Tanzania Journal of Engineering and Technology 2022, **41(4)**:133-147
OPEN ACCESS articles distributed under Creative Commons Attribution Licence [CC BY-ND]
Websites: https://www.ajol.info/index.php/tjet; https://tjet.udsm.ac.tz

ISSN 1821-536X (**print**); ISSN 2619-8789 (**electronic**)
DOI: https://doi.org/10.52339/tjet.v41i4.785

Full Length Research Paper

Design and Implementation of Cardiopulmonary Resuscitation Simulation Model

Georgia Rugumira, Mbazingwa E. Mkiramweni[†], and Napendael T. Msangi

Department of Electronics and Telecommunications Engineering, Dar es Salaam Institute of Technology, P.O. Box 2958, Dar es Salaam, TANZANIA

[†]Corresponding author: mbazingwaem@yahoo.co.uk; ORCID: https://orcid.org/0000-0001-8086-2898

ABSTRACT

Cardiopulmonary resuscitation (CPR) is a life-saving procedure that can multiply a person's chances of survival after a cardiac arrest. The effectiveness of CPR procedures is heavily influenced by the individual skills of the rescuer providing assistance. Chest compressions delivered at an appropriate depth and rate, allowing full chest recoil and with minimal interruptions, are critical for improving cardiac arrest survival. The lack of quality CPR training models in developing countries has a significant impact on the quality of CPR training and skills acquired. Therefore, in this paper, we aim at improving CPR training by designing a high-fidelity CPR training manikin. The model includes a feedback mechanism for monitoring CPR performance status to allow for effective practice and rehearsal until required CPR skills are acquired. An in-depth study of existing training systems was conducted to ensure the proper design of the proposed system. The test results show that the designed manikin prototype analyses the quality of CPR performance and provides appropriate feedback to the trainee. The model can be used for training medical students and other practitioners to correctly perform CPR.

ARTICLE INFO

Submitted: September 27, 2022

Revised: Nov. 20, 2022

Accepted: **Dec. 19, 2022**

Published: Dec. **30, 2022**

Keywords: *Cardiac arrest, Cardiopulmonary Resuscitation model, Training model, Manikin, chest compression model*

INTRODUCTION

Cardiac arrest is one of the leading causes of death worldwide (Wong et al., 2019). The global incidence of out-of-hospital cardiac arrests ranges from 49 to 83 per 100,000 people per year. In-hospital arrests range from 1 to 5 per 1,000 patients, and annual sudden cardiac death estimates in the United States range from 180,000 to more than 450,000. Survival rates for witnessed out-of-hospital arrests with cardiopulmonary resuscitation (CPR) administered by a bystander range from 2% to 7%, and 15% to 20% for in-hospital arrests with CPR administered by trained professionals (Meaney et al., 2013).

Cardiac arrest occurs when the heart's electrical system fails, causing the heart to quiver instead of beating normally. When this happens, the heart loses its ability to pump blood to the rest of the body. Other major concerns, aside from the high risk of death, are the effects of prolonged oxygen deprivation on the brain and other vital organs, as well as the damage that can occur within a few minutes of the heart stopping. The brain can sustain damage after only four minutes of no blood flow, and irreversible damage can occur after only seven minutes. Other vital organs in jeopardy include the lungs, liver, and kidneys. Except for individuals suffering from hypothermia, who can last up to 45 minutes, if blood flow is interrupted for more than 20 minutes, death occurs. Therefore, in general, emergency aid is only effective if administered within seven minutes of the cessation of blood flow (Bircher et al., 2019). Individuals suffering from heart disease, medication overdose, trauma, excessive bleeding, choking, poisoning, or drowning may experience cardiac arrest.

CPR is the procedure used to provide immediate assistance to a person who has gone into cardiac arrest. It combines chest compressions with, in some cases, artificial ventilation in an attempt to manually restore spontaneous blood circulation and breathing in a person who has gone into cardiac arrest. Chest compressions delivered at an appropriate depth and rate, allowing full chest recoil and with minimal interruptions, are critical for improving cardiac arrest survival. Extending the depth of compression beyond the optimum limits blood flow by depleting the volume in the cardiac chambers; it also contributes to rib fractures, which are common in people who have received CPR. Shallow compression has been linked to a lower Return of Spontaneous Circulation (ROSC) and a lower chance of survival. Similarly, exceeding the optimum compression rate reduces the ability of the heart chambers to pump blood. If complete recoil (above 90%) is not allowed, blood cannot return to the heart, and thus cardiac i. output degrades (UT Southwestern Medical Center, 2015).

Out-of-hospital and in-hospital studies on CPR quality show that delivering an adequate rate and depth of chest compressions is difficult (Berger et al., 2019). It has also been demonstrated that the use of real-time CPR feedback devices has improved the quality of CPR provided by laypeople and trained rescuers in both simulated and real-world scenarios. Because of the direct effects of chest compression on the heart's electrical activity and circulation in general, as well as the risk of rib fractures, lung damage, and other organ damage during CPR, it is illegal to perform CPR on someone who does not need it. This highlights the importance of having adequate and high-fidelity training models for the procedure. These models will provide medical personnel and the public with the ability to perform an effective CPR procedure.

For quality CPR procedures, models having the sensation of a real human chest as well as a feedback system are ideal (Shaw & Marvin, 2019). Through them, learners may make mistakes and grasp the repercussions, as well as learn how to prevent them before encountering real patients. Therefore, in this paper, we propose a high-quality, high-fidelity, and cost-effective CPR training model to aid in quality simulation-based procedural training and thereby enhance CPR performance. The training model will make simulation-based CPR training more affordable and provide better equipment to the medical sector. This will address the issue of a scarcity of high-fidelity training models with performance feedback owing to expense, while also improving the quality of CPR performance.

