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AUTOMATIC BELT CARDIOPULMONARY RECISUTATION (CPR) DEVICE AND TEST SYSTEM DESIGN

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Keywords
CPR,
Heart Massage,
Test Simulator.

Abstract

The test system was created by adding flex and force sensors to this manikin to evaluate the results of heart massage applied on an artificial adult manikin, which has a spring that can give the chest stiffness of an adult human. This test system monitors and analyzes cardiopulmonary resuscitation (CPR) applications performed by the automated CPR device or manually by the person. The signals received from the sensor are transferred to the computer via the serial port with the Arduino Uno card and displayed in real-time in MATLAB graphical user interface (GUI). This GUI, designed with Matlab 2021a software, analyzes the sensor signals resulting from CPR. It gives a graph of the repeats of compression per minute, the depth of each compression, and the compressions rate variable performed by the user or the automatic CPR device during the CPR application. This created test system can evaluate the accuracy of both the automatic CPR device performed in this study and the manual CPR application. The test system designed in this respect can be used in the training and evaluation of cardiac massage applications, which is included in the first aid courses in secondary education, associate degree, undergraduate, and vocational education courses.

OTOMATİK KEMERLİ KARDİYOPULMONER RESİSÜTASYON (KPR) CİHAZI VE TEST SİSTEMİ TASARIMI

Anahtar Kelimeler
KPR,
Kalp Masajı,
Test Simülatörü.

Öz

Test sistemi, yetişkin bir insanın göğüs sertliğini verebilecek bir yaya sahip yapay bir yetişkin manken üzerinde uygulanan kalp masajının sonuçlarını değerlendirmek için bu mankene esneklik ve kuvvet sensörleri eklenerek oluşturulmuştur. Bu test sistemi, otomatik kardiyopulmoner resisütasyon (KPR) cihazı tarafından veya kişi tarafından manuel olarak gerçekleştirilen KPR uygulamalarını izler ve analiz eder. Sensörlerden alınan sinyaller Arduino Uno kartı ile seri port üzerinden bilgisayara aktarılır ve MATLAB grafiksel kullanıcı arabirim (GUI) tasarımında gerçek zamanlı olarak görüntülenir. Matlab 2021a yazılımı ile tasarlanan bu GUI, KPR sonucunda sensör sinyallerini analiz eder, dakikadaki basınç sayısı, sıkıştırma derinliği değerlerinin gerçek zamanlı izlenmesini sağlar. Ayrıca bu arayüz KPR uygulaması sırasında kullanıcı veya otomatik KPR cihazı tarafından gerçekleştirilen sıkıştırma hızı değişiminin bir grafiğini verir. Oluşturulan bu test sistemi, hem bu çalışmada gerçekleştirilen otomatik KPR cihazının hem de manuel KPR uygulamasının doğruluğunu değerlendirebilir. Bu yönüyle tasarlanan test sistemi ortaöğretim, önlisans, lisans ve mesleki eğitim kurslarında ilk yardım dersleri içerisinde yer alan kalp masajı uygulamalarının eğitiminde ve değerlendirilmesinde kullanılabilir.

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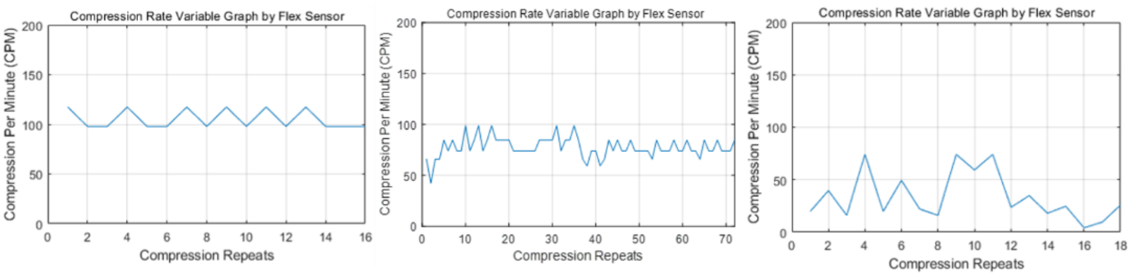
Highlights

- An automatic CPR device and a test system that evaluates the accuracy of CPR are designed.
- Effectively, 100 to 110 CPM and a depth of 5 cm per compression were achieved.
- The sensitivity of the heart massage performed by the people can be monitored and recorded.
- This study reveals the importance of automatic CPR devices in CPR practice.

Graphical Abstract



Automatic CPR Device | Trained Person | Untrained Person

Figure. Comparison Of Compression Rate Variable Graphs For Three Different Applications.

Purpose and Scope

This study aims to design an automated CPR device and to perform a test system that evaluates the accuracy of both this automated CPR device and manual CPR applications.

Design/methodology/approach

In this study, a mechanical CPR device that can operate for about 45 minutes with a capacity of 14.8V and 10400mAh has been carried out. The Arduino Mega2560 card with an ATmega2560 processor operated and controlled the designed automatic CPR device. This system contains a piston system that converts circular motion to horizontal motion and a DC motor. The motor with a power of 140 W can efficiently perform heart massage with force increased significantly with a 1/3 reducer. Also, a test system has been created to check its accuracy during the operation of the automatic CPR device. This test system was carried out by placing two types of sensors, flex and force, to detect the compression depth and applied force, designed to simulate the chest stiffness of an adult individual with a spring. With this test system's graphical user interface (GUI), information such as compression force of piston movements, depth, and variable rate graph can be displayed. This GUI, designed with Matlab 2021a software, analyzes the sensor signals resulting from CPR.

Findings

The developed automatic CPR device is both portable and easy to use. In addition, with the designed test system, it was observed that automatic CPR works efficiently at 100 to 110 CPM per compression and at a depth of 5 cm. According to the experimental application data obtained from the test system, it is seen that the compression rate variable graphs of the data obtained from the automatic CPR device are stable.

