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Immersive Virtual Reality-Based Cardiopulmonary Resuscitation Interactive Learning Support System

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ABSTRACT Traditional cardiopulmonary resuscitation training does not allow learners to accurately grasp power, depth and frequency. Therefore, this study aims to improve traditional training and reduce training volume, weight and price by using VR-CPRs learning support system. This study also provide immersive learning at a price lower than that currently prevalent in the market to impart the same level of learning and make CPR training more common. Our system makes it easier for individuals to learn cardiopulmonary resuscitation, making cardiopulmonary resuscitation training more common. Our system includes video health education, assisted real-time interactive operation tools, learning tests and other self-learning functions. Learners can practice on their own after watching the training film. The system reverberates the learner's power and frequency through a force-sensitive model to ensure that they are properly trained. Encourage users to learn CPR skills through immersive virtual reality settings that guide somatosensory interactions and support game-based learning. The study collected 100 college students who had never received CPR training. Before performing cardiopulmonary resuscitation on the force-sensitive model, participants were asked to complete a pre-test questionnaire to obtain pre-intervention learning outcomes. We introduced VR-CPR into CPR learning (intervention), assessed the outcome of the intervention, and asked participants to complete a post-test questionnaire. The study used VR-CPR to intensively study 85% of participants, indicating that the system is effective in promoting CPR learning, cultivating CPR learning interest, and improving public CPR ability.

INDEX TERMS Cardiopulmonary resuscitation (CPR), chest compression, virtual reality (VR).

I. INTRODUCTION

Brain cells can be damaged when the heart suddenly stops and die after 4–6 min of cerebral hypoxia. When cerebral hypoxia lasts for more than 10 min and no first aid is applied, brain damage becomes irreversible [1]. Cardiopulmonary resuscitation (CPR) is a crucial basic life-saving technique. CPR involves artificial respiration and chest compressions until the arrival of professional emergency personnel. Chest compressions enable blood to flow toward the brain, thus ensuring continuous oxygen supply to the brain and preventing brain damage. Thus, hypoxia can be delayed and mortality can be reduced by 25% to 30% [2]. CPR performed by skilled personnel improves the survival rate of patients experiencing cardiac arrest [3], [4].

The problems with CPR training are as follows:

1. Each lecturer has a different style of training [5]. Traditional CPR training includes 30 min of health education, 30 min of instructional videos, and 3 h of practice with the Rescue Anne model [5]. The absence of uniform teaching and evaluation criteria affects not only the quality of teaching but also students' learning.

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2. The biggest obstacle in CPR training is that people do not accurately understand aspects such as the duration of chest compressions and the press position [6]. When using the Rescue Anne mannequin the depth of the actual press cannot be visualized. The student cannot learn from the demonstration because the depth of the compressions is not apparent. The lecturer cannot deduce whether the student has learned the technique correctly; they can only pass judgment on whether the learner can obtain a license [7]. A metronome can be used to help the learner achieve appropriate compression frequency [8]. However, external help is still required. The learner does not learn to control the force of the compression.
3. VR learning systems have some problems that can be improved. An interactive computational environment has facilitated the development of educational games used for training and knowledge acquisition [9], [10]. In the medical domain, VR has been used for simulating clinical settings to enable both individuals and groups to learn a specific technique and improve teamwork [11], [12]. For this type of professional training, the instantaneous performance feedback and summative evaluation provided by the VR system can boost learning [13]. For single-session or multiple-session group training, summative evaluation (including ranking and comparing performance and familiarity with other people) can be used to monitor the progress of the group [11]. Therefore, the use of VR game-based interactions can increase people's learning motivation and improve their learning outcomes.

The Italian Resuscitation Council released a VR CPR learning system in September 2018. In the system, the learner can walk anywhere in the VR area. A monitoring device is placed on the learner's hands. The data of the learner's hand movements are displayed on the glasses. Tips regarding the force and frequency can be displayed to improve the efficiency of the training [14], [15].

LISSA is a CPR learning system in a three-dimensional (3D) virtual environment. The system can be used on smartphones and tablets. The learner has to select automated external defibrillator (AED) first or CABD (Compression-Airway-Breathing-Defibrillation). If the learner selects the incorrect option, his or her score is reduced. While performing CPR and AED, the learner has to control the hands on the screen and put them in the right position. The screen also displays tips related to compression frequency when a learner performs compression. However, this system cannot detect the learner's compression depth and strength accurately. Some unclear descriptions of movement in the game may also cause confusion in learners [16].