The proposed CPR training model has a feedback mechanism for monitoring CPR performance status. It mimics scenarios and events that occur during a real CPR procedure, which is dependent on the quality of the individual's performance. This will allow for practice and adjustments until effective CPR skills are attained.

In summary, the main contribution of this paper includes designing and implementing cheaper models with sensors for CPR training.

A real-life CPR training model that provides feedback on exactly what a trainee is doing by providing a visual observation of the compression depth and rating the compression-to-ventilation ratio as a trainee practice on the model. A model that provides a realistic feel in terms of stiffness and force characteristics, similar to a real human chest.

In the following sections, we review related works regarding CPR training, procedures, and models; discuss the conception and implementation of the proposed system; and describe the system design and analysis, as well as the performance of CPR procedures using the designed model. We also summarize the findings and recommendations for further research.

LITERATURE REVIEW

CPR is an emergency lifesaving technique to aid in the resuscitation of a cardiac arrest victim. Providing high-quality CPR will improve the chances of survival for the victims, as most of them have "hearts too good to die" (Timmermans, 2001). To perform high-quality CPR, chest compressions must be done at an adequate depth and rate. Thus, for effective CPR, training models for the procedure are needed especially in countries where medical practitioners have less knowledge about CPR (Kaihula et al., 2018).

The efficiency of any medical procedure is dependent on the type and nature of training the medical practitioners obtain before their encounter with real patients. Research shows that simulation-based training is a vital technique, especially in practical-oriented cases (Berger et al., 2019). Quality training is even more crucial in the case of CPR. This is because the quality of CPR highly depends on the physical skills a rescuer has when performing CPR. Continuous high-quality practice is very important for mastering the depth approximations as well as the pace to achieve the required rate. In light of this, the American Heart Association's (AHA's) 2017 guidelines for CPR training place the requirement that all training models for the CPR procedure be equipped with feedback devices by January 31, 2019 (Bhanji et al., 2017).

The guidelines for the performance of the CPR procedure set limits as to what the training should consider and target to achieve. They are the defining terms for the design criteria of the CPR training models. For example, the set standards for effective CPR performance adopted as per the AHA guidelines are shown in Table 1 (Kleinman et al., 2018).

Table 1: Standards for Effective CPR performance as per AHA

	Adult	Child	Infant
Hand position	Two hands centre of the chest, the lower half of the breastbone	Two hands centre of the chest, the lower half of the breastbone	Two - three fingers in the centre of the chest, the lower half of the breastbone
Compression depth in inches	2-2.5	About 2	About 1.5
Ventilation	Look for chest rise and deliver breaths over 1 second	Look for chest rise and deliver breaths over 1 second	Look for chest rise and deliver breaths over 1 second
Compression to breaths ratio	30:2	30:2	30:2
Compression rate	100/min	100/min	100/min

There are a variety of training techniques and methods used for CPR procedure training. Among which is theoretical knowledge. In this type of training, a trainer gives an oral presentation concerning the performance of the CPR procedure. The trainer provides theoretical knowledge to the trainees concerning what the procedure is, why it is done, and how it is done. This is done via lectures, through which conceptual knowledge is passed down to the trainees. When done effectively, this training allows theoretical knowledge to be applied in practice in real scenarios. Students can understand and memorize all the necessary steps and information concerning the procedures. This improves the drive and courage to the take initiative to perform the procedure on a victim in need of it. Understanding its necessity as well as the possible impacts when the procedure is done below standards are important factors accounting for the quality of the procedure's performance (Lund-Kordahl, 2019).

Another training technique is through video content. This is a type of training whereby students view video content with information concerning the performance of CPR. These videos are available on platforms such as YouTube and are uploaded by various individuals with the interest of broadening the knowledge of CPR performance to the public. These videos include animated films of scenarios where CPR is performed. Others include scenarios where CPR is performed on a variety of training models. Throughout the session, the involved instructor demonstrates how the procedure is supposed to be performed, emphasizing the important things to consider for the procedure to be effective (Blewer et al., 2016). This technique provides a visual demonstration and has greater accessibility for training. However, it provides visual knowledge and, in case it is not efficiently done, variations in standards to be adopted for effective CPR occur (Murugiah et al., 2015).

The use of training manikins is among the methods used that involve the practice of CPR performance on a training manikin. This is the recommended training method for the CPR procedure (Sherwood & Francis, 2018). A typical example of a designed manikin is the CPR manikin with a human-like thorax, which is aimed at making a manikin that offers high anatomical and physiological fidelity (Thielen et al., 2017). The design includes a cardiac and respiratory system along with integrated flow sensors to monitor cardiac output and air displacement in response to cardiopulmonary resuscitation. Through such manikins, learners get hands-on practice, skills for effective CPR performance, and experience similar to what they are likely to face in a real CPR event. Some advanced training manikins are equipped with feedback mechanisms to enhance chest compression quality (Kaihula et al., 2018; González-Otero et al., 2014). These allow learners to identify the effects of their performance, practice adjustments, and manage crisis events during training and be better prepared before they encounter real patients (UT Southwestern Medical Center, 2015). The main advantage of this method is that it provides a platform for hands-on practice before a real CPR procedure.

However, most manikins' electronic feedback indicates the success of the procedure, while a few rank the performance status but do not indicate exactly what the trainee is doing wrong (Netherton, 2018). Moreover, the proposed models lack the feel of real human chest stiffness and force characteristics. One study shows that the human chest exhibits non-linear force characteristics during CPR (Stanley et al., 2017). This characteristic affects the compression counts made during a practice session. When a model does not consider this in the design, the number of compressions counts per unit time will be affected. This is one of the challenges facing the available training models.

METHODS AND MATERIALS

System Design

The proposed system for the improvement of CPR training involves the design of a high-fidelity CPR training manikin. The model is equipped with a feedback mechanism for the monitoring of the CPR performance status. The designed model mimics scenarios and events that occur during a real CPR procedure that depends on the quality of its performance by an individual. This will allow room for rehearsal and adjustments until the skills for effective CPR are acquired. Figure 1 is the block diagram for the electronic circuit of the proposed system.