Social Implications

The test system designed in this study can be used in the training and evaluation of cardiac massage applications in first aid training courses in secondary education, associate degree, undergraduate and vocational education.

Originality

This work is the only test system that simultaneously provides compression depth, compression force, and CPM information. It is shown that a meaningful way to analyze the accuracy of CPR applications is the compression rate variable graph. In this way, the importance of automatic CPR devices in saving a life has been revealed.

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1. Introduction

A Chest compression method (heart massage) is a first aid method used in cases such as cardiac arrest to bring the person back to life and ensure oxygen delivery to the brain by providing blood circulation. With this method, a person whose blood circulation has stopped is interfered with externally using supporting devices or manpower. For the heart massage to be performed effectively, it is necessary to apply force to the middle part of the sternum about 100 times a minute and at a depth of 50 mm. Damage to the brain when blood circulation is not provided by this method of application has been revealed in studies (Matheny et al., 1982; Yeong-Tak et al., 2011).

The application, called cardiopulmonary resuscitation (CPR) in the literature, is a set of methods used in emergency cases such as sudden cardiac arrest and respiratory arrest. It is also known as cardiac massage and artificial respiration. It is a well-known fact that 7% of patients can return to life without problems if CPR is performed in the first four minutes at the latest in cases such as cardiac arrest or inability to breathe as a result of a heart attack. No brain damage occurs in the first four minutes. If CPR is started during this time, there is a chance to save the patient without damaging the brain. But between four to ten minutes, brain damage begins. After ten minutes, permanent damage to the brain starts to occur. For this reason, CPR is a first aid method that should be applied as soon as possible (Polat., 2022).

Incomplete and short applications cannot be effective because the heart massage performed with human power is irregular and insufficient (Steen et al., 2002; Rubertsson et al., 2005). That is why automatic heart massage devices are of vital importance. Automatic heart massage devices used today are divided into two classes reciprocating and banded (Remino et al., 2018). In devices using a band system, the chest is wrapped with a band that can be stretched and compressed. This band is attached to a backboard the size of the patient's back on which the patient is laid. By moving it in the opposite direction with two direct current (DC) controlled motors located in the backboard, it is ensured that the tape is stretched and, as a result, the chest is compressed. All electronic and mechanical systems, such as the control motor and the control board, the tensioning equipment connected to the motor, and the battery, are located on the tread board (Ikeno et al., 2003). The second system performs heart massage with the help of a piston. In order for the device to stand in the air, it is attached to the board, which is placed on the patient's back with the help of a support arm from the sides and has the task of holding the arms. There are devices that are attached to the patient with a belt instead of a support arm or supported with a single arm. The device has a piston that moves up and down, a DC motor that provides movement, a battery, and control cards that move up and down. Unlike the tape system, these devices do not have any electronic and mechanical systems on the tread board. When the engine starts to rotate, the movement is transferred by a belt to the gear that rotates a long shaft. When the shaft starts to rotate, it pushes the pipe that grasps the outer part forward or backward thanks to the teeth on it, turning the circular motion into linear motion. Thanks to the control card and the buttons located on the device, intermittent CPR applications can be changed so that there are two artificial breaths per 30 heart massages so that continuous CPR or artificial respiration can be performed on the device (Remino et al., 2018; Carl et al., 1985).

The importance of heart massage and test systems in sudden cardiac arrest has been emphasized in many studies. Some of these can be summarized as follows:

A study using the CPREzy brand CPR test device emphasized the difficulty of applying CPR and that people reached less depth of compression as the application time progressed (Noordergraaf et al., 2006). In another study conducted to ensure that the CPR application is performed effectively and accurately, the CPREzy brand CPR test device was used again. This study investigated whether the test device creates extra work in regular heart massage applications (Berkom et al., 2008). In a study conducted in 2011, cardiac massage performed without feedback and using the PocketCPR brand CPR test device was evaluated. As a result of this evaluation, it has been revealed that CPR using a test device is of higher quality (Pozner et al., 2011). In a study by Majer et al., they used a TrueCPR brand test device on the CPR test system. In this study conducted with intern doctors, the compression frequency and depth information were compared to the CPR application without using the device. The comparison concluded that the compression depth and frequency were more accurate when the CPR test device was used (Majer et al., 2019). In the study of İnal et al., to determine the validity and accuracy of the CPR, feedback was given to the Expert Trainer on whether an ideal massage was performed with an Artificial Intelligence (AI) classifier based on the data collected from the sensors placed on the manikin (İnal et al., 2021). In their study, Araç et al. stated that approximately 20% of all deaths are caused by cardiac arrest, and it is necessary to establish recording systems and standardization to increase the quality of CPR (Araç et al., 2021).

This study aims to design an automatic CPR device and implement a test system that evaluates the accuracy of both this automatic CPR device and manual CPR applications. For the aim of this study, a mechanical CPR device that performs heart massage with the help of the piston, whose system block diagram is shown in Figure 1, and a test system were developed. The test system displays and analyzes the signals coming from the sensors with the MATLAB GUI interface. In addition, the test system was used to obtain the compression depth, compressions per minute, and compression rate variable graph. Force and flex sensor circuits were placed on the manikin to get these values. The automatic CPR device consists of a microcontroller, a motor driver, a DC Motor, a reducer, a control panel for user communication, a piston system, and a battery.

