

Automated Cardiopulmonary Resuscitation (ACR): Enhancing Life-Saving Interventions during Cardiac Arrest

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ABSTRACT

Aim of the Study: The heart is the body's primary pumping organ, and disturbance in the pumping of blood leads to the organ failure due to inadequate blood supply. Due to the pumping disturbance patient may suffer from different problems mainly origins cardiac arrest (CA), which is the leading cause of death. During CA within 3 to 5 minutes of collapse if emergency treatment not provided to the patient, it can lead to brain hemorrhage, organ failure and even death (Cunningham et al., 2012). To overcome these issues Basic life support (BLS) is essential for resuscitation (i.e., CPR) after cardiac arrest, ensuring suitable ventilation and circulation until the primary cause of heart failure is addressed. Cardio pulmonary resuscitation (CPR) requires continuous, steady, and fine chest compressions carried to the patient until medical help arrives. However, the traditional manual method requires significant energy and qualified healthcare experts Furthermore, the consistent and effective chest compressions are not possible in manual method (Paratz et al., 2020). To eliminate the human component and ensure continuous compressions according to the assigned time, 'Self-Operated CPR' would be the greatest option.

Methodology: The proposed Self-Operated CPR prototype is designed to be adjustable in height and effectively deliver sternal compressions. At its core, it uses a crankshaft assembly that moves a shaft in and out to apply the necessary force to the chest. This movement is precisely controlled by a microcontroller, ensuring accurate and consistent compressions. Force sensor will continuously monitor the compression force being applied on the chest and whenever it exceeds the limit or when the force applied is not within the range, an alarming signal will be generated to stop the procedure and escapes the patient from the any unwanted event or danger. The heart rate sensor monitors the patient's heart beat. This prototype guarantees CPR quality and enhances the survival rates by automating the procedure of CPR.

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Findings: The prototype was tested on the mannequin; it provided satisfactory results which were within the CPR guidelines. The total number of chest compressions that the prototype provided in 2 minutes was 148, with a delay of 2 seconds for analysis of the victim's heart rate. And the proposed prototype also achieved a compression depth of 2 inches.

Conclusion: The most effective tools for addressing issues in medicine or the medical industry are biomedical devices. One of the medical problems that occur within the blink of an eye is sudden cardiac arrest. It requires early detection and prompt treatment without any delay. The prototype that we have designed is a life-saving device/product that addresses the issues related to SCA.

Keywords: Cardiac Arrest, Basic Life Support (BLS), CPR, Chest compression, Automation, Sensors.

1. INTRODUCTION

In hospitals, patient health is a primary concern, and SCD is a serious issue that accounts for a substantial number of fatalities. The global fatality rate from sudden cardiac death (SCD) is approximately 7 million. Due to Sudden cardiac disease SCD causes unpredictable natural death in a short period of time (Wong et al., 2019). SCD is a disorder where the heart rhythm does not quickly return to normal within ≤ 1 hours of the onset of symptoms, which causes brain damage and ultimately leads to death. Doctors refer to the condition as "sudden cardiac arrest" or "cardiac arrest" because it is brought on by a breakdown of electrical impulses produced by the heart that halt the heart's pumping action (Müller et al., 2006).

There are numerous reasons why SCA happens both within and outside of hospitals; however the following are the most well-known:

1. Arrhythmia and ventricular fibrillation
2. Heart enlargement, or cardiomyopathy
3. CAD, or coronary artery disease(de Vreede-Swagemakers et al., 1998) For survival, sudden cardiac arrest needs quick action, specifically:

1.1 Basic Life Support (BLS)

This is the first stage of patient stabilization. BLS's primary objective is to assist the patient in an emergency until EMS comes for additional evaluation. It just involves an automated external defibrillator (AED) and manual cardiopulmonary resuscitation (MCPR), and it is done without the use of medications (*Basic Life Support BLS Training | American Heart Association CPR & First Aid*, n.d.).AEDs are sophisticated, user-friendly medical devices that can measure heartbeats and, if necessary, it delivers the shock to all the muscles of heart to contract in unison (defibrillation), assisting the heart in returning to its regular rhythm(*What Is AED? | Learn What an AED Is | Red Cross*, n.d.).