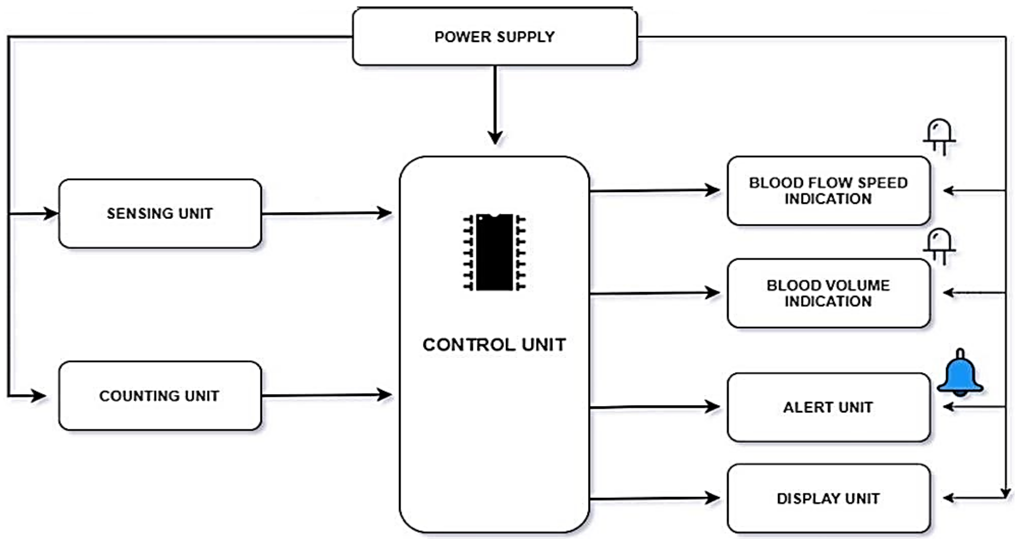

Figure 1: Block diagram for the proposed electronic system.

The system will be battery-powered to allow flexibility and easy movement of the manikin. The sensing unit consists of a displacement sensor that is directly attached to the model to capture the compression quality as performed by a trainee. The counting unit provides the number of times the compressions are made in order to monitor the compression rate and the compression-to-ventilation ratio. The control unit is the central unit of the system responsible for making decisions regarding the system's operation. It consists of a stored program that analyses the parameters from the input unit, processes them, and gives the corresponding output. The blood volume indication unit is an inbuilt part of the model to visually aid the practitioner in observing the impacts of their compression depths. The blood volume in real scenarios is directly proportional to the depth of compressions made during CPR. A blood flow speed indication unit is also an inbuilt unit that responds to the quality of the compression rate during CPR. A good volume of blood flow may be assisted during CPR, but unless the compressions are done at the right rate, blood will not reach the brain. The patient may be saved but be a victim of brain damage. The better the compression rate, the higher the speed of blood flow and the easier it reaches vital organs such as the brain. The alerting system comprises an audio alerting system that notifies the users that it is time for the ventilation interruption. It also notifies the user to observe the display in case a mistake is made. The display unit displays important parameters such as the compression rate. It also displays the type of mistake the practitioner is making during the performance, hence indicating changes until they do it right.

The designed model consists of an upper-body manikin with a recreated feel of a real human chest. The mechanical structure of the design is proposed to be as shown in Figure 2. It is to be equipped with a compression unit with enhanced nonlinear force-displacement characteristics. A trainee will perform chest compressions on the model during a training CPR practice. The compression unit will contain a sensing unit that will capture the quality of the compressions done on it for analysis and feedback.

The captured information will be the compression depth as well as the compression rate and the compression-to-ventilation interruption ratio. The captured information will then be analyzed by the control unit in order to trigger an output corresponding to the quality of the performance. The model will also include a feedback unit that will give different responses depending on the analyzed information. The blood volume indication unit is proportional to the compression depths achieved during a CPR procedure. The blood flow speed indication unit accounts for the proportionality relationship between the blood flow speed and the compression rate. During the training, when a mistake is being made in either the depth, rate, or compression to ventilation ratio, the alert will notify the trainee to look at the display unit and observe the exact mistake that they are making. The trainee can thus make adjustments accordingly until they acquire the required standards of performance.

To enhance the functionality of the designed system, a program with a set of instructions was prepared using Arduino software. The program controls the execution of each task and was written as per the following flow chart shown in Figure 3.