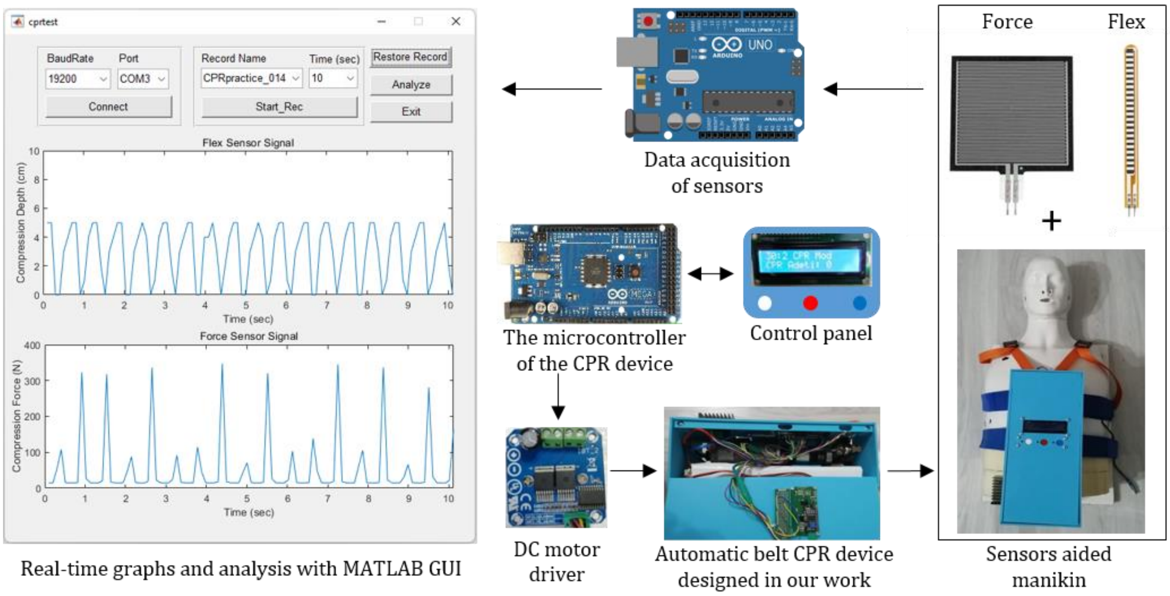

Figure 1. Block Diagram Of The Study

2. Material and Method

2.1. Automatic CPR Device Design

CPR devices should be mobile (portable) devices because should use them in emergencies such as cardiac arrest. For this reason, there should be a quick, convenient and easy control system for the user, a compact and long-term battery system with as small dimensions as possible, and an easy-to-carry and uncomplicated way of use. The device designed in this study is connected to the patient with a belt (Figure 2), providing significant advantages both by reducing the total carrying weight, taking up less space and by convenient installation.

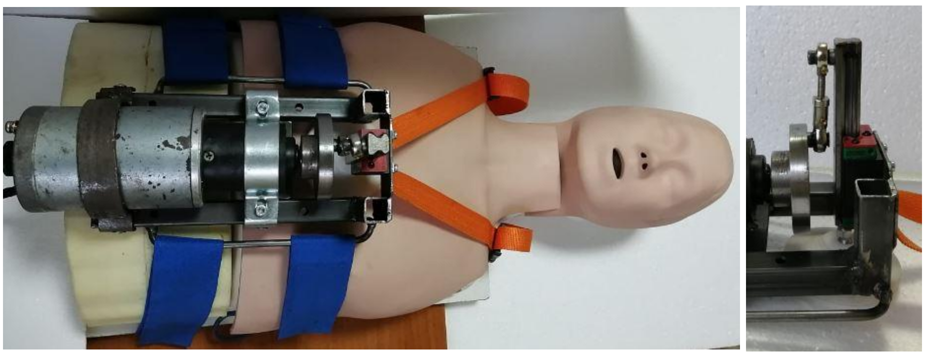

Figure 2. Designed Automatic CPR Device And Piston System

The motor to be used in the automatic CPR device should be easy to control and have high performance. DC-powered motors can be controlled more easily than alternating current (AC) powered motors (Çolak et al., 2005). Since the batteries used in portable systems are DC, a DC motor with a 12 V reducer is preferred in the device motor. The motor with a power of 140 W can efficiently perform heart massage with force increased by three times with a 1/3 reducer. The circular motion received from the motor moves down and up, and for the heart massage to be performed, it must be translated into linear motion. This motion transformation is provided by the eccentric transfer method in the device (Figure 2). In the system, a 68 mm thick and 11 mm thick circular iron piece is attached and centered on the clay when the motor is removed from the reducer. A 10 mm diameter pin is inserted 25 mm out of the center of this part and at one point. When the distance of 25 mm up and down is added up, the length of the movement is precisely 50 mm. If it is a rail track moving down and up, there is the same pin on the circular path. To these two pins, the movable part with mobility of 360^0 of the region to which the pin is attached is connected. This way, the piston moves down and up if the engine runs right or left in both directions.

For the operation and control of the designed automatic CPR device, the Arduino Mega2560 card with an ATmega2560 processor and an operating frequency of 16 MHz was used (Figure 3). The user can quickly start, stop and change the mode of operation of the device with three buttons. There are two different modes on the device. The first is continuous CPR, that is, the mode that continues the heart massage process until it is stopped by the user when the device is started. The second is the 30:2 mode. The second is the 30:2 mode. The number of CPR performed in this mode is counted. When the number reaches 30, the automatic CPR device stops the heart massage for a while. This period is for the patient to be given external air twice. The automatic CPR device only performs CPR. The designed system does not control the patient's respiratory status or heartbeat status during CPR. The user can see which mode he is in and the number of CPR and exhalation warning information in the second mode from a liquid-crystal display (LCD) screen with a 2x16 pixel used. The motor control is provided by the IBT_2 H bridge DC motor driver controlled by the Arduino Mega2560 board (Figure 3).

Figure 3. Arduniomega, LCD Display, And İmages İn Both Modes, IBT_2 Driver

CPR is performed for about 45 minutes (Ikram et al., 2008). The application may be terminated early if the patient is brought back to life earlier. A total of 16 3.7V 2600 mAh Sony Vtc5 lithium-ion batteries were used in the operation of the device, four of which were parallel to each other and connected in series with each other in these similar groups. These rechargeable batteries can output a current of up to 30 amperes. With a total capacity of 14.8V and 10400mAh, it allows you to use the device for a long time.