MircoSim is a CPR process developed by Laerdal Medical Co., Ltd. Several emergency scenarios and simulations of drug usage are enacted using the computer. Learners practice different methods of AED, CPR, and chest compression. This training is freely configurable, and the system can be adjusted to satisfy the diverse needs of learners. Teachers can also understand the progress of each learner through the information shared automatically by the system. This makes training more effective. However, this system is only available on computers. Thus, learners cannot train by themselves.

Despite the well-recognized effects of video games on knowledge acquisition and skill training, the use of video games in teaching remains a controversial research topic [17], [18]. Video games boost learner's interest. Therefore, various video games have been developed for learning the skills, competence, and critical knowledge required in the real world [19]. The aim of this study was to provide immersive learning at a price lower than that currently prevalent in the market to impart the same level of learning and make CPR training more common. The scientific solutions proposed in this study to solve the problems of CPR training are as follows:

1. Assisted training through standardized intelligent learning systems; both lecturers and learners have criteria for making judgments.
2. Pairing Arduino kits with mobile applications and using VR to develop a set of software and hardware support systems that the public can use and learn from repeatedly.
3. The weight and the size of the CPR–VR pressure sensing board are only 30% of the Rescue Anne. The board is portable and the price is reasonable. Thus, more institutions can purchase it and more people can acquire CPR skills. People can be shown that pressing only can avoid the health problems caused by mouth-to-mouth training and effectively extend the period of use of the system.
4. Learning professional skills through digital interactive games enhances learners' willingness to learn and increases participation.
5. A force-sensitive resistor can be used to measure the depth of the compression performed by learners. Thus, learners can understand the rate and depth of the force and learn effectively. When learners are training, the screen displays the frequency of the compressions and instantaneous depth feedback, which helps learners follow the rhythm exactly and adjust their force.

II. CPR AND VR OVERVIEW

The American Heart Association established a CPR committee for CPR research in 1963 and has promoted CPR to the public since 1973. This study adopted a new protocol for designing the VR-CPRs. C-A-B-D refers to the following:

1. C (compression, for chest compression): implementing closed-chest compression,
2. A (airway, for opening the airway): keeping the airway open,
3. B (breathing, for artificial ventilation): providing artificial ventilation,
4. D (defibrillation, for electric shock defibrillation): using AED.

TABLE 1. CPR situation application.

Software	911	U-CPR	Crowdsav platform	Virtual Reality CPR [14]	VR-CPRs
Author	Oak et al.	Song et al.	Srither et al.	F.Semeraro et al.	Yang et al.
Year	2014	2015	2016	2018	2018
App development software	UNITY3D	LABVIEW	Crowdsav	UNITY3D	UNITY3D
Hardware	smartphone	smartphone	smartphone	computer	1. Arduino 2. smartphone 3. Bluetooth 4. VR headset
Sensor	Built into smartphone	Displacement sensor		HTC Vive	Force-sensitive resistor
Criteria	1. CPR specifications	1. CPR specification s 2. Reclined angle for compression	1. 100 compressions per minute 2. Compression depth 50 mm	1. 100 compressions per minute 2. Compression depth 50 mm	1. CPR specifications 2. 200 to 240 compressions per minute, 1.6 compressions per minute, no interruption longer than 10 minutes 3. Compression weight: 36 to 45 kg 4. Compression depth: 50 mm
Operating method	Game	Software simulation	Mannequin	1. Mannequin 2. Immersive VR 3. Actions can not meet the CPR standards.	Immersive VR game
Number of participants tested	0	36	138 for experimental group 171 for control group	43	100 for pretest and posttest

A. CPR SITUATION APPLICATIONS

The benefits of using video games for knowledge and skill acquisition have been recognized by educators. Incorporating video games into professional skill learning can increase learners' participation, boost their learning motivation, and make learning fun. Recent studies have performed differentiation analysis on game-situation-based CPR learning. Using a smartphone with a built-in sensor, Oak and Bae simulated the scenario of a patient calling 911. The user must administer CPR to keep alive the patient with cardiac arrest until the arrival of an ambulance. This game provided a sense of immersion [21]. Song *et al.* [22] used U-CPR smartphone software to provide virtual feedback to improve CPR performance accuracy on a patient in a reclining position. The study showed that the reclining position has an effect on how CPR chest compressions are performed [22]. Srither *et al.* created a CPR learning application by pairing a CPR mannequin with a smartphone for monitoring chest compression performance and rate. They included a 30-s audio recording to remind people of CPR techniques after long periods of nonuse [23].