MCPR continues to pump blood until a qualified medical practitioner arrives to assist. "CAB" encapsulates the fundamental steps of CPR:

1. **Compressions (C):** Begin with chest compressions to support blood flow.
2. **Airway (A):** Ensure the airway is clear to allow air into the lungs.
3. **Breathing (B):** Provide breaths to deliver oxygen (Pinto et al., 2013).

Traditionally, rescue breathing and chest compressions are used in CPR to improve blood circulation and ventilation. Make sure the airway is clean before beginning, and check the circulation and respiration. Hands-only CPR is the most popular technique, but mouth-to-mouth CPR is also an option. Manual CPR is currently performed in public places, hospitals, ambulances, and places with few medical facilities.

However, it takes a lot of work and energy and can result in problems like internal injuries, lung bruises, and rib fractures (Pinto et al., 2013). Over time, the physical strain on medical personnel may cause chest compressions to become less effective. When ROSC (return of spontaneous circulation) occurs, which is usually only detected with a heart rate sensor, and then CPR should be halted (Wampler et al., 2012). In order to address cardiovascular-related problems, the concept of "Self-Operated CPR" was developed in response to the aforementioned circumstances.

1.2 Self-Operated Cardiopulmonary Resuscitation (SCPR)

The ACR prototype restores respiration and blood supply to the brain by automatically performing chest compressions. It monitors the victim's pulse using a heart rate sensor; if the pulse is not normal, the sensor notifies the microcontroller, which then turns on a motor and relay module to regulate the crankshaft's compression mechanism. A force sensor warns the operator if changes are required and makes sure the applied pressure stays within safe bounds. The sensor alerts the microcontroller to halt compressions when it senses the return of spontaneous circulation (ROSC).

2. LITERATURE REVIEW

2.1 Thumper

The first automated CPR machine was the Thumper 1007CC. With an adjustable depth of 0–3.2 inches and a pace of 100–120 compressions per minute, it employs pressurized gas to deliver continuous chest compressions. There are two versions: one for compressions only, and one that offers ventilation plus chest compressions (5:1 ratio). Cons: Expensive (around \$11,000) and potentially harmful continual chest compression (Luo et al., 2023).

2.2 Electro-pneumatic Machine

The electro-pneumatic machine delivers compressions using a spring-loaded piston and a gas-driven cylinder. For cardiac support, it is synchronized with the patient's ECG. Cons: Inconsistent compression speed, costly compressed air, and rib fracture risk (Golycheva et al., 2003).

2.3 Vest CPR

This machine uses a pneumatic bladder around the patient's chest to provide cyclical compressions. It administers compressions at 60 beats per minute at a pressure of 250 mmHg while adjusting for chest size. The "Auto-Pulse distributing band," as it is now known, enhances blood flow to essential organs. Cons: Expensive (around \$1,200), criticized for short battery life, attachment problems, and backboard placement (Beattie et al., 1991).

2.4 Corpuls CPR

An electrically powered piston-mounted apparatus that delivers 80–120 compressions per minute at a depth of 2–6 cm. Three kinds of compression are available: 15:2, 30:2, and continuous. It has Bluetooth communication, SD card data storage, and is interoperable with both air and ground ambulances (Eichhorn et al., 2017). Cons: It could raise mean arterial pressure (MAP), harming the heart's muscles.

3. MATERIALS AND METHODS

This prototype consisted of two main sections hardware and software.

3.1 Hardware Components

The components utilized in the prototype are listed below:

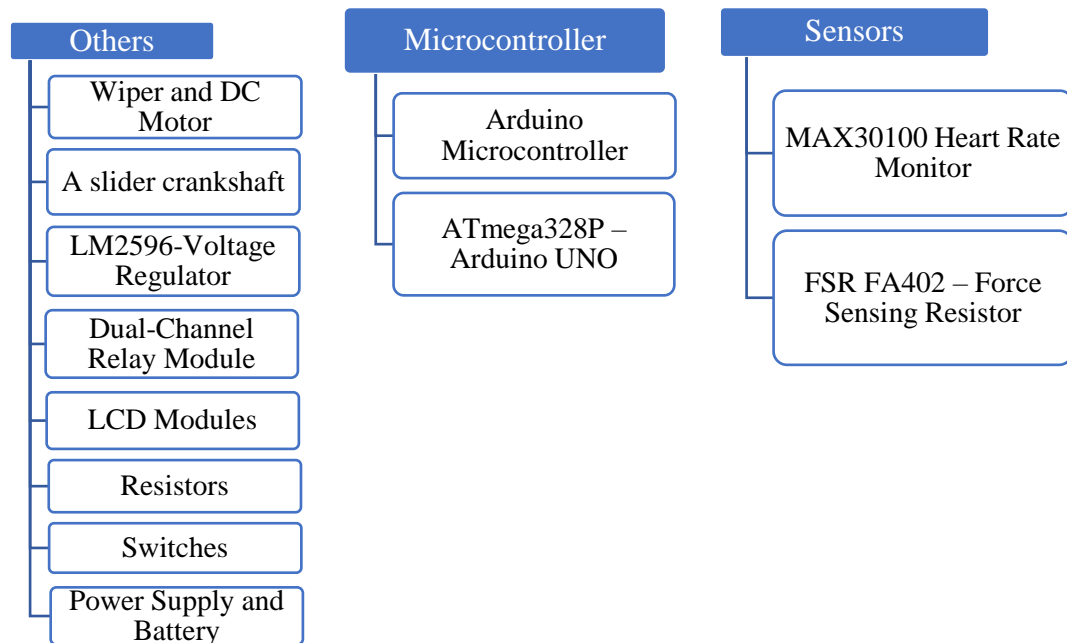


Figure 1. Major Hardware components

i. A Slider Crankshaft

A slider crankshaft is basically a mechanical setup for providing a linear motion from a circular motion and vice versa. Crank is the series of crankpins or cranks to which the shaft or rod is attached and they altogether work in a series of pattern that basically converts the circular motion to linear motion and vice versa (Ha et al., 2006).

ii. Wiper and DC Motor

The wiper motor is the torque motor and simple DC motor with or without brushes and copper wire armature with permanent magnets. In comparison with the square shape of those that use electromagnets, it typically has a cylindrical shape. There are also variable speed wiper motors and the main difference between them is the number of brushes, two brushes are used in the single-speed motor and three in the two-speed motor (Yang et al., 2012).

iii. Microcontroller

a) Arduino Microcontroller

An Arduino is an open-source electronic device that can be used in both hardware and software interfaces. Hardware part consists of an Arduino board that reads input commands and generates output (Arduino - Home, n.d.).

ATmega328P – Arduino UNO

ATmega328P is a single microchip on Arduino UNO microcontroller which belongs to 8-bit mega AVR family. It is a board that consisted of a number of digital and analog input/output pins, a power jack, an RST button, a USB connection, and an ICSP (In-Circuit Serial Programming) header. With the help above components an Arduino UNO performs its overall operation, moreover it is supplied with an AC or DC adapter or a USB cable or any battery (Gadekar et al., 2021).

iv. Sensors

a) MAX30100 Heart Rate Monitor

The MAX30100 is a low-power plug-and-play sensor that is based on an I2C interface. It is both a heart rate sensor as well as a pulse oximeter (Shiv Prasad et al., 2024).

b) FSR FA402 – Force Sensing Resistor

An Arduino-compatible force sensing resistor (FSR) is used for the quantitative analysis of force applied on the surface of the sensor (Sadun et al., 2016).

1. Software

The software used for the programming is Arduino IDE. The figure below illustrates all the connections made on the IDE:

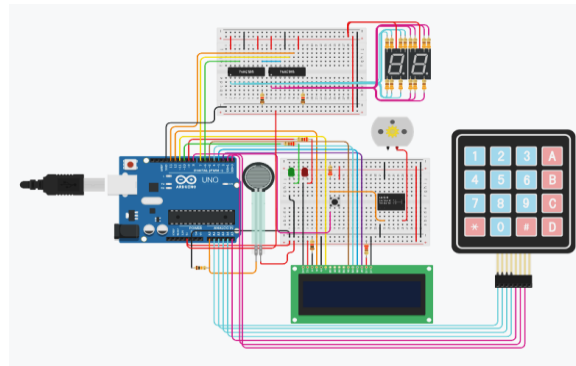


Figure 2. Circuit Diagram of ACR

The ACR prototype restores blood flow to the brain and respiratory activity by automating CPR and administering chest compressions at a depth of 1.5 to 2 inches. It monitors the victim's pulse via a heart rate sensor and takes action when it detects an irregular heartbeat, such as one that is less than 60 beats per minute. A microprocessor receives the information from the sensor and uses a relay module to power a motor that regulates a crankshaft mechanism for compressions. As the technology continuously tracks the heartbeat, caregivers may determine the necessary compression count based on the CPR protocol. This guarantees accurate, effective, and prompt CPR assistance.

2 modes incorporated in this prototype:

Mode 1 (Autonomous)

This mode is selected by using a switch or a toggle button. It is further categorized into two:

- 1st mode (30:2 compressions to ventilation mode-5 cycles)
- 2nd mode (continuous compression mode till 30 minutes)

In the 30:2 compression-to-ventilation mode, the gadget performs five cycles of 30 chest compressions with 2-second breath intervals, followed by condition assessments. Compressions cease if the heartbeat is restored; if not, i.e., 2nd mode, they continue for up to half an hour until cardiac activity returns. In light of the patient's reaction, this guarantees adaptive CPR support.

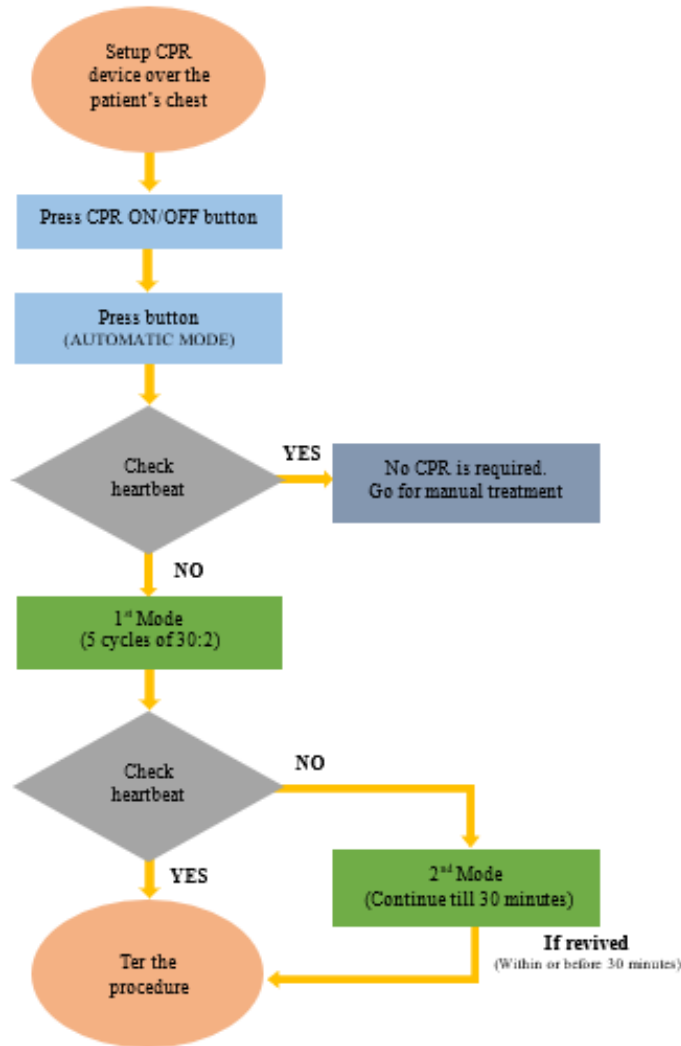


Figure 3: Flowchart for Autonomous Mode

Mode 2 (Manual)

This mode is selected by using a switch or a toggle button. In this mode, we have 3 sub-modes that provide the compression rate by using 3 push-on release-off buttons.