2.2. Description of the Test System and the Developed Application

A test system has been prepared to check its accuracy during the operation of the automatic CPR device. This test system provides information such as the compression force, the compression depth, and the compression rate variable graph at the piston movements. Thus, we can have this information for the device, and the heart massage people perform. An artificial manikin that can simulate a person is needed to create the test system. Therefore, this study used a BASICBilly+ model CPR manikin of the 3B Scientific brand for the test system (Figure 4).

Figure 4. BASICBilly+ Model CPR Manikin

The chest of an adult individual is simulated by a spring of a specific stiffness. The compression force required for the stiffness of the 50 mm spring in the manikin was made with a Zwick/Roell Z1200 model tensile-compression test machine. As a result of this test, it was found that a force of about 360-370 Newtons is needed to apply a 50mm compression (Figure 5).

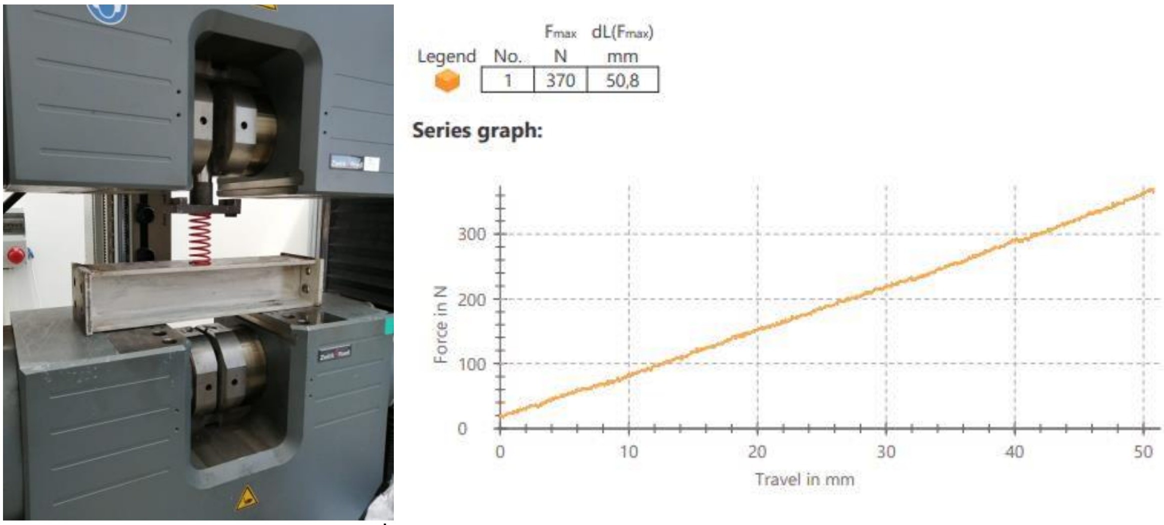

Figure 5. The Spring İn The Manikin Tension-Compression Test Machine Test Results

It is essential to get information about how deep the compression goes and the repeat of compression per minute (CPM) when the heart massage is performed by the device or by a person. This information is obtained using the RP-S40-ST model force sensor and 2.2-inch flex sensor in the designed test system (Figure 6). The information received from both sensors is transmitted to the computer via Arduino Uno.


Figure 6. Placing Force And Flex Sensors İn The Manikin

The developed application is designed to obtain force and flex sensors signals, present user visual information, and create a record file to analyze record data for detecting the compression force, the compression depth, and the compression rate variable graph. The MATLAB GUI interface of the developed application is presented in Figure 7.

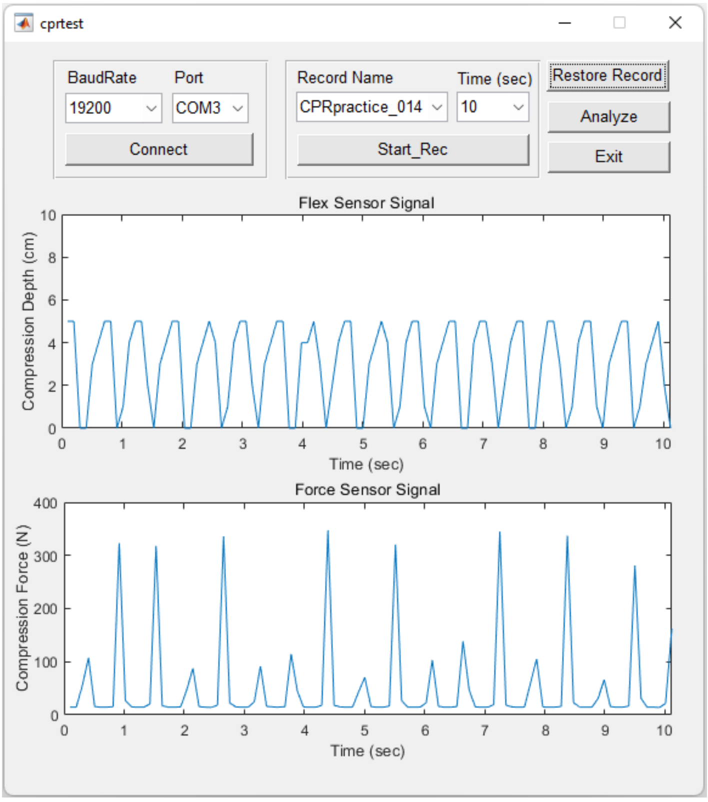

Figure 7. The GUI Of The Developed Application

The "Connect" button is used to connect a serial port of Arduino Uno to the developed application. The "Start_REC" button is used to start recording the flex sensor and the force sensor signals throughout the specified recording time. Signals from the flex sensor are scaled to show the compression depth as a cm. Signals from the force sensor are scaled to show the compression force as a Newton. The "Restore Record" button is used to re-visualize the desired recorded signals from the specified record names. The "Analyze" button is used to show the compression rate variable graph in a separate figure window, as shown in Figure 8, from the signals shown in the main form. At this stage, individual peaks are marked in the force and flex sensor signals using the Peak detection algorithm built in Matlab 2021a software. Using the time change amounts between these marked peaks, the compression rate variable is determined per minute and presented graphically.