Combining UNITY and Arduino, this study's VR-CPRs is different from the CPR learning systems developed by other studies. First, the proposed VR CPRs requires learners to attach their smartphone to the VR headset, and a force-sensitive resistor is incorporated to support immersive learning. This makes the chest compression experience when using the VR-CPRs realistic. Moreover, in the immersive VR setting, users are guided through somatosensory interactions and game-based learning, which can increase their participation and learning motivation. Second, the force-sensitive resistor makes autonomous learning convenient and ensures the correctness of learning by monitoring the CPR compression rate and depth of the force and offering related feedback. CPR situation applications are presented in Table 1.

B. VR IMMERSIVE LEARNING

In VR, a 3D virtual but immersive and realistic world is created through computer simulation using a VR headset. In the 3D virtual space, a sensor is required for the user to perceive and interact with objects. When the user moves, the sensor detects the motion and send signals to the computer, which conducts complex computation and sends sensor-related signals back to create the sense of immersion in the scenario [24], [25]. This technology integrates computer graphics, sensors, artificial intelligence, image processing, product design, and many other technologies. It can be viewed as a high-tech simulation system that is facilitated by computer technology [26]–[28].

Immersion is the awareness of being in a specific environment or event. It is commonly realized using VR technology and often employed in video games to create a strong visual and sensory representation. Together with somatosensory interactions, immersion makes the user feel involved in the event or present in a particular environment [29]–[31].

In a VR environment, the user is completely detached from the visual environment of the real world and becomes completely immersed in the virtual environment. Immersing people in a simulated realistic situation is useful for getting them fully involved in skill training or knowledge learning; consequently, VR immersive teaching has gained considerable attention in education and technical teaching. Although they are extensively applied in various domains, VR systems are more commonly used in games and entertainment rather than education. Haptic VR systems can be used for thematic learning [28].

FIGURE 1. Interactive VR-CPRs for health education.

III. METHODS AND MATERIALS

Although the technology of CPR is not difficult, it is not easy to operate it correctly [32]. It's clean to know that retaining CPR skills is closely related to the frequency of training. Deliberate practice is one of the best teaching strategies for learning and retaining the messages you get in practice [33]. The elements of successfully achieving deliberate practice include [34]:

1. Clear learning objectives and mission,
2. Clear emphasis,
3. Strict and reliable measurement result according to the deliberate practice,
4. The feedback form educational resources,
5. Promote monitoring, debugging, and other effective practices,
6. There are the next levels of mission to challenge.

Effectively simulated learning has been widely recognized in existing medical education programs [35], also the researchers believe that conscious practice is the core of effective simulation [36]. In terms of CPR training, CPR educators also believe that automated systems can help learners remember the order of operations [37]. The learners who have received practical courses are significantly better than those who only listened to the instructors. Through the continuous visual and vocal feedback from the human body model, the energy and the concentration of learners can be increased. This training has a significant improvement in short-term (6 weeks) memory [38].

This study designed VR-CPRs, a health education–oriented CPR learning system, by pairing Arduino with a smartphone and VR headset. With this system, the learners can simply put on the VR headset to begin CPR learning. Fig. 1 shows the interactive CPR health education scenario where the VR headset is used in combination with the hardware for interactive learning of correct CPR procedure. The hardware components and sensors are detailed in below subsections.

A. ARDUINO AND SENSOR

Arduino (https://www.arduino.cc/en/guide/introduction), the open-source software and hardware architecture developed by an Italian researcher with his students, provides an integrated development environment (IDE) for users to write programs to control the hardware of a single-chip microprocessor [39], [40]. Arduino has a simple input–output interface and can be paired with other sensors and Bluetooth modules for data transmission.

In addition to having a user-friendly IDE and abundant references available, Arduino development is known for easy expansion and development, low price, and cross-platform development for Windows, Macintosh, and Linux. In general, Arduino can be divided into three major types: Arduino hardware, Arduino software, and Arduino expansion components. Arduino hardware sensors can be purchased according to design and development needs. Arduino software can be downloaded from Arduino's official website for free. Arduino expansion components can also be purchased according to the needs. Arduino development is thus economical [39], [41].