1st mode (2 cycles of 30:2 compressions to ventilation)

2nd mode (4 cycles of 30:2 compressions to ventilation)

3rd mode (continuous compressions to ventilation till 30 minutes)

In the first mode, two cycles of 30:2 compressions are offered, and then there is a 2-second pulse analysis delay. The second mode applies four cycles of 30:2 compressions if no heartbeat is detected. The third option offers continual compressions for up to half an hour till cardiac activity starts up again if the pulse doesn't return. Chest compression pressure is tracked by a force sensor, which sounds an alert if the force beyond acceptable bounds. The patient's pulse is continuously monitored by the heart rate sensor, which alerts the microcontroller to stop compressions when spontaneous circulation (ROSC) is detected.

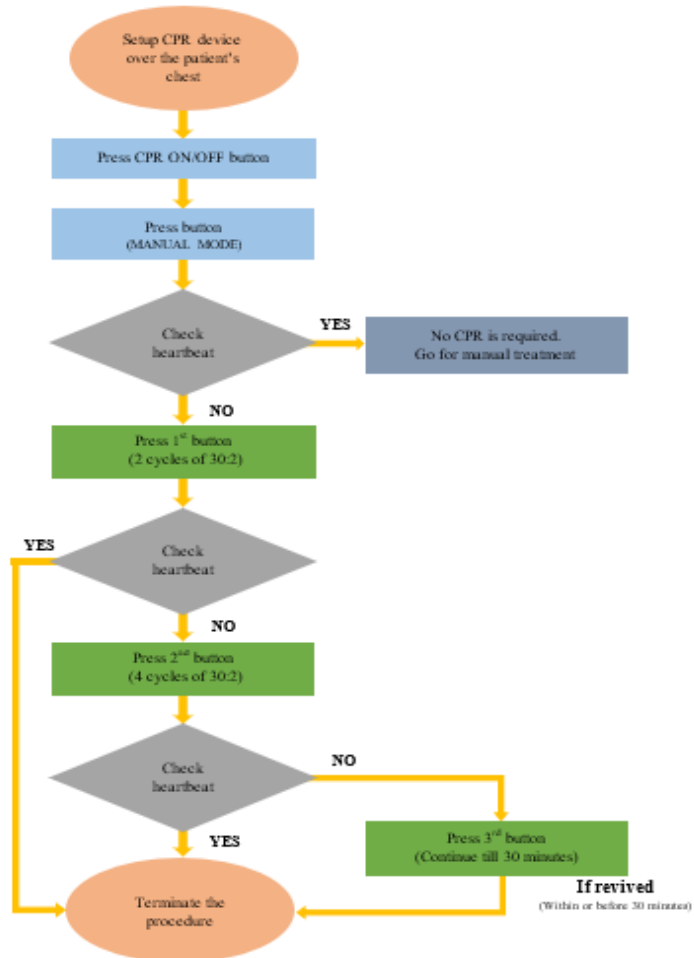


Figure 4. Flowchart for Manual Mode

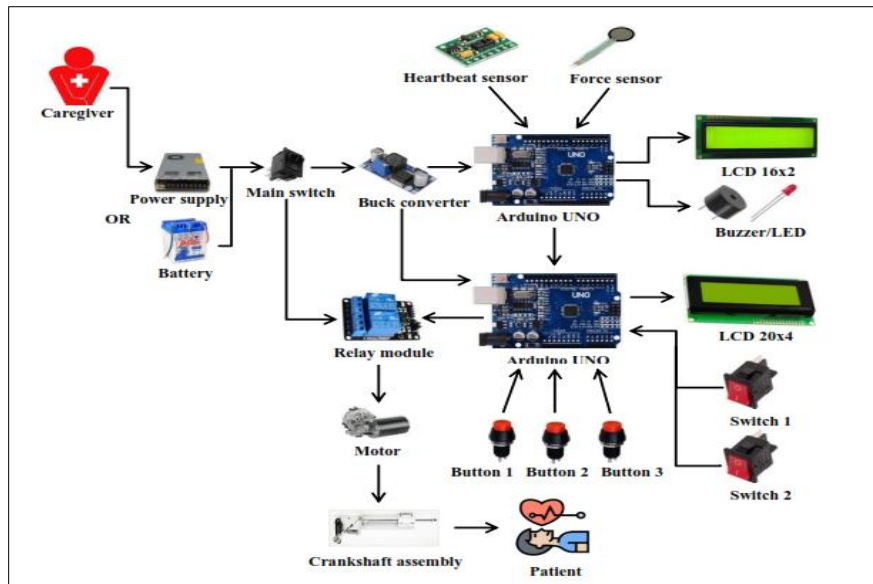


Figure 5. Block diagram of the Prototype

4. RESULTS & DISCUSSION

The prototype of the proposed device was developed in the Engineering Laboratory at the Institute of Biomedical Engineering, LUMHS, Jamshoro. It operates using a crankshaft mechanism to deliver chest compressions. When tested on a mannequin present in the skill lab of LUMHS, the device performed well, meeting CPR guidelines and demonstrating its potential effectiveness. In a 2-minute test, the prototype delivered a total of 148 chest compressions, with a 2-second pause to analyze the victim's heart rate. It successfully achieved a compression depth of 2 inches. The device also measures the applied force in Newtons and triggers an alarm if the force exceeds or falls outside the required range, alerting the caregiver to stop the procedure. Overall, the prototype operates with an impressive 99% accuracy.

The prototype's main stake is to stop CPR as soon as it detects a heartbeat. This feature was confirmed during testing on a mannequin present in Skill lab of the University as shown in figure 6.



Figure 6. Final Prototype testing on mannequin

Results of the prototype when autonomous and manual mode is under operation as shown in Figure 7. During testing of prototype multiple cycles provided under different conditions like abnormal and normal pulse, irregular and regular heart beat and the output taken from the mannequin observed on the LCD display and multiple screen shots shown in figure 7.



Figure 7. Results of Compressions to Ventilation Mode with multiple Cycles

The final prototype with two different modes of operations successfully working as per directions and commands and it will provide the CPR automatically presses the mannequin's chest by almost 1.5-2 inches' depth which re-establish normal respiratory activity and blood circulation towards the brain. The prototype model analyzes the heartbeat of the person with the help of a heart rate sensor as shown in figure 8. When an abnormal pulse i.e., below 60bpm is