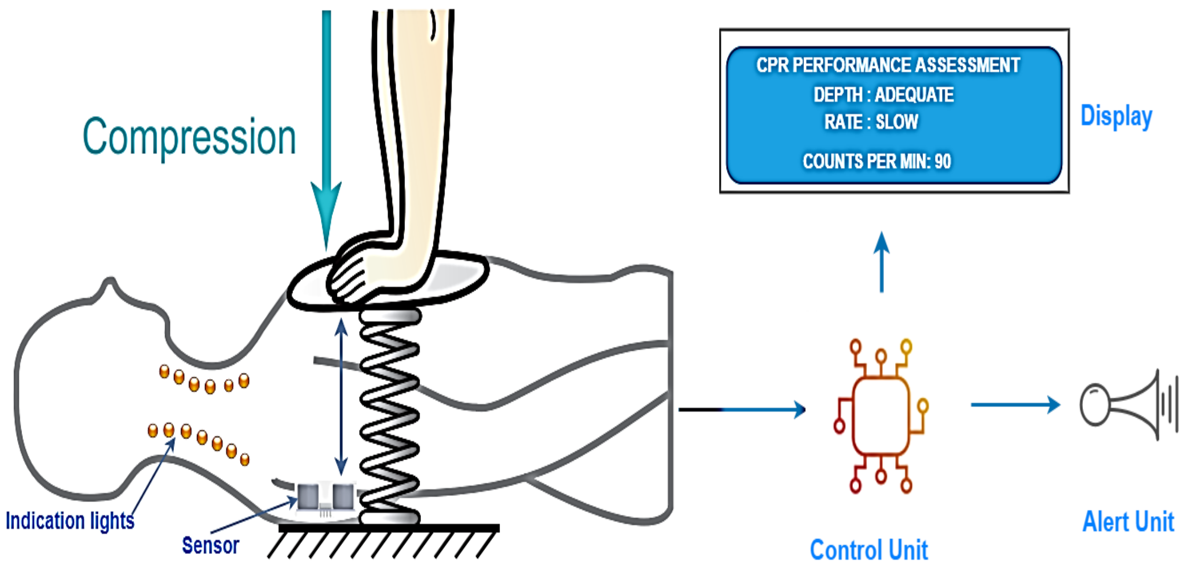

Figure 2: Conceptual diagram of a manikin model.

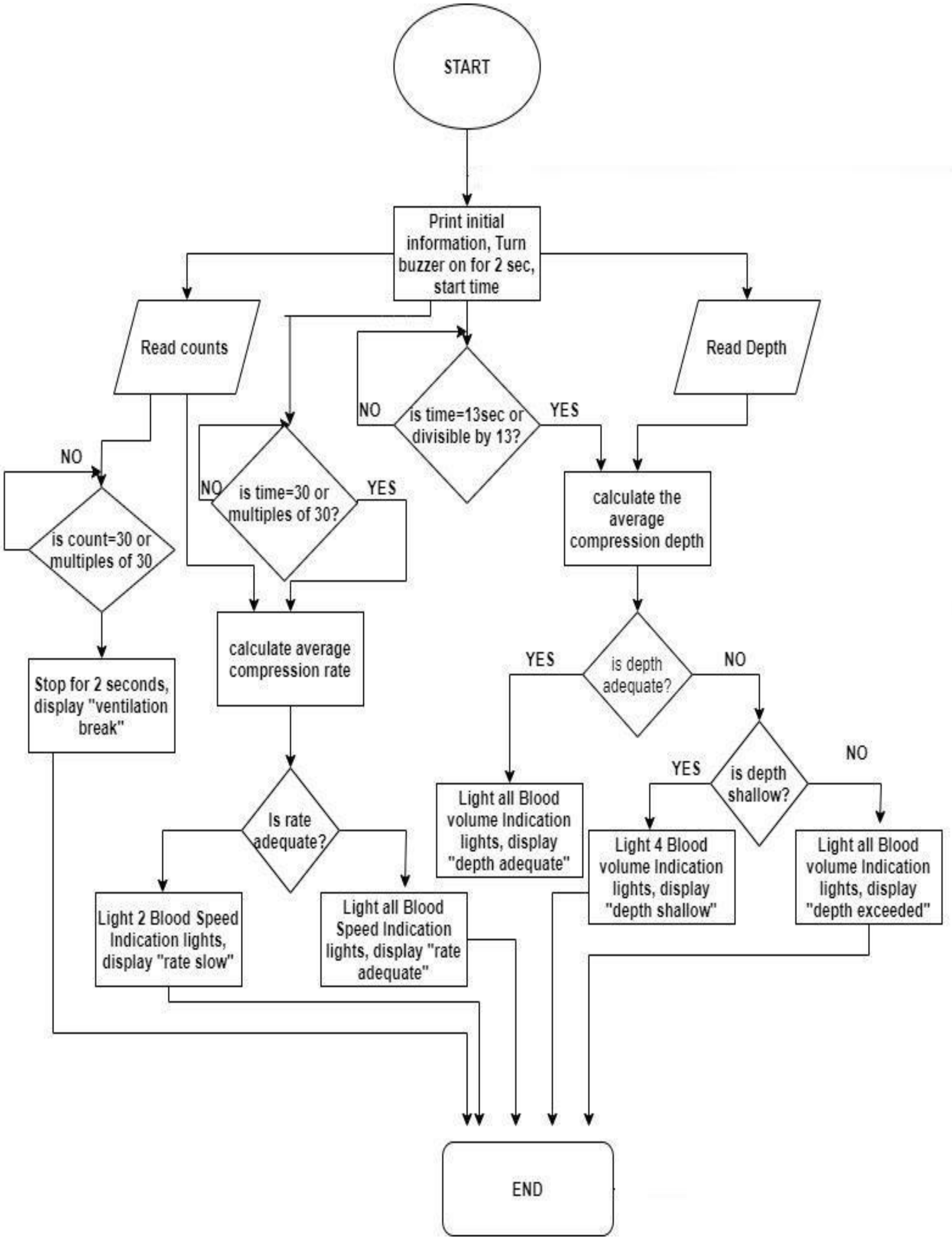

Figure 3: System Flow Chart of the proposed manikin.

SYSTEM ANALYSIS FOR CPR TRAINING

The proposed CPR model is a high-quality and high-fidelity training model to aid quality simulation-based training of the procedure with a feedback mechanism. It uses sensors and counters to detect and count the compression, process the actions, and give feedback through indicators, alerts, and display to provide feedback to the trainee. As a broad category, the manikin has three main parts: detection and counting, control and processing, and the indication part.

Sensing and Counting of Compressions

Compression detection

The compression is detected by the hardware at which a practitioner will exert the compression force. It is desired that the unit resemble and feel like a real human chest. Studies on the force displacement characteristics of the average aged human during CPR indicate that a force of 444.8 N to 533.8 N is required to give the required compression depth of 2 to 2.5 inches, and the force that a human chest exerts when fully compressed to its greatest depth is 600 N (Kuchenbecker., 2017).

