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DESIGN AND DEVELOPMENT OF A MECHATRONICS SYSTEM TO PERFORM CONTINUOUS CHEST COMPRESSIONS DURING CARDIOPULMONARY RESUSCITATION

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Abstract— This paper presents the design and development of a Mechatronics system for controlling Pressure regulator of pneumatically operated parallel manipulator used for Cardiopulmonary Resuscitation (CPR). It addresses the drawbacks of CPR performed manually by a human and why the need for a CPR robot. This paper mainly focuses on the studies done, the conceptual design and development of the mechatronic system. It also focuses on determining the pressure required for a person depending on the stiffness of the patient. Stiffness is determined by the displacement of the piston stroke. An algorithm is created on the function of the system and a flow chart is made. Based on the algorithm and flowchart, a program is written to carry out the necessary functions and calculate the required values for the process to take place. Based on the stiffness, the pressure of the FRL unit is altered by the help of a stepper motor. Once the pressure is adjusted, the program then initiates the CPR function, where the system gives 100-110 compressions per minute (i.e.3 sets) with 30 compressions and 2 ventilations in a set.

keywords— CPR; Stiffness; FRL.

I. Introduction

The human heart's main role is that of circulating blood throughout the body. Cardiac arrest occurs when the heart loses its function and stops circulating the blood to the whole body. Common causes of cardiac arrest are smoking, abnormal cholesterol, diabetes, high blood pressure, stress, abdominal obesity, sedentary lifestyle, eating too few fruits and vegetables, and abstaining from alcohol. Many vital organs can be damaged from the lack of blood flow. The brain, more than others, can be severely damaged if the blood is not supplied for a minimum of 4 to 5 minutes. Once the victim has received brain damage, the chances of eventual recovery drop significantly. Cardiopulmonary Resuscitation (CPR) is the emergency procedure that helps restore the circulation of blood after a person experiences cardiac arrest. CPR is performed using a combination of rescue breaths and chest compressions. Chest compressions must be applied at a rate of 100/120 per minute in order to create artificial circulation by manually causing the heart to pump blood through the body. From the statistical research, if the CPR is applied immediately and correctly, this procedure can return life to a person from cardiac arrest 3 times more than without it.Effective CPR can as much as triple the chance of survival. However, high quality CPR is difficult to maintain.

a) Cardiopulmonary Resuscitation Procedure

To properly perform Cardiopulmonary Resuscitation, after assessing the situation to make sure it is safe for the victim to be treated, check to see if the victim is responsive by calling to them and gently shaking them. If they are non-responsive, immediately call for help or designate someone to call the emergency number. After calling for help, tilt the victim's head back and lift the chin to open their airway. Once the airway is open, pinch the nose closed, take a normal breath, cover the victim's mouth with yours and blow out until you see the chest rise. Then give a second breath. If the chest doesn't rise, open the airway again and repeat the breaths. Next place the heel of one hand in the center of the chest and your other hand on top of it. Press the victim's chest clown approximately 2 inches. Perform thirty compressions at a rate of one hundred per minute. Finally, repeat the breaths and compressions until help arrives, or the victim is revived.[1]

b) Manual CPR

Today most rescuers often perform CPR manually. But it is very hard to compress the chest using only their arms and hands and achieve success in a timely manner. There are three factors that are needed to perform successful CPR. The chest compression should he given quickly, forcefully, and consistently. As the time passes after the cardiac arrest, effective CPR process becomes increasingly more important. Sometimes effective CPR determines whether or not the patient will live. Therefore CPR must be applied as soon as possible after the rescuer arrives at the victim. If CPR is applied as little as live minutes after the patient suffered sudden cardiac arrest, there is a greater potential that the patient will not recover. The CPR process must be applied as soon as possible. No matter how the rescuer performs CPR, the patient will have a better chance to live if the process is applied quickly. This is why the quickness of CPR is important. The second factor of good chest compression is force. To achieve the perfect

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compression, the average compressive force must be equivalent to 490.5 Newton's. This force must be consistent through the entire action when CPR is being performed. Manual CPR begins to lose its quality after 1 minute and after 4 minutes the rescuer only achieves 30% of proper quality chest compressions. This means the effectiveness of CPR is lower and not enough force is delivered to the heart. Therefore, good and consistent force of chest compressions should be applied during the CPR process. The last factor of good quality CPR is consistency. Losing consistency means stopping the flow of blood and after sometime the patient's organs suffer from lack of oxygen. This means if there is any interruption in the CPR process the patient's survival rate will greatly decrease. However, it is very difficult to deliver consistent chest pressure in a moving ambulance. Sometimes automated CPR or a defibrillator is required to solve this problem. By combining this with the other factors. the perfect chest compression can be performed and the patient's survival rate will be increased[2].