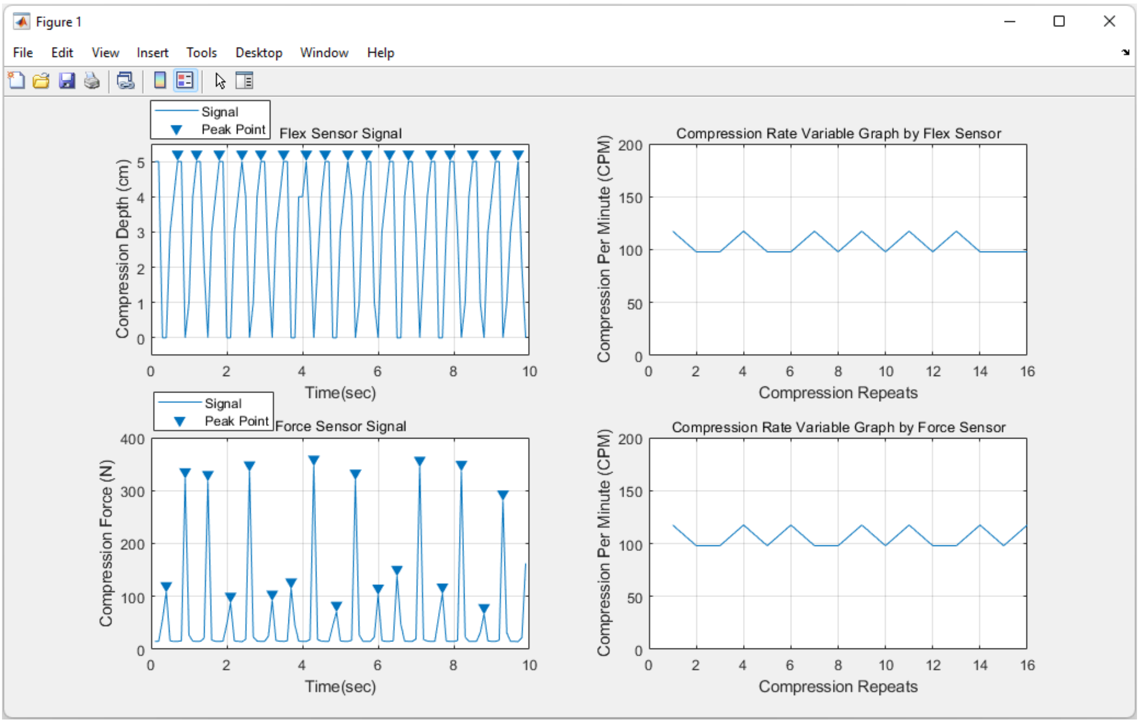

Figure 8. The Figure Window Showing Analysis Results

3. Results and Discussions

The data obtained from the applications made with the test system were converted into graphics via the MATLAB GUI interface. These graphs contain information about the compression depth, the compression force, and the CPM and present the compression rate variable graph from the recorded signals. While recording, the data were obtained for three applications: the automatic CPR device, trained persons, and untrained persons. The practical application's realization views are presented in Figure 9.

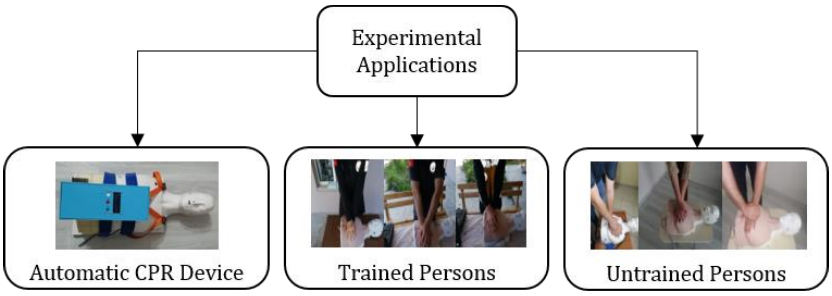

Figure 9. The Experimental Applications Realization Views

The automatic CPR device is designed to reach a depth of 5 cm at each press and to apply the 370N force required for this depth. The automatic CPR device was installed in the test system with the help of a belt. The analyses taken from the MATLAB GUI interface during the application are shown in Figure 10. The stability at the compression depth of the automatic CPR device can be seen on the compression depth-time graph in Figure 10 (a). The compression depth-time graph was obtained from the test system's flex sensor. A constant depth of 5 cm was reached with each press. The compression force-time graph in Figure 10 (c) was obtained using data from the force sensor on the manikin. Slight changes were observed in the compression force-time graph because the manikin flexed during CPR application. As the motor gained momentum due to the spring thrust in the manikin during its upward movement, there were pressure force changes due to the precise measurement of the force sensor. In addition, compression rate variable graphs are given separately for each sensor in Figure 10 (b) and (d). Thus, it is possible to observe whether this application is successful or not by detecting the CPM and the time-dependent changes. In this study, observations were made and interpreted on six people, three trained persons and three untrained persons, thanks to the GUI interface design.

