IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

# A Low Cost Robotic Medical Simulator for CPR Training

To cite this article: A A Freire Fiallos *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **575** 012019

IOP Conf. Series: Materials Science and Engineering **575** (2019) 012019 doi:10.1088/1757-899X/575/1/012019

# A Low Cost Robotic Medical Simulator for CPR Training

**A A Freire Fiallos, F M Rosero Plúa and S N Rea Minango**

Departamento de Ciencias de la Energía y Mecánica. Universidad de las Fuerzas Armadas ESPE, Av. General Rumiñahui s/n, Sangolquí, 171-5-231B, Ecuador

snrea@espe.edu.ec

**Abstract.** Medical simulators have become an important tool for teaching and developing skills in health personnel. The present work describes the design and construction of a simulator for cardiopulmonary resuscitation in adults, of intermediate fidelity, equipped with monitoring software. This device has an adult-size torso, with sensors and actuators controlled and monitored wirelessly through the user's computer. The prototype aims to assist in the training of paramedics and first responders, due to its ability to show real-time data on the execution of the cardiopulmonary resuscitation maneuver. The simulator has been designed in a modular way so that it allows an easy assembly and change of pieces if necessary. The graphical interface gives feedback in real time on the effectiveness of the maneuver. Based on surveys carried out in trained personnel, it was confirmed that the simulator is very useful to carry out practices for which it was designed, as well as to reduce the cost of implementation by being built with materials available in the local market.

## 1. Introduction

These Cardiopulmonary resuscitation (CPR) is an emergency life-saving technique, used when a person has stopped breathing, or the beating of its heart has stopped. Its purpose is to re-establish regular heart activity, for which chest compressions are administered, enabling air to enter the lungs for oxygenating the blood [1]. CPR maneuver has basic performance aspects, such as proper compression depth and ratio, so that health staff is trained for accurate execution, applying mannequins or simulators.

Simulation is the process of designing a model of a real system and carry out experiences with it, to understand the behavior of the system or evaluate new approaches within the functioning limits, imposed by a certain criterion [2]. For medical simulation, devices and systems have been created and are classified into three levels according to their electronic complexity: a) high fidelity focused on instruction of complex skills; b) medium fidelity, employed to acquire repetitive skills; and, c) low fidelity, for simple skills, designed for heavy use [3].

The use of robotic medical simulators allows the continuous practice of various maneuvers required to save people's lives, where feedback is essential to correct errors and improve technique. However, due to its high cost, its use has been limited in countries like Ecuador, which is why its development is necessary with available, low-cost elements.

## 2. Materials and Methods

According to [3], there are certain factors that must be considered when designing a CPR simulator to guarantee a CPR maneuver has quality and effectively helps a person:

- The minimum compression rate is 100 beats per minute, and the upper is 120 [4];
- Chest compressions should be applied with a minimum depth of 5 cm in an adult of medium build, and not exceeding 6 cm;
- Avoid leaning on the chest of the patient between compressions;
- Interruptions between compressions should be minimal because they reduce the effectiveness of the maneuver

### *2.1. Mechanical structure*

*2.1.1. External structure.* The base body of the CPR simulator is a plastic mannequin due to the need for a resistant structure for the maneuver execution (figure 1) and it is sized according to the constitution of an average Ecuadorian. For a better representation of the thoracic area and the correct identification of the compression area, models resembling ribs and sternum were created.

The manikin was modified to enable movement in the joints. The union between the body and the head was adapted to allow hyperextension of the neck. The base skull was 3D printed and covered with a latex mask, like the rest of the body, to resemble the human skin.

**Figure 1.** CPR simulator external structure.

*2.1.2. CPR structure.* The CPR structure that allows performing the compression maneuver (figure 2), is composed by a compression spring, a support table, and the electronic subsystem.

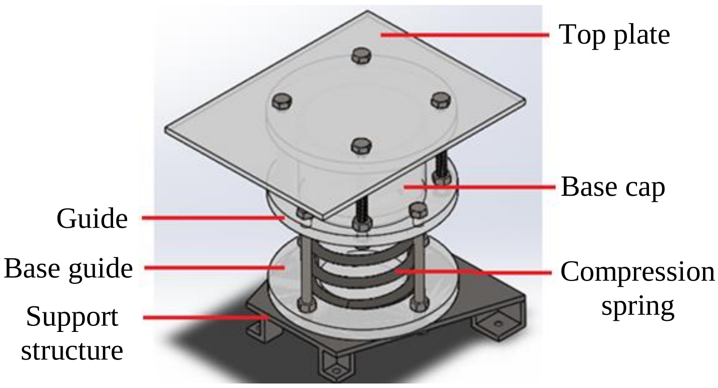


**Figure 2.** CPR structure.

The compression spring supports the force to move the chest the distance necessary for the maneuver to be correct and was designed to fit in the thoracic cage, using the parameters shown in table 1.