A passive mechanical element (a coil spring) is used as the actuator for the design. This is because an active electromechanical system like a DC motor or a solenoid might provide the most controllable force output, but such a device would need to be very large to recreate the forces that a human chest exerts when fully compressed. In addition, using a cable transmission to gear down a large DC motor would have an effective inertia that would be too high to represent the low mass of the chest. Moreover, the coil spring has little inertia and would generate low heat.

The type of spring used in the design was determined by a study that compared the force characteristics of a human chest to the spring constants of various springs. Averaging the stiffness values from all of the compression cycles gave the spring constant k = 7956 N/m (Stanley et al., 2017).

Displacement sensing

The sensing unit has the sole responsibility of capturing the quality of the compressions performed on the training model. This unit consists of a displacement sensor that is directly attached to the model; the sole parameter to be captured is the compression depth. According to the data presented in Table 1, a depth of 2-2.5 inches is required for compression to be considered effective. This depth can be achieved by applying a force of 444.8 N to 533.8 N. Any depth lower or higher than this has been considered incorrect (Netherton, 2018). Thus, the sensing unit has to detect all displacements ranging from 0 to 3 inches.

The promising type of sensor for the sensing unit is the HC SR04 Ultrasonic Sensor. The HC SR04 has greater accuracy in measuring thickness and distance, high frequency, sensitivity, and penetrating power, making it easy to detect external or deep objects. Moreover, the HC SR04 can easily be interfaced with microcontrollers or any type of controller; and they are very robust against noise and relatively cheaper in terms of cost. The HC SR04 Ultrasonic Sensor waves travel faster than the speed of audible sound. They have two main components: the transmitter (which emits the sound using piezoelectric crystals) and the receiver (which encounters the sound after it has travelled to and from the target) (Jost, 2019).

In order to generate the ultrasound, the trigger pin is set on a high state for 10 µs. That will send out an 8-cycle sonic burst, which will travel at the speed of sound, and it will be received by the Echo Pin. The Echo Pin will output the time in microseconds the sound wave travelled (Dejan, 2016).

Compression counting

This unit aids in the provision of the number of times the compressions are made in order to monitor the compression rate and the compression-to-ventilation ratio. According to the data shown in Table 1, the required compression counts are 100-120 per minute for effective CPR. Thus, for practice, the counting unit has to be capable of counting from one to 120 compressions per minute. The counting unit is designed using a push button circuit attached to the compression site. This provides a digital input into the control unit with every change of state counted. This is so since it meets the design requirements, is a relatively cheap method, and is easy to implement and troubleshoot.

The resistance value selected is 10 kΩ because typical pull-up resistor values recommended for the switch and resistive sensor applications range from 1 to 10 kΩ (EE Power, 2019).

Control and Processing

The control part is the brain of the system. It is responsible for analyzing the quality of compression performed on the model and issuing appropriate feedback. The inputs to this unit are the signals from the sensing unit as well as from the counting unit. Whereas the outputs from the unit are signals to the blood flow and volume indication units, the alert unit, and the display unit.

The microcontroller ATMEGA328 is used for the design of the manikin. It has 32K of ROM, 256 RAM, 28 I/O pins, an operating voltage of 1.8-5.5 V, an operating frequency of up to 20 MHz, and a built-in ADC. It is small in structure and requires fewer hardware connections. Furthermore, it has other advantages, including cost efficiency, low power dissipation, ease of programming, and a real-time counter with a separate oscillator.

The Atmega328 is interfaced with an external oscillator to govern the speed at which the processor executes instructions, and a reset button to restart the program. A high logic on reset pin for about two machine cycles will reset the device.

Feedback Indication

Alerting sound

The alert unit notifies the user to observe the display in cases when a mistake is made. It also indicates the times when the ventilation was interrupted. The input to this unit is the signal from the control unit, which will occasionally depend on the reason for the alert. The output is a sound notification.

For this unit, a piezo buzzer was selected as the sound-producing device. This is because buzzers are small and compact; they are easily used on a breadboard, a Perf Board, or even on Printed Circuit Boards (PCBs). The piezo buzzer is simple to install, small in size, low in height, and lightweight. To connect a piezo buzzer, one leg of the buzzer is connected to the board ground and the other leg to a PWM-capable or analog output of the microcontroller board.

Display Unit

The purpose of the display unit is to display the time-lapse from the beginning of the activity, the number of compressions made, and the errors the practitioner is making during the activity. The input to this unit is an output from the control unit, whereas the output expected is a display of the required parameters. The LCD 20 × 4 was chosen as the display in the proposed model. The displays have dimensions that enhance comfortable viewing even in haste. To configure the display, a potentiometer output is connected to V_o (output voltage) to allow the setting of the contrast for optimal viewing of the display. LCD contrast adjustment is required to make the display viewable and to compensate for the correct contrast over the full temperature range of the product. This is necessary since temperature extremes may affect the LCD contrast over time. Usually, a 10k pot is used.

Blood flow and volume indication Units

These units are included in the design to indicate the volume of blood produced during the practice as well as the speed of blood as aided by the chest compressions. The volume of blood assisted depends on the compression depth, while the speed of blood flow during CPR depends on the compression rate.

The blood volume indication unit should have a linear response to all compression depths between 0 inches and 2.5 inches and should provide a visual indication. The blood flow indication unit is required to have a linear response to the possible range of 0 to 100 per minute compression counts made per unit compression cycle. The suitable indication device selected for these units is the LED strips. Figure 4 shows the simulation of blood flow and blood volume.

