Ventricular systole delay = (0.375 * one cycle delay)

3 Results and Discussions

We began by creating a virtual simulation of the model consisting of 4 servo motors for linear actuation, a Microcontroller (ATMEGA328p), an LCD Display for readings, and a 3*4 Keypad for input. The simulation is performed on Proteus software.In the simulation, 3-digit BPM input was fed through the keypad to the microcontroller. The Servo motor would rotate with Speed according to the BPM value. The motion of the four servo motors was such that two upper servo motor when moves Clockwise representing a contraction of two atria the lower servo motors would move in an anticlockwise direction representing an expansion of the ventricles section. The motion altogether showed the motion of the human heart. The hardware model was made according to the simulation. The observation test performed on the model fetched the practical speed of the model. The linear required displacement of the atrium is 12-14 mm and fir the ventricle is 27-29 mm. The comparison between the simulation and the hardware model observation concluded that the motion of the servo motors had no error in linear displacement till the normal BPM range in the hardware model. The input of BPM range above 110 showed error in each servo motor displacement of 8-12 % and increases proportionally to the BPM value input.

The observation of software simulation and hardware models are noted.

Table 1: Linear Displacement four servo motors attached to four parts of Heart

Heart Sections	BPM	Required Displacement	Practical Displacement	Error in %
Right Atrium	45	12mm	12mm	0
	70		12mm	0
	115		11mm	8.4
Left Atrium	45	14mm	14mm	0
	70		14mm	0
	115		12mm	14
Right Ventricle	45	27mm	27mm	0
	70		26mm	3.7
	115		24mm	11.1
Left Ventricle	45	29mm	29mm	0
	70		29mm	0
	115		26mm	10.4

In the future, the tests performed on the complete model with the outer 3D-designed covering will depict the practical parameters of the model. The feasibility of the application of this model is determined by this test result.

4 Conclusion

In summary, the mechanical heart beat generating system can produce sufficient displacement of outer jacket providing an efficient and reliable testing medium for devices such as rechargeable pacemakers. It has a huge benefit towards biomedical experiments. Also the displacement of heart depends on value of BPM provided by user. Further research can be done on the outer jacket material composition and durability. In the further research, model performance and precision observation will be performed with the change in different parameters.

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