To guarantee a long lifetime and good performance, the spring was designed for a static and cyclic load of 80 kg, although in reality forces during training were rated between 45 and 55 kg.

**Table 1.** Compression spring parameters.

| Parameter | Value |
|---|---|
| Outer diameter | 92 mm |
| Free length | 150 mm |
| Solid length | 70 mm |
| Wire gauge | 8 |
| Material | Stretched solid wire A227 |
| End type | Square frosted |

A support table built in ASTM A36 steel give the manikin a flat surface to support the structure and the compressions. The design of this table was validated using CAE software, for an applied force of 80 kg.

For an adequate simulation of the CPR process, it is necessary to emulate the pulmonary behavior, which is why a pulmonary system was created. This system allows 1observing the insufflation of the chest and is composed of a plastic bag of 500 ml (figure 3) placed on a support table and two electrovalves that will control the air passage from a compressor to the lungs or from the airway to them.

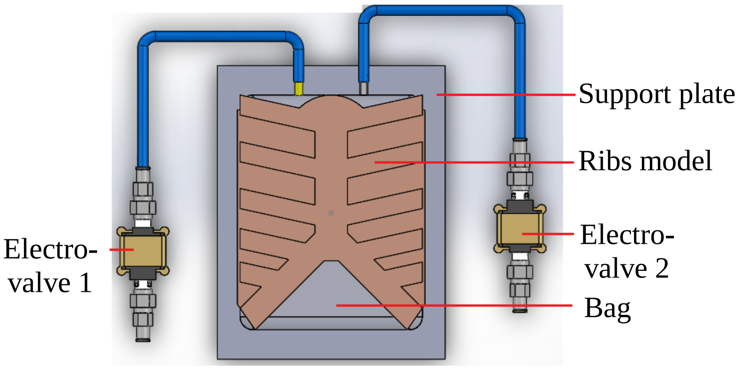


**Figure 3.** Pulmonary system.

*2.2. Electronic system*

Two data acquisition boards, a Raspberry Pi 3 model B and an Arduino Nano, were used in the simulator to read both the analogue and digital sensors and are connected to each other through a USB port. Additionally, several sensors and actuators were included in the simulator for specific purposes:

- Proximity sensor - to measure the depth of chest compressions.
- Servomotor – for jaw opening and closing.
- Solenoid valve – to simulate insufflation of lungs.
- Flat vibrating motors – to simulate the carotid, brachial and radial pulse.

Due to a large number of connections generated with the Raspberry and Arduino boards, it was necessary to create another board that was used as a connecting bridge between sensors, elements, and data acquisition cards. The design of the control circuit was based on the need to feed sensors that operate at different voltage values, which are 3 and 5 V. The Raspberry card provides these voltage sources, for this reason, the design connects all the sensor inputs to be used with their respective voltage and to simplify the connections. 12 V were also required to activate the solenoid valves, for this reason, an external source was used. This source also allows the vibrating motors to take the necessary current for their proper operation.

*2.3. Software*

The software contains one main window, three windows that allow to monitor and control the different processes of the simulator; and two auxiliary windows, which allow observing the results after having performed the CPR maneuver. Its programming was made using Python language.

The main window is used to connect to the control board of the simulator through TCP/IP protocol using the IPV4 address, and to access the windows of the simulator's functionalities.

The window of CPR function (figure 4), allows to monitor and graph the data read by the proximity sensor in real time, to establish the depth of the chest compressions and provide feedback with the results obtained, in the secondary windows.


**Figure 4.** CPR monitoring window.

The software internally has two important modules: one for the CRP training and the other for the different cardiac rhythms simulated. As for the CPR monitoring, the main function of this module is to plot the Sinus rhythm in a time of 1 to 10 seconds, ventricular fibrillation in a time of 10 to 30 seconds and asystole in a time of 30 to 40 seconds. This function detects if there is a compression during ventricular fibrillation and calls the function responsible for taking data from the proximity sensor and plot them in real time. In case of not detecting any compression in the period of ventricular fibrillation, the program will continue until asystole ends.

The second module is capable of representing seven of the most common cardiac rhythms observed in an EKG according to [5], as shown in figure 5. To generate them, an equation composed of six harmonics was used, each harmonic correspond to P, Q, QRS, S, T, and U, based on the work of [6], using the values listed in table 2.