detected, then the signal from the heartbeat sensor is transmitted to the microcontroller which activates the relay module by analyzing the signal. The relay module then acts as a switch and activates the motor which in turn controls the extension and retraction mechanism of the crankshaft through which compressions are provided. While analyzing the heartbeat of the subject, simultaneously the number of compressions as needed in the CPR procedure is set by the caregiver by selecting the required mode.



Figure 8. Heart rate Pulse sensor and Force sensor working

5. CONCLUSION

The most effective tools for addressing issues in medicine or the medical industry are biomedical devices. One of the medical problems that occur within the blink of an eye is sudden cardiac arrest. It requires early detection and prompt treatment without any delay. The prototype that we have designed is a life-saving device/product that addresses the issues related to SCA. The prototype provides consistent and uninterrupted chest compressions by employing automatic and manual modes, thus increases the chances of patient's viability, especially when extended CPR is necessary. Self-operated CPR gets rid of the laborious manual resuscitation technique currently used in emergencies.

From the piston-driven "Thumper" to sophisticated systems like LUCAS, successive generations of gadgets demonstrate advancement. According to AHA criteria, the suggested prototype, which is based on a crankshaft mechanism driven by a DC torque motor, provides continuous compressions and is appropriate for hospitals, public areas, and ambulances. This research increased the likelihood of survival during prolonged CPR by providing continuous chest compressions in both automatic and manual modes. With a target force of 100–125 pounds and a pace of 120 compressions per minute, it satisfies AHA guidelines; in tests on a mannequin, it achieved 22 pounds (*What Is CPR | American Heart Association CPR & First Aid*, n.d.). Although the Self-Operated CPR prototype worked well on a CPR mannequin to meet the necessary CPR standards, but the testing was insufficient to put the prototype to the test on a person or an animal. This electro-mechanical design acts as a unique platform for people in the medical and non-medical fields.

6. FUTURE WORK

When designing a medical device, the main thing to be considered is the safety of the patient. This CPR prototype ensures the safety of the patient. But there are still some safety parameters that must be implemented in the device. One of the future approaches is to integrate high quality force sensor with the device. It will continuously monitor the force and terminate the compressions when a force greater than the required range is applied to the patient. Also, the force that will be applied to the patient will be made adjustable according to the victim's age, weight, etc.

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