Arduino has been applied in medical development. For example, Kemis researcher use the Arduino applied to Ubiquitous healthcare (u-Healthcare). u-Healthcare is an emerging paradigm in the healthcare environment [42]. One of the most promisiapplications for u-Healthcare is the ubiquitous smart home and smart hospital, health monitoring system. Gajjala Ashok used Arduino in the Medical field which is used forpulse rate monitoring of patient and it warns if the pulse rate exceeds beyond the limit [43] (pulsation). Dr. G.R. Patil applied Arduino for fall detection and monitoring of older people [44].

B. FORCE-SENSITIVE RESISTOR RATA CONVERSION

Force sensing resistor is mainly made of piezoelectric polymer. When point A and point B are in the non-conductive state, the resistance is infinite. Once the user applies force to the sensor, the resistance will generate conductivity, and the resistance value will fall into the measurable range. The force can be calculated by detecting the resistance value. The size of the contact area changes depending on the force applied (different resistances). When there is no force applied, the resistance is zero; however, once force is applied, the contact area of the resistor changes accordingly. After Bluetooth online app is connected to the CPR control firmware model for control, the value of the reverberant force sensitive resistor in the pressing process is then obtained. After simulating the three forces of pressing the CPR pressure sensing module: strong, small and moderate, observe whether

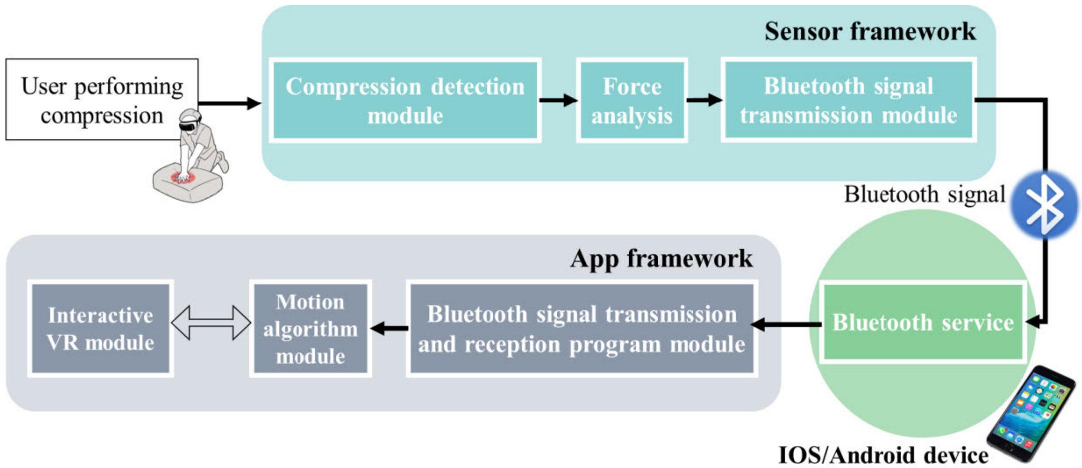

FIGURE 2. The architectural model of VR-CPRs.

the value conforms to the normal range. The CPR criteria used in designing this study's VR-CPRs are as follows:

1. Effective compression force: 3.2–4.2 V,
2. Insufficient compression force: 0.488–3.2V,
3. No compression force: 0–0.488 V,
4. Excessive compression force: 4.2–5 V.

The Arduino voltage conversion is calculated by $a \times (5/1023)$ where a is the force-sensitive value. The voltage read by Arduino UNO is between 0 and 5 V, and then the analog to digital function of Arduino UNO converts the above voltage to a value from 0 to 1023, at 0.00488 V per unit. The main hardware components are the Arduino board, Bluetooth module, and a voltage sensor.

C. UNITY

UNITY is a cross-platform game engine for developing standalone games for various platforms, including Swtich, Xbox, Windows, Android, and iOS. By installing a plugin, UNITY can be accessed from its web page [45]–[47].

In addition to the comprehensive built-in game engine, UNITY provides a complete physics engine, PhysX, and a particle system for development. PhysX is developed by AGEIA and can be applied for processing highly complex physics computations quickly, even on a low-end computer. UNITY can be used for developing multiple types of game, and it facilitates developing two-dimensional and three-dimensional games.

D. SYSTEM STRUCTURE

The VR-CPRs comprises two parts; the first part is the hardware and sensor system. The second part involves the app and VR interaction.