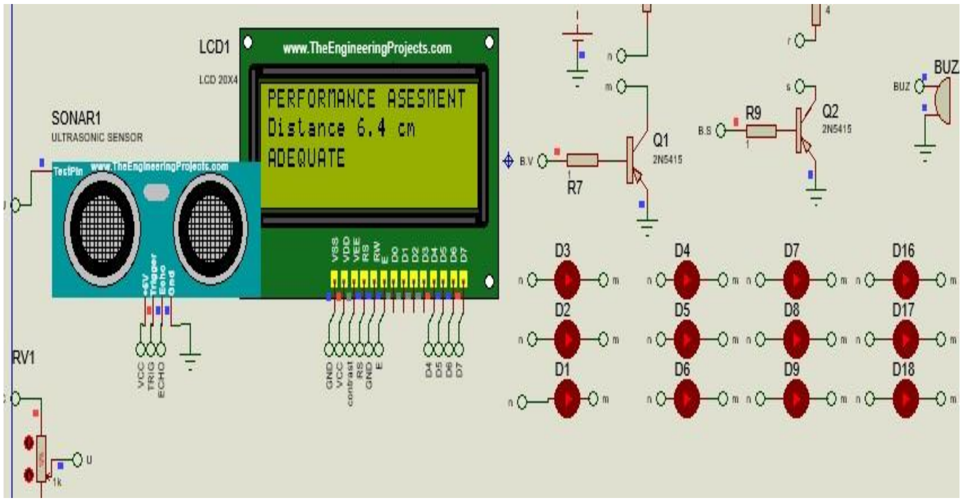

Figure 4: Simulation of blood flow and volume indication units.

PROTOTYPE, RESULTS AND DISCUSSIONS

This is the implementation and testing stage that proceeds after the completion of the system analysis, design, and simulation stages. It involves a series of procedures performed in order to achieve an actual and working prototype.

Printed circuit board development

The PCB layout was designed using Proteus version 8.6 software. The schematic circuit of the designed system was used as the basis of the layout design. Figure 5 shows the designed PCB layout and 3D presentation as displayed in Proteus software.

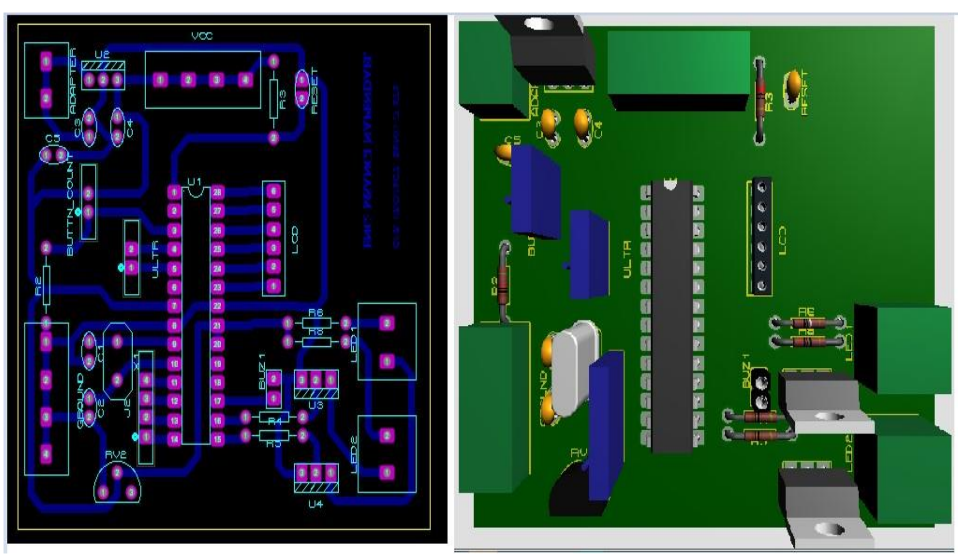

Figure 5: PCB Layout and 3D visualization.

After designing the PCB layout, the layout was transferred to the PCB board using ultraviolet (UV) exposure, followed by the etching process. Succeeding this stage, the drilling of pinholes and mounting of the components on the board was done as depicted in Figure 6.

Complete Prototype

All units of the system were then connected and assembled into the overall prototype. The complete manikin is given in Figure 7.

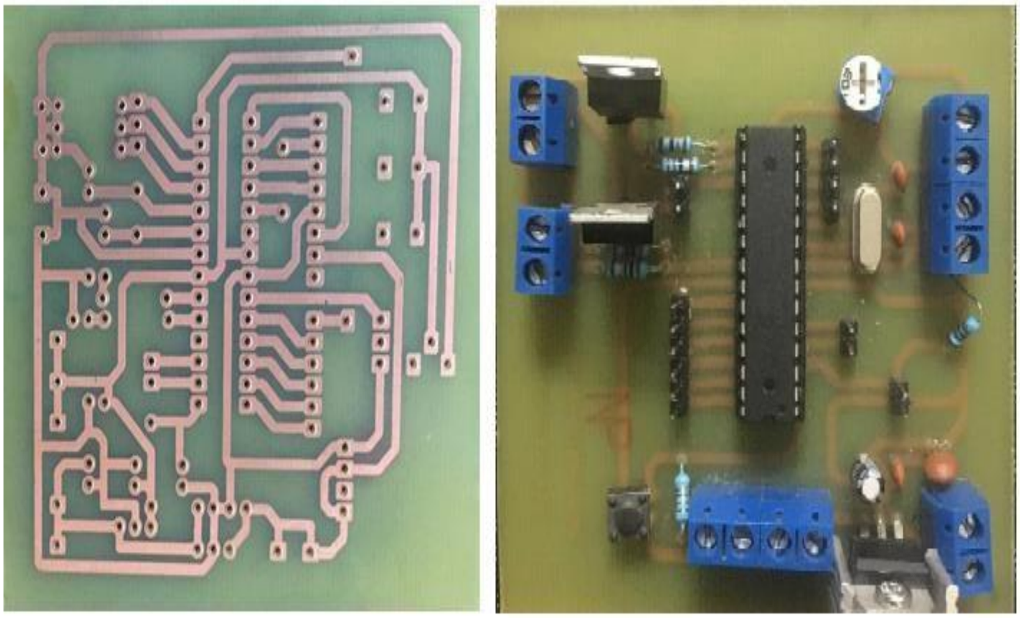

Figure 6: Printed circuit and device mounted on the board.