**Table 2.** Compression spring parameters.

| | a | *I* | B | *l* | X |
|---|---|---|---|---|---|
| **Harmp** | 0.25 | 0-100 | 9.26 | 0.4167 | 0.17:0.01:2.17 |
| **Harmq** | 0.25 | 0-100 | 12.62 | 0.4167 | 0.176:0.01:2176 |
| **Harmqrs** | 1.6 | 0-100 | 7.57 | 0.4167 | 0.01:0.01:2 |
| **Harms** | 0.25 | 0-100 | 12.62 | 0.4167 | -0.08:0.01:1.91 |
| **Harmt** | 0.35 | 0-100 | 5.87 | 0.4167 | -0.19:0.01:1.8 |
| **Harmu** | 0.035 | 0-100 | 17.5 | 0.4167 | -0.423:0.01:1.567 |

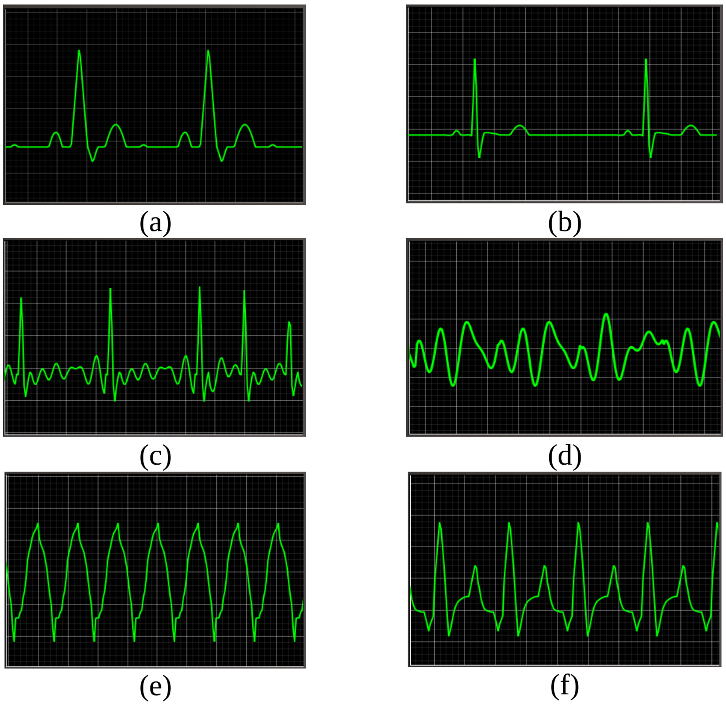


**Figure 5.** Cardiac rhythms generated. (a) Sinus rhythm; (b) Sinus bradycardia; (c) Atrial fibrillation; (d) Ventricular fibrillation; (e) Ventricular tachycardia; (f) Supraventricular tachycardia.

The amplitude, period and width were modified to generate 7 waves to be able to graph them continuously. This module helps the training of medical personnel in the identification of cardiac arrhythmias.

## 3. Materials and Methods

For testing the prototype, "RCP" tab was activated and an EKG showing sinus rhythm appeared. When fibrillation starts, chest compressions were applied. After starting the chest compressions, their frequency and intensity are shown in the graphical interface. The graph shows peaks corresponding to each compression made (Figure 6).


**Figure 6.** CPR monitoring window showing chest compressions.

A general summary of the practice is shown at the end of the training (see figure 7). When pressing the "Detail" button a list of the executed compressions appeared, classified by color as shown in figure 8.