Cardiopulmonary Resuscitation is the best emergency procedure to restore circulation from cardiac arrest, but there are some issues that have arose. One of the major issues is concerning the chest compressions. Different performers of CPR will give different compression depths and rhythms.. A major cause of the inconsistency is fatigue; humans are susceptible to fatigue. The survival rate of CPR for outside of hospital is less than 5% these days[3].

c) Mechanical CPR

Mechanical CPR has proven to be easier for the rescuer, safer for the patient, and more effective in pumping blood through the body. Mechanical chest-compression devices provide an alternative to manual CPR. Physiological and animal data suggest that mechanical chest-compression devices are more effective than manual CPR. [11]Current mechanical CPR devices, utilize a load-distributing band to apply circumferential chest compressions. The device will provide sufficient depth of anterior-posterior chest compressions to victims and will be able to be used by rescuers with minimal training.[3]

d) Common Side Effects of CPR

It is very easy to break a victim's ribs during CPR. About 30 percent of cardiac arrest patient had cracked the ribs after they got CPR. It happens more often to older people because the cartilage is less compliant and the bone is easier to break. Even though breaking ribs cause bad effect to patient such as chest tenderness, rapid breathing, anxiety and agitation.

However EMS and all other CPR performer do crack ribs if necessary, because the broken ribs will be healed their own after one or two months and it is believed that it is always better to have cracked ribs than to let the patient expire.[5]

II. Software and Hardware Platform Used

a) Hardware Used

Arduino Uno, Stepper Motor, Ultrasonic Sensor, L298N Motor Driver, Dual Relay Driver Board , 3 RPS parallel Robot, Ambu manikin, Cylinder, Compressor, DCV, FCV, FRL Unit, Coupling

Software used

Arduino IDE, Ambu Software

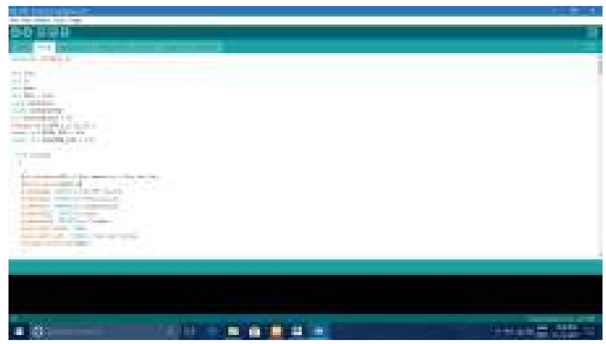

Fig.1 Arduino IDE is used to code the microcontroller.

III .BLOCK DIAGRAM

The working algorithm and block diagram is shown in *Fig 2*

a) Arduino Uno

The Arduino Uno is a microcontroller board based on the ATmega328P. All the required components are embedded into it.It is an open source platform. It has 14 digital input/output pins of which 6 can be used as PWM outputs, 6 analog inputs, a 16 MHz quartz crystal, a USB connector, a power jack, a reset button.[6]

b) Stepper Motor

Stepper motors are DC motors that move in discrete steps. They have multiple coils that are organized in groups, they are called phases. Energizing each phase in a order, the motor will rotate a step at a time. We can get precise positioning and controlling by using a controller. Stepper motors come in many different sizes and styles and electrical characteristics. Stepper motors are the motor of choice for many precision motion control applications.

c) Ultrasonic Sensor

An Ultrasonic sensor is a sensor that can measure the distance to an object by using sound waves. It measures distance by sending out a sound wave at a specific frequency and responding for that sound wave to bounce back. By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sensor and the object.[5]

d) **L298N Motor Driver**

H-Bridges are used to control motor speed and direction. An H-Bridge is a circuit that can drive a current in either polarity and be controlled by Pulse Width Modulation (PWM). The longer the pulses the faster the wheel will turn, the shorter the pulses, the slower the wheel turns. Pulse Width Modulation is a means in controlling the duration of an electronic pulse. [6]

e) **Dual Relay Driver Board**

It's a simple and convenient way to interface 2 relays for switching application. It can drive a variety of relays, including a reed-relay.This relay driver boosts the input impedance with a regular BC547 NPN transistor. Transistor Q1and Q2 are a simple common-emitter amplifier that increases the effective sensitivity of the 12 volt relay coil about a 100 times. [6]

f) **3 RPS parallel robot**

The 3 RPS parallel robot consists of a fixed plate and a movable plate both made of aluminum. Both these plates are connected together by means of three double acting cylinders with the fixed plate. The fixed plate has three revolute joints for each piston having one degree of freedom each. The piston-cylinder arrangement forms the prismatic joint. The movable plate has 3 spherical joints (Ball and Socket Joint).It is fastened to the cantilever beam .It provides single axis rotation to the cylinder by means of revolute joints for every cylinder. A sternum block made of nylon is attached to the movable plate so that the force is distributed exactly and uniformly to the sternum of the victim. Spherical joints are mounted on the movable plate where the pistons meet the movable plate.(10)

g) **Ambu manikin**

It is a highly developed instruction and training manikin for the simulation of realistic, correct anatomical and physiological conditions during CPR. Readings can be recorded and the values can be analyzed using the Ambu CPR software. The stiffness of the chest can be changed and adjusted with a screw.There are three stiffness modes in the Ambu manikin which gives low, medium and high sternal stiffnesses respectively. (7)

h) Cylinder

Three double acting pneumatic cylinders are used in the RPS parallel robot. These cylinders use the power of compressed gas to produce a force in a reciprocating linear motion on the sternum.(9)

i) Compressor

An air compressor is a device that converts power into potential energy stored in pressurized. The compressed air, then, is held in the tank until called into use.When tank pressure reaches its upper limit the air compressor shuts off. The energy contained in the compressed air can be used for a variety of applications, utilizing the kinetic energy of the air as it is released and the tank depressurized. When tank pressure reaches its lower limit, the air compressor turns on again and re-pressurizes the tank.(8)

j) DCV

A solenoid Direction Control Valve is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid in the case of a three-port valve, the outflow is switched between the two outlet ports.