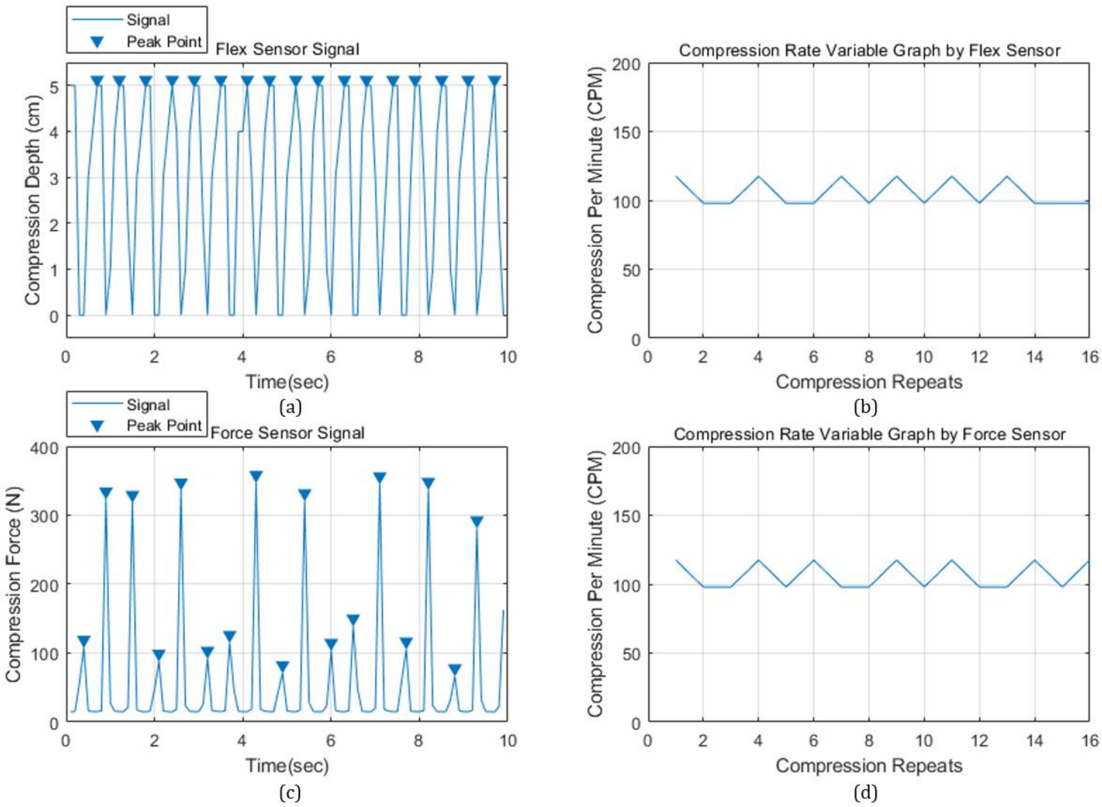

Figure 10. Results Of CPR Application Records Obtained By The Designed Automatic CPR Device

3.1. Observing of Data Obtained from Trained Persons

Three persons working in the emergency service, trained in CPR, participated in this practice. Participants were expected to perform CPR for 60 seconds, and the designed GUI interface recorded the practices. Images from the practices of trained persons performing CPR are shown in Figure 11.

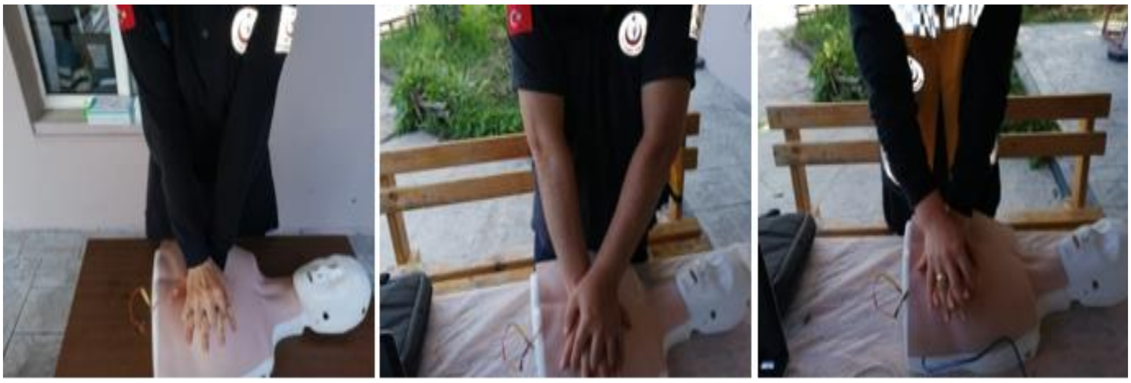

Figure 11. CPR Practice With Trained Persons.

Figure 12 shows the results of the analysis of CPR performed by a trained person. This person was able to continue CPR for 60 seconds. It is understood from the graph in Figure 12 (a) that when the person making the application increases the compression depth to 6 cm, albeit very slightly, it remains at 3 cm from time to time. In Figure 12 (b) and (d), when the compression rate variable graphs are examined, it is seen that the speed change in the data obtained from both sensors is almost stable, but it is seen that it is below 100 CPM.