Figure 7: A working manikin.

Prototype testing and results

In order to evaluate the performance of the designed prototype, various measurements were done at each of the designed units. The results of the tests are shown in Table 2. Figure 8 presents the comparison of the expected values to the obtained values after the rigorous test of the prototype.

Table 2: Expected results compared to measured results

S/No	Process	Expected Value (V)	Measured Value (V)
Power Supply	12 V Power supply	12.00	11.85
	5 V Regulator Output	5.00	4.99
Sensing Unit	Output voltage at a maximum depth	5.00	4.98
	Output voltage at an adequate depth of 6.4cm	0.68	0.61
	Out voltage at a minimum depth	0.00	0.00
Counting Unit	Output voltage when the button is pressed	5.00	4.99
	Output voltage when the button is not pressed (released)	0.00	0.00
Alert Unit	The voltage across the buzzer when the alert signal is present	5.00	4.95
	The voltage across the buzzer when the alert signal is absent	0.00	0.00
Blood Volume Indication Unit	Output voltage when compression depth is adequate and exceeded	5.00	4.87
	Output voltage when compression depth is shallow	0.00	0.00
Blood Speed Indication Unit	Output voltage when the compression rate is adequate	5.00	4.85
	Output voltage when the compression rate is slow	0.00	0.00

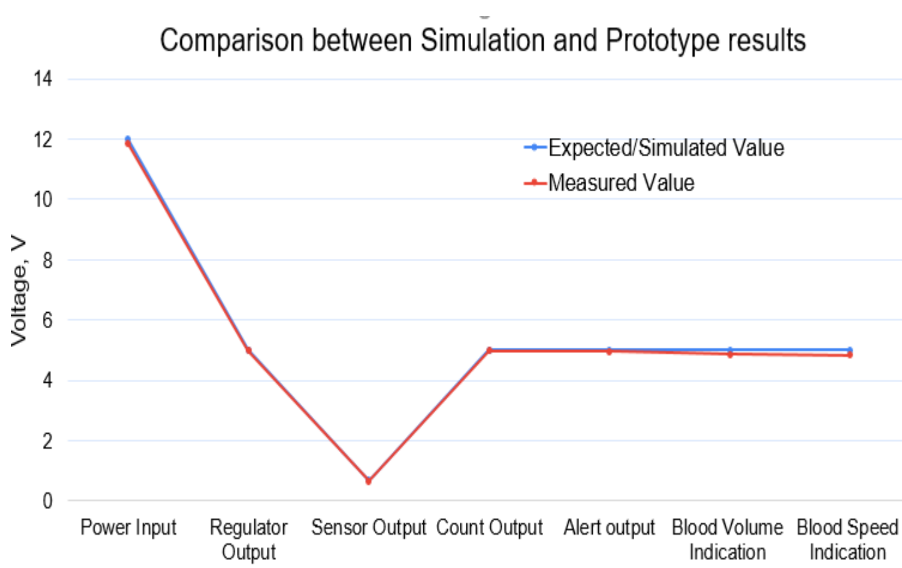

Figure 8: Comparison between simulation and prototype results.

RESULTS AND DISCUSSION

The prototype operation with respect to the expected and simulated results can be concluded as follows:

- The sensor attached to the manikin detects the compression depth whenever a compression is made. The accumulated depth values for 13 seconds trigger subsequent feedback from the alert, display, and blood volume indication units.
- The counting unit attached to the manikin captures the compression counts whenever a compression is made. The control unit increments these counts and provides the compression rate as well as appropriate feedback every 30 seconds. This ensures an appropriate analysis of the number of counts that can be made in under a minute.
- The control unit analyses the inputs from the sensing unit and counting unit and issues appropriate outputs with accuracy and without delay.
- The alert unit issues a sound notification every 30 counts. This is for the ventilation break. It also effectively gives a sound alarm (of a different frequency) whenever an error is made.
- The blood volume indication unit implemented using neopixel lights produces a glow of red light every 13 seconds depending on the performance within the given time lapse. The glow is such that all neopixels illuminate upon the adequate depth and only half of the strip illuminates at an inadequate depth.
- The blood speed indication units, which are implemented using neopixel lights, produce a high speed all strip illumination at an adequate rate and a quarter strip illumination at a slow rate.
- The display unit attached to the prototype case displays the performance evaluation accordingly and without delays.

In conclusion, based on the obtained prototype results, the overall system performance is good since the performance parameters agree with the design requirements and objectives.

CONCLUSION

In this paper, a high-fidelity CPR training model was designed and implemented. The proposed system and its working mechanism have been well elaborated. The designed system has proven to be working effectively. Implementation of the designed manikin is a great achievement, as it will enable effective training in the CPR procedure. This will improve the individual skills of healthcare providers and the general public at large, lowering cardiac arrest mortality.

However, further improvements can be made to the design. This includes things such as the incorporation of design for ventilation performance training on the CPR manikin. Further, more portable wearable devices to monitor CPR performance in a real-life CPR scenario can be developed.

REFERENCES

Berger, C., Brinkrolf, P., Ertmer, C., Becker, J., Friederichs, H., Wenk, M., Van Aken, H. and Hahnenkamp, K., (2019). Combination of problem-based learning with high-fidelity simulation in CPR training improves short and long-term CPR skills: a randomised single blinded trial. *BMC medical education*, **19**(1):1-10.

Bhanji F., Donoghue A., Wolff M., & Flores G. E., (2017). American Heart Association (AHA) Requirement on Use of Feedback Devices in Adult CPR Training Courses, American Heart Association.