The Arduino development board was paired with a force-sensitive resistor and a Bluetooth module for data transmission. The operating process is shown in Fig. 2. The learner performs compression on the force-sensitive resistor, and the Bluetooth module converts the compression force to the corresponding value, which is then transmitted to the mobile device. When the mobile device receives the data, it performs interval comparison to determine if the compression force satisfies the requirements (motion algorithm module). If the requirements are met, interactive VR displays are triggered. A force-sensitive resistor, the FlexiForce A401 (https://www.tekscan.com/news/a401-announcement), was used as the input end of the hardware. When the learner activates the health education system app, signal transmission and reception begins, and when the smartphone end receives a Bluetooth signal, force signal processing begins. After processing the signal, completing signal sample database comparison, and examining whether the force interval meets the requirement, the avatar performs the corresponding physical action if the force requirements are met.

The focus of the app of this system is CPR health education. First, CPR training is given, and then hands-on CPR compression is practiced. The CPR training framework and CPR compression simulation procedure are shown in Fig. 3, respectively. After a Bluetooth signal is received, motion algorithms determine if the compression is acceptable. If so, the avatar performs the compression action; if not, the CPR performance is considered failed, and the software checks for any new compression sensor signal. To improve force signal accuracy, the researchers of this study established a motion algorithm module. The first step is to determine if a received signal is noise or a signal from the force-sensitive resistor by comparing the signal with the corresponding mobile-end signal sample. This step includes determining whether the force increases gradually or immediately. Next, the signal is extracted to determine the correctness of the force. Because CPR compression force increases gradually instead of instantaneously, a filter was created to eliminate noise (according to the compression criteria).

For VR interactions, the learner performs compression, and the size of the force is monitored. An app determines the correctness of the number and frequency of compressions and the

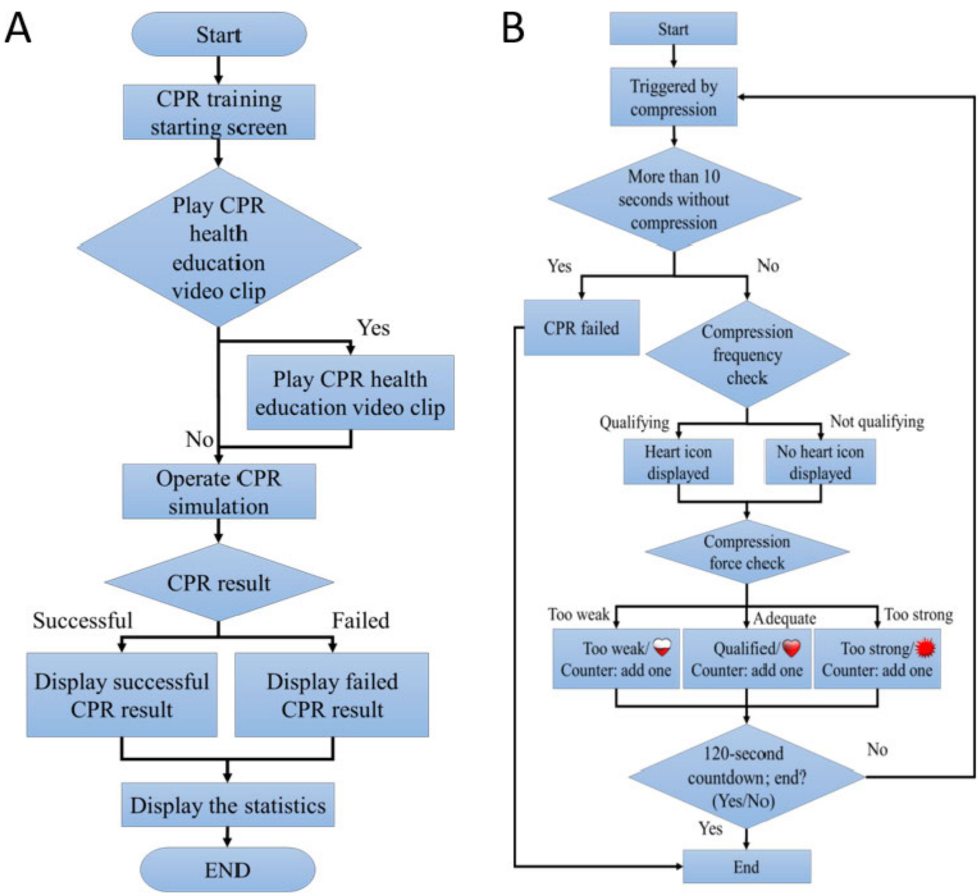

FIGURE 3. **(A) VR-CPRs training framework. (B) Simulation procedure.**

compression force is classified as one of four levels: effective compression force, insufficient compression force, no compression force, and excessive compression force. More details about force-sensitive data conversion are provided as follows.