k) FCV

A FCV regulates or controls the flow or pressure of a fluid. Flow control valves are normally fitted with actuators and positioners.Flow control valves respond to signals generated by independent devices such as flow meters or temperature gauges. (9)

l) FRL Unit

Before compressor uses air,it need to filtered, regulated and lubricated. An airline filter cleans compressed air. It strains the air and traps solid particles (dust, dirt, rust) and separates liquids (water, oil) entrained in the compressed air. Filters are installed in the air line upstream of regulators, lubricators, directional control valves, and air driven devices such as cylinders and air motors.(9)

m) Coupling

The rotation of the motor should be connected to the FRL unit of the pneumatic system and thus a coupling device is manufactured. It is made up of high speed steel and is cylindrical in shape. The top and bottom of the device is attached to the motor shaft and the knob of the FRL unit respectively.

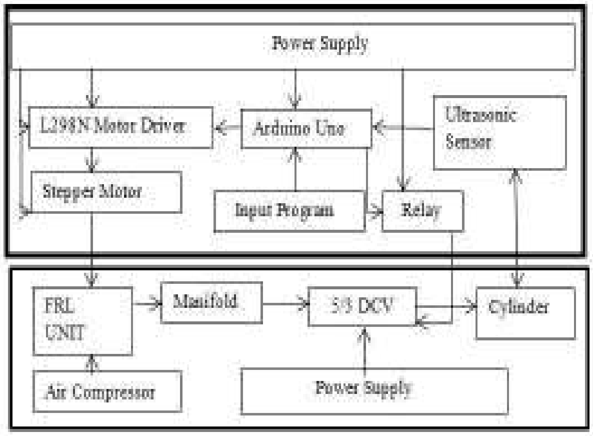

Fig.2 Block Diagram of CPR

IV. Working and simulation results

The experimentation was done with the help of Ambu manikin. Readings can be recorded and the values can be analyzed using the Ambu CPR software.

There are three stiffness modes in the Ambu manikin which gives low, medium and high sternal stiffness respectively.

Fig.3 Experimental setup of Ambu manikin during CPR using mechanical compressions

- Firstly the elevation of the cantilever is adjusted such that the movable plate of the parallel robot firmly touches the sternum of the Ambu manikin
- Fasten the safety belts
- Turn the system on.
- The FRL Unit is adjusted to 8.5 bar, and the initial stroke is given.
- Ultrasonic sensor measures the displacement of the movable plate.
- Based on the measurement, the code gets executed.
- The stepper motor is rotates to the fixed position, and CPR is started.
- Parameters such as depth of compression, time taken for each set of 30 compressions and the time taken for every sequence of compressions is noted in real time on the CPR software.
- The obtained dynamic mechanical parameters of the human chest is then studied and compared with the manual compression method.

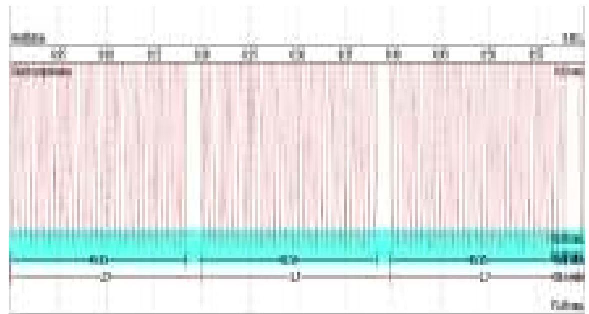

Fig.4 Experimental result obtained in Ambu software during CPR using mechanical compressions

V. Future Scope

All of these ideas had pros and cons, but for some of these, current technology is not yet sufficient enough to support the design of these devices. It is hoped that in the future this device will be as widely available and therefore be able to prevent more deaths and injuries from heart attacks and CPR respectively. There are many future possible designs that can result from this project. Possible designs suggested during this project included a self-contained vest for high-risk victims. Another major idea was to use a single piston to perform the compressions. A third design combined the two previous by being a portable apparatus that wraps around the victim and uses compressed air distributed on all sides of the body to perform compressions.

VI. Conclusion

CPR given here is effective and safe for the patient. CPR certification will not be necessary in order to operate this. This device can provide high quality chest compressions in a moving ambulance, which is very difficult to accomplish with manual CPR, and may allow a reduction in the number of emergency medical systems (EMS) personnel needed to perform resuscitation. It produces the same depth in every compression. This device will be automated and user-friendly, any rescuer can use it. This device will be more cost efficient and accurate, thereby making it more accessible to the general public.

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