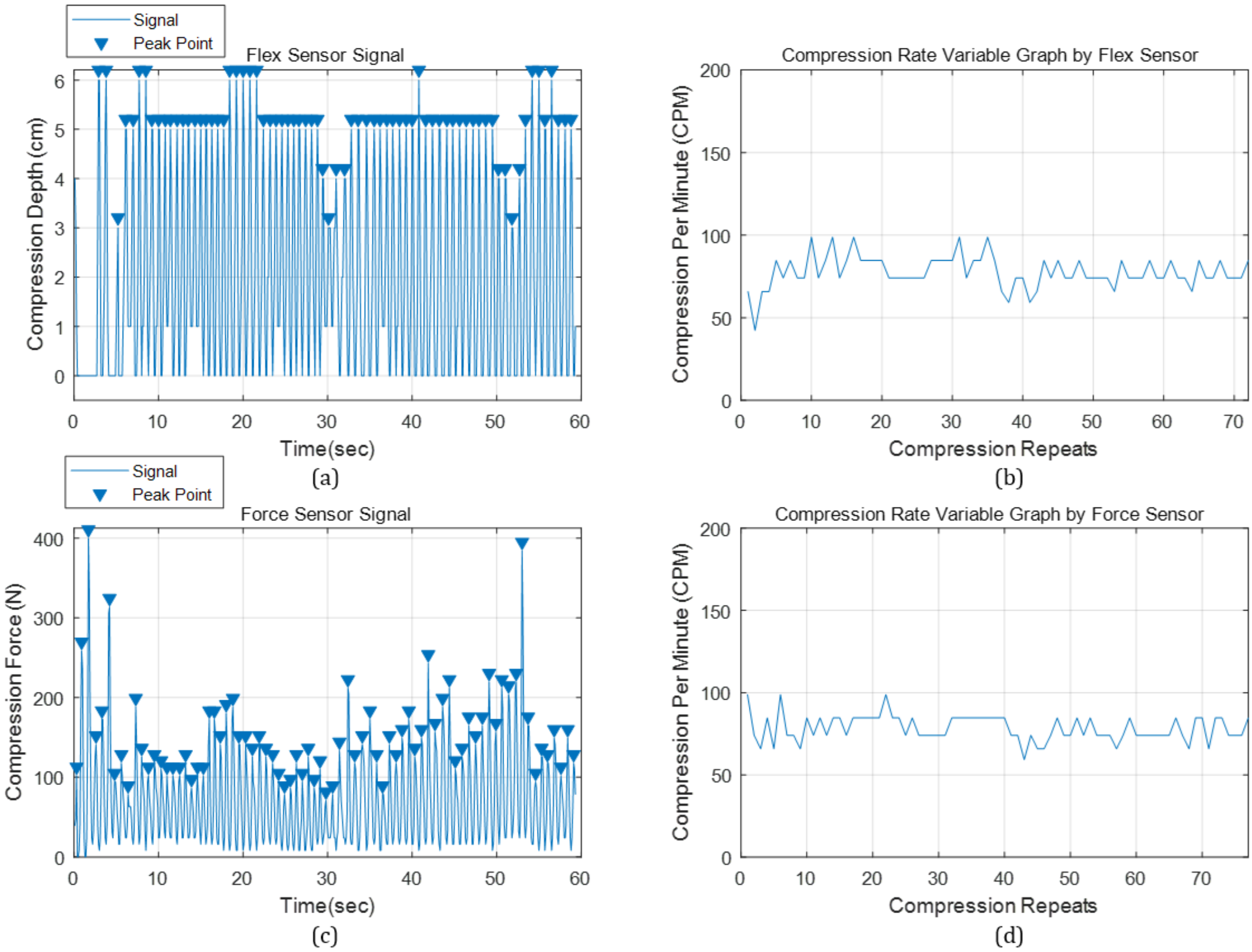

Figure 12. CPR Practice With Trained Person.

3.2. Observing of Data Obtained from Untrained Persons

Three persons not working in the emergency service, untrained in CPR, participated in this practice. Participants were expected to perform CPR for 60 seconds, and the designed GUI interface recorded the practices. Images from the practices of untrained persons performing CPR are shown in Figure 13.

Figure 13. Cpr Practice With Untrained Persons.

Figure 14 shows the results of the analysis of CPR performed by an untrained person. This person was able to continue CPR for 60 seconds. In Figure 14 (b) and (d), when the compression rate variable graphs are examined, it is seen that the speed change in the data obtained from both sensors is very unstable and varies between 25 CPM and 75 CPM.