E. VR-CPRs MATERIALS AND EQUIPMENT

The hardware used in this study is shown in Table 2, and the actual screens are shown in Fig. 4.

TABLE 2. **List of VR-CPRs electronic parts.**

Equipment	Description
Arduino series model	Arduino Genuino Uno X 1
Force-sensitive resistor	FlexiForce A401 X 1
Bluetooth module	DX-BT05 X 1
VR headset	VIRTUAL REALITY GLASSES-RK3PLUS
Total	$200

F. QUESTIONNAIRE DESIGN

This study designed two questionnaires assessing the intervention effect of VR-CPRs on CPR learning outcome: a pretest questionnaire and a posttest questionnaire. The pretest questionnaire was implemented before introducing the VR-CPRs, and it contained questions regarding personal data, including age, gender, and education; general CPR awareness; and CPR performance knowledge. The objective was to assess learners' awareness and knowledge of CPR before introducing the VR-CPRs developed by this study.

The posttest questionnaire was given after the participants had trained with VR-CPRs. In addition to the CPR awareness and CPR performance knowledge questions, which were also asked in the pretest questionnaire, this questionnaire included a satisfaction survey (on a five-point scale) on VR-CPRs learning outcome, overall design and services, and smoothness of system operation. The results are presented as means.

For the five-point scale, five points were assigned for those answering highly satisfied, four points for satisfied, three points for acceptable, two points for dissatisfied, and one point for highly dissatisfied. Questions not answered were excluded from scoring. Higher the scores indicated greater satisfaction. The objective was to assess whether the learners' awareness and knowledge were improved by the VR-CPRs and to understand the level of satisfaction with the system. The information is useful for future studies.

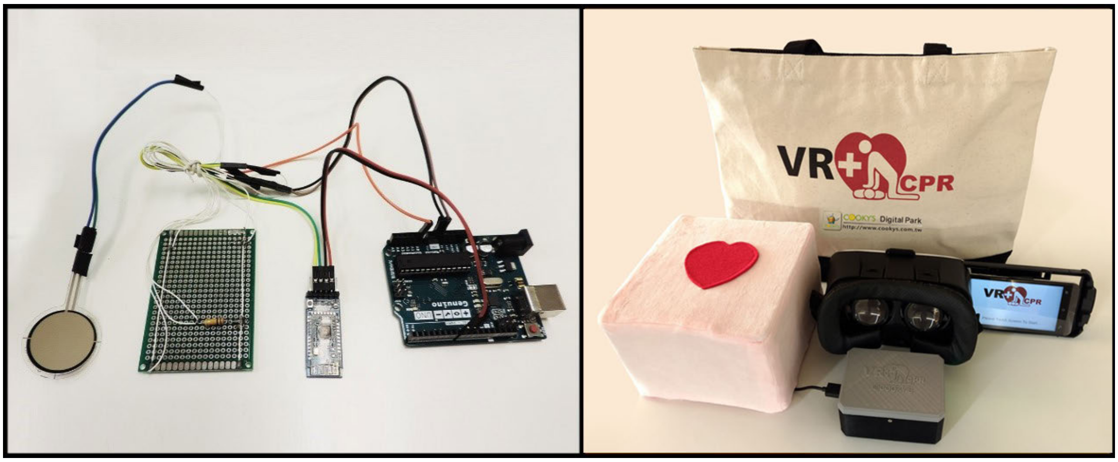

FIGURE 4. Pairing Arduino with a voltage sensor and a Bluetooth module: hardware before assembly and finished set.

IV. RESULTS

A. DATASET

The study participants were undergraduate students majoring in information-related fields at National Kaohsiung First University of Science and Technology, Chia Nan University of Pharmacy and Science, and Tajen University. There were 60 male participants and 40 female participants, and their ages were 19 to 23 years. All participants were current students and had never received any CPR training. These participants were randomly selected, and the objective of this study was to examine the effect of a VR-based interactive learning support system on CPR learning.