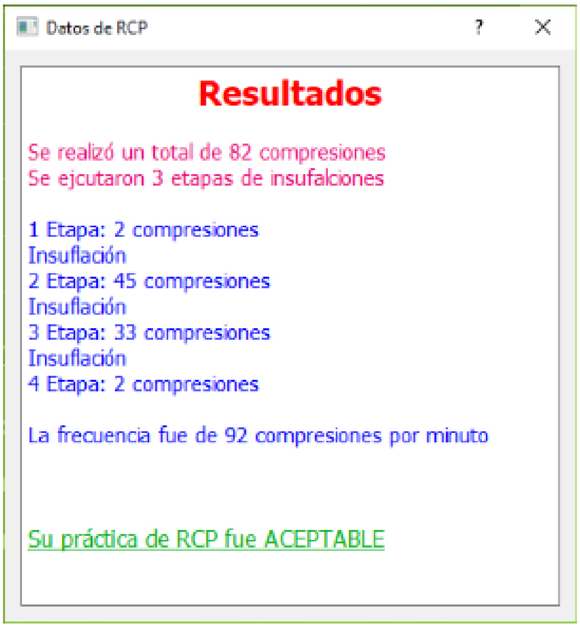


**Figure 7.** CPR's results window.

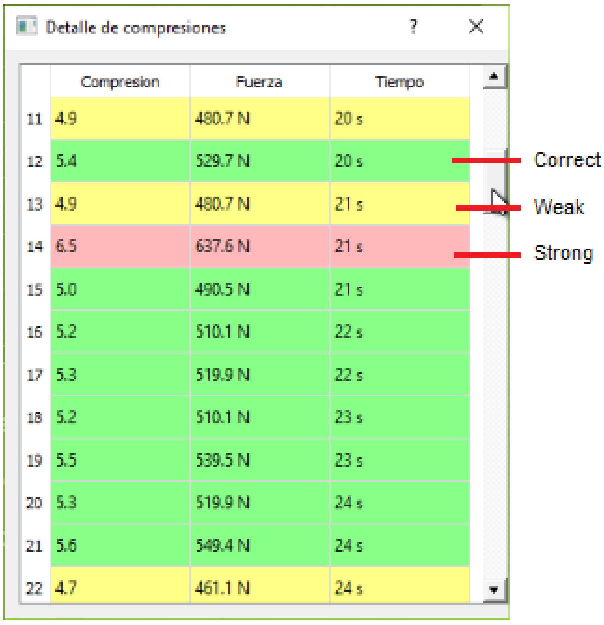


**Figure 8.** CPR's detailed results window.

## 4. Discussion

The details and anatomically elaborated parts give the simulator a more realistic appearance, for example, the head allows its inclination and jaw opening for the correct application of insufflations after each cycle of compressions, and this gives realism to the maneuver.

The practices carried out by the personnel of the Ecuadorian Red Cross (figure 9) show that the CPR structure has adequate resistance that simulates the torso of a person, based on the fact that applying a force of 50 kg in a person of normal build generates a displacement of the torso of 5 cm, parameter recommended by the American Heart Association for quality CPR.

**Figure 9.** Validation of the prototype.

The user interface facilitates the performance monitoring in the CPR maneuver. The wireless connection between the elements of the simulator and the user interface allows the personnel operating the device to circulate freely in the work area in which the simulator is positioned, in this way the structure of the simulator is not compromised. Additionally, each of the cardiac rhythms loaded in the software presents unique characteristics when graphed.

The results obtained in the tests were positive, but it is important to mention that there are recommendations that can significantly enhance the designed simulator. These recommendations are:

- Expanding the library of cardiac pathologies and adding sounds would be very useful for those who use the simulator;
- CPR interface can be improved, including a scenario where if the maneuver is not being performed properly, the software stops reading data and automatically restarts the execution so that the user detects when his practice is not correct;
- Adding extra functions to offer a more realistic scenario.

Finally, the total value of the project determines that it is possible to produce a low-cost medical simulator, using materials available in Ecuador, with good functionality and anatomical structure. Comparing it with a "MegaCode Kelly Basic" simulator that has similar characteristics, the low-cost prototype represents a 71% savings, proving the viability of the project.

## 5. Conclusions

The research carried out on the anatomy and dimensions of the different parts of the body such as skull, torso and respiratory system streamlined the design of the structure of the simulator, the selection of sensors, electronic and mechanical devices necessary for the project. It also facilitated the CAD design of the structure to properly position each of the elements used, without compromising the performance of the physical structure of the simulator.

The control and monitoring software developed for the simulator validates the design of the mechanical components that intervene in the CPR maneuver, which together with the sensors generate the necessary information to provide feedback to each of the practices carried out by the students.

The interface of clinical scenarios, being fully configurable, allows students to program different situations that can compromise the health of a patient, thus practicing the actions to be taken when facing those anomalies.

The tests carried out by the staff of the Red Cross, which is trained to perform the CPR maneuver, corroborated the hypothesis because the surveys confirmed the applicability of the simulator implemented in the instruction to personnel of health, as well as its help in the generation of skills.

## 6. References

[1] AHA 2015 *Aspectos destacados de la actualización de las Guías de la AHA para RCP y ACE*
[2] Galindo J and Visbal L 2007 Simulación, herramienta para la educación médica. *Salud Uninorte* **23** p 79-95
[3] Narváez M 2015 *Ag. Inf. Conacyt* Available: http://www.conacytprensa.mx/index.php/ciencia/salud/2755-centro-de-simulaciones-medicas-implementacion-tecnologica-para-el-aprendizaje-practico.
[4] Mitchell B *Introducción a las arritmias* Available: https://www.msd manuals.com/es-ec/hogar/trastornos-del-corazón-y-los-vasos-sanguíneos/arritmias/introducción-a-las-arritmias
[5] MedLine 2018 *Arritmias* Available: https://medlineplus.gov/spanish/ency/article/001101.htm
[6] Raviprakash K 2016 *ECG Simulation using MatLab* Available: https://www.mathworks.com/matlabcentral/fileexchange/10858-ecg-simulation-using-matlab

## Acknowledgments

Support provided by Universidad de las Fuerzas Armadas ESPE was greatly appreciated.