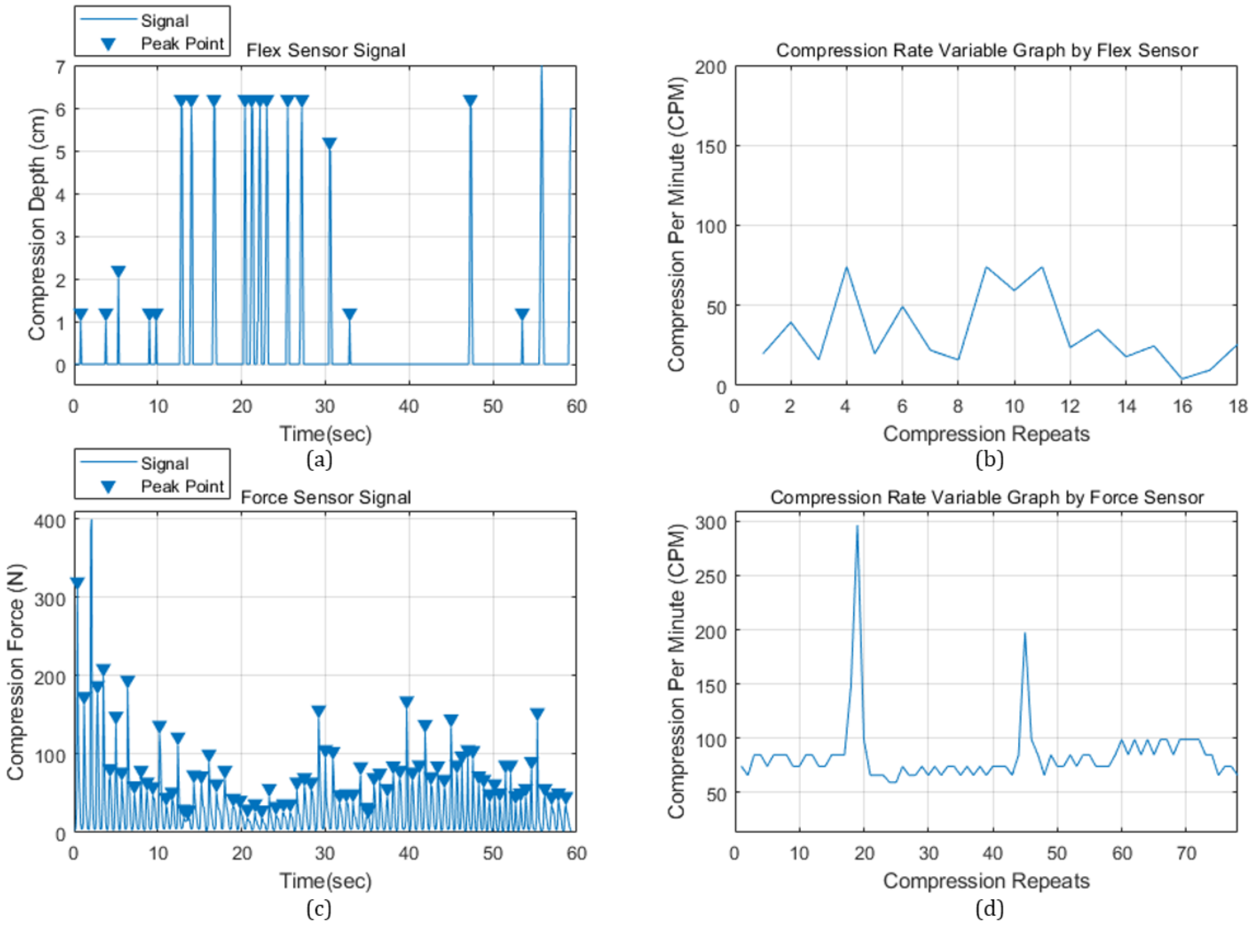

Figure 14. CPR Practice With Untrained Persons.

3.3. Comparison with Similar Studies

Some parameters indicate the correct application of cardiac massage. These are compression depth, compression force, and CPM. Since CPR application is a repetitive compression process, these parameters should be similar in each repetition for correct and high-quality CPR. The best way to observe this is with the compression rate variable graph. Looking at this graph, the evaluation of CPR application can be handled more holistically, and correct interpretations can be made. In Table 1, a comparison is given to show the difference between our work from other test systems. As seen here, the compression rate graph is presented only in our work. Also, our work is the only test system that simultaneously provides compression depth, compression force, and CPM information. Apart from our work, test devices that receive compression depth information do not receive force information using force sensors.

Table 1. A Table Showing The State-Of-The-Art Test Systems And Our Test System.

CPR Test Systems	Sensor Type	Indicator	Compression Depth	Compression Force	CPM	Compression Rate Variable Graphs
Our work	Flex, Force	Matlab GUI	√	√	√	√
CPREzy (Berkom et al., 2008)	Not known	Led lights	√	X	X	X
BASICBilly+	Optical-based	Mobile application	√	X	√	X
PocketCPR (Pozner et al., 2011)	Accelerometer	Led lights, sound	√	X	√	X
TrueCPR (Majer et al., 2019)	Triaxial Induction Magnetic Field	Graphic display, sound	√	X	√	X
Test System (İnal et al., 2021)	Load Cell	WebSocket	X	√	√	X

4. Conclusions and Recommendations

Rapid intervention to the patient is critical in cases such as cardiac arrest. The devices used must be portable to be able to intervene at the scene. Therefore, the realized device is relatively small and portable. Installation is also quite easy. As a result of its fastening with belts, the total weight and size of the device have been reduced. Effectively, 100 to 110 CPM and a depth of 5 cm per compression were achieved.

With the test system, both the accuracy of the operation of the device and the accuracy of the heart massage of the people who applied manually could be monitored and recorded. Many different compression depths, compression force, and compression rate variables were recorded in practical applications created with automatic CPR devices, personnel trained in CPR applications, and the person who does not know about CPR applications.

According to the experimental application data obtained from the test system, it is seen that the copression rate variable graphs of the data obtained from the automatic CPR device are stable (Figure 15). The data obtained from the trained personnel is more variable than the automatic CPR device, and the data obtained from the untrained persons is much more variable than the trained persons. Thus, the importance of automatic CPR devices in CPR has proven to be important.

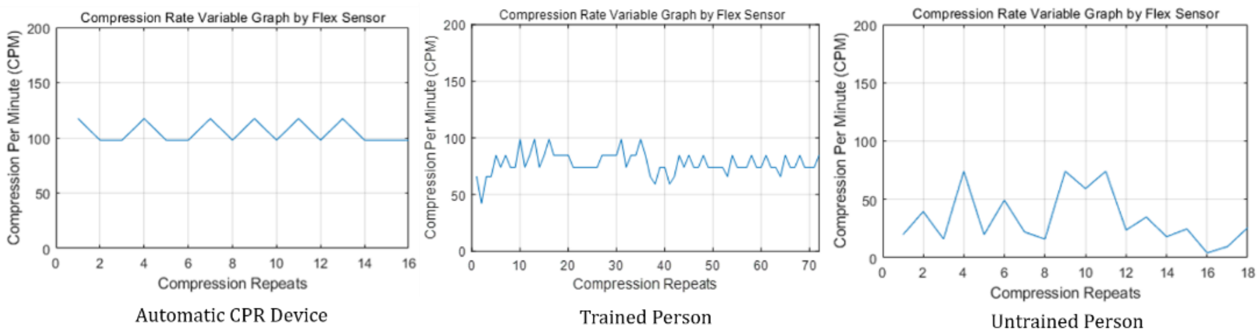

Figure 15. Comparison Of Compression Rate Variable Graphs For Three Different Applications.

This test system, which enables the comparison of CPR practices of trained and untrained persons, can be used in the education and evaluation of cardiac massage practices in the first aid training courses in secondary education, associate degree, undergraduate, and vocational education.

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Conflict of Interest

No conflict of interest was declared by the authors.

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