Bircher, N. G., Chan, P. S., Xu, Y., & American Heart Association's Get With The Guidelines–Resuscitation Investigators (2019). Delays in Cardiopulmonary Resuscitation, Defibrillation, and Epinephrine Administration All Decrease Survival in In-hospital Cardiac Arrest. *Anesthesiology*, **130**(3): 414–422. https://doi.org/10.1097/ALN.0000000000002563

Blewer, A. L., Putt, M. E., Becker, L. B., Riegel, B. J., Li, J., Leary, M., Shea, J. A., Kirkpatrick, J. N., Berg, R. A., Nadkarni,

V. M., Groeneveld, P. W., Abella, B. S., & CHIP Study Group (2016). Video-Only Cardiopulmonary Resuscitation Education for High-Risk Families Before Hospital Discharge: A Multicenter Pragmatic Trial. Circulation. Cardiovascular quality and outcomes, **9**(6): 740–748. https://doi.org/10.1161/CIRCOUTCOMES.116.002493

Dejan, (2016), *Ultrasonic Sensor HC-SR04 and Arduino - Complete Guide | How to Mechactronic*, Retrieved September 10, 2022, from https://howtomechatronics.com/tutorials/arduino/ultrasonic-sensor-hc-sr04/

EE Power, (2019). Pull-up and Pull-down Resistors Chapter 5 - Resistor Applications Resistor Guide, Retrieved September 12, 2022, from: https://eepower.com/resistor-guide/resistor-applications/pull-up-resistor-pull-down-resistor

González-Otero, D. M., Ruiz, J., Ruiz de Gauna, S., Irusta, U., Ayala, U., & Alonso, E. (2014). A new method for feedback on the quality of chest compressions during cardiopulmonary resuscitation. *BioMed research international*, *2014*, 865967. https://doi.org/10.1155/2014/865967

Jost D., (2019), Sensors: What is an Ultrasonic Sensor? | Fierce Electronics, Retrieved on September 12, 2022, from https://www.fierceelectronics.com/sensors/what-ultrasonic-sensor

Kaihula, W. T., Sawe, H. R., Runyon, M. S., & Murray, B. L. (2018). Assessment of cardiopulmonary resuscitation knowledge and skills among healthcare providers at an urban tertiary referral hospital in Tanzania. *BMC health services research*, **18**(1): 935. https://doi.org/10.1186/s12913-018-3725-2

Kleinman, M. E., Goldberger, Z. D., Rea, T., Swor, R. A., Bobrow, B. J., Brennan, E. E., Terry, M., Hemphill, R., Gazmuri, R. J., Hazinski, M. F., & Travers, A. H. (2018). 2017 American Heart Association Focused Update on Adult Basic Life Support and Cardiopulmonary Resuscitation Quality: An Update to the American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*, **137**(1): e7–e13. https://doi.org/10.1161/CIR.0000000000000539

Lund-Kordahl, I., Mathiassen, M., Melau, J., Olasveengen, T. M., Sunde, K., & Fredriksen, K. (2019). Relationship between level of CPR training, self-reported skills, and actual manikin test performance-an observational study. *International journal of emergency medicine*, **12**(1): 2. https://doi.org/10.1186/s12245-018-0220-9

Meaney, P. A., Bobrow, B. J., Mancini, M. E., Christenson, J., de Caen, A. R., Bhanji, *et. al*., (2013). Quality Summit Investigators, the American Heart Association Emergency Cardiovascular Care Committee, and the Council on Cardiopulmonary, Critical Care, Perioperative and Resuscitation Cardiopulmonary resuscitation quality: [corrected] improving cardiac resuscitation outcomes both inside and outside the hospital: a consensus statement from the American Heart Association. *Circulation*, **128**(4): 417–435. https://doi.org/10.1161/CIR.0b013e31829d8654

Murugiah, K., Vallakati, A., Rajput, K., Sood, A., & Challa, N. R. (2011). YouTube as a source of information on cardiopulmonary resuscitation. *Resuscitation*, **82**(3): 332–334. https://doi.org/10.1016/j.resuscitation.2010.11.015

Netherton S. (2018). CPR Update Series Part 2- Depth of Compression, *In Medical Concepts*.

Shaw R. W., & Marvin J. D., (2019). Single use mannequin having chest compression feedback mechanism for use in simulated cardiopulmonary resuscitation (CPR) training. *U.S. Patent* 10, 482, 791.

Sherwood, R. J., & Francis, G. (2018). The effect of mannequin fidelity on the achievement of learning outcomes for nursing, midwifery and allied healthcare practitioners: Systematic review and meta-analysis. *Nurse education today*, **69**: 81–94. https://doi.org/10.1016/j.nedt.2018.06.025

Stanley A. A., Healey S. K., Maltese M. R., Kuchenbecker K. J. (2012). Recreating the feel of the human chest in a CPR manikin via programmable pneumatic damping. *In Proceedings, IEEE Haptics Symposium,* 37-44, doi:10.1109/HAPTIC.2012.6183767

Thielen, M., Joshi, R., Delbressine, F., Bambang Oetomo, S., & Feijs, L. (2017). An innovative design for cardiopulmonary resuscitation manikins based on a human-like thorax and embedded flow sensors. *Proceedings of the Institution of Mechanical Engineers. Part H, Journal of engineering in medicine,* **231**(3): 243–249. https://doi.org/10.1177/0954411917691555

Timmermans, S. (2001). Hearts Too Good to Die: Claude S. Beck's Contributions to Life-Saving. *Journal of Historical Sociology,* **14**: 108-131.

UT Southwestern Medical Center, (2015). Depth and rate of chest compressions during CPR impact survival in cardiac arrest. ScienceDaily. Retrieved on September 10, 2022, from www.sciencedaily.com/releases/2015/02/150205155638.htm

Wong, C. X., Brown, A., Lau, D. H., Chugh, S. S., Albert, C. M., Kalman, J. M., & Sanders, P. (2019). Epidemiology of Sudden Cardiac Death: Global and Regional Perspectives. *Heart, lung & circulation,* **28**(1): 6–14. https://doi.org/10.1016/j.hlc.2018.08.026