The 100 participants were first asked to complete the pretest questionnaire and then perform CPR chest compression simulation on the force-sensitive model to assess their rate of successful CPR performance, which was treated as the preintervention learning outcome. Next, the participants were asked to put on the VR-CPRs device, a VR-based interactive learning support system, to perform CPR chest compression simulation to assess their rate of successful CPR performance, which was treated as the postintervention learning outcome.

B. SOFTWARE OPERATION AND RESULTS

Operation of the software involved the following steps; app screens are shown in Fig. 5.

1. The smartphone was attached to the VR headset, and the app was turned on. The learner put on the VR headset and started the CPR session. The "GO" button was pressed to start CPR training (Fig. 5(a)).
2. The learner watched the health education video clips to learn about CPR knowledge and procedure (Fig. 5(b)). After playing the video clips in sequence, the VR mode was enabled automatically (Fig. 5(c)).
3. After the VR mode was enabled, the learner placed both hands correctly on the force-sensitive model for the virtual world to be displayed. The system assessed the learner's compression force.

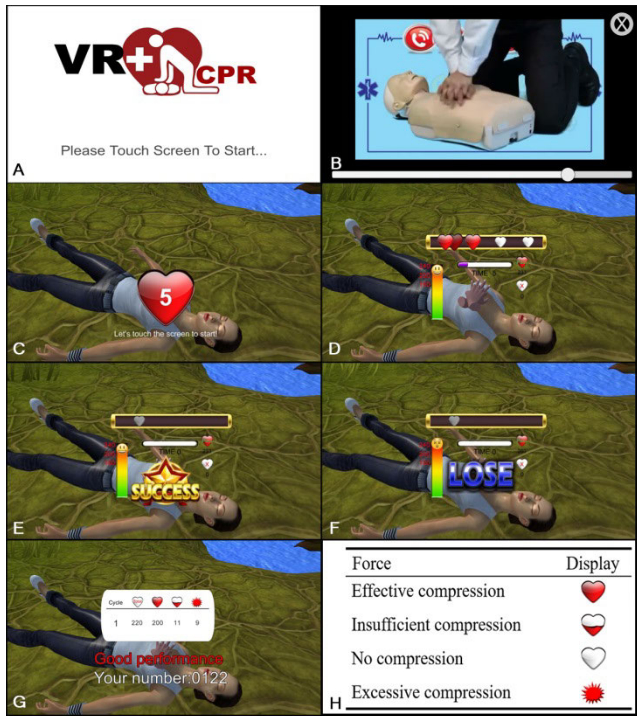

FIGURE 5. Successful CPR screen of the CPR learning app.

When the system was running, a countdown was initiated (Fig. 5(d)). Each round lasted 120 seconds; in each round, the system assessed whether the compression had reached 200 to 240 compressions per round (CPR standard: 100 to 120 compressions per minute). The successful CPR performance screen and statistics of successful CPR performance are shown in Figs. 5(e) and 5(f), respectively. The compression force was classified into four levels: effective compression, insufficient compression force, no compression force, and excessive compression force (Fig. 6). For successful chest compression, the learner must reach 200 to 240 compressions per 120 seconds (a round) to wake the patient. When the

TABLE 3. Comparison of system functions based on VR devices on the market.

Comparison	COOKY'S	Studio Evil & Italian Resuscitation Council [14][15]	Dustin Kinch[a]	Resuscitation Council UK[b]	HKU Emergency Medicine Unit[c]	Laerdal[d]
Country	Taiwan	Italy	Unknown	United Kingdom	Hong Kong	Norway
Produce	CPR-VRs	VR CPR	VR CPR	Lifesaver VR	EMU Resus Training	Resusci Anne QCPR Torso
Price (Unit:TWD)	6,000	18,488 ~ 31,643	18,000	500	Free Download	53,000
Equipment volume and weight	The total weight: 0.7 kg. Description: 1. A mobile phone (approximately 0.2 kg) 2. A set of VR virtual glasses (approximately 0.5 kg) 3. A set of CPR pressure sensing and control module	The total weight: 22 kg. Description: 1. HTC Vive kit (approximately 9.07 kg) or Valve Index kit (approximately 7.26 kg) 2. One host (approximately 13 kg)	The total weight: 16.72 kg. Description: 1. Oculus Rift kit (approximately 3.72 kg) One host (approximately 13 kg)	The total weight: 0.7 kg. Description: 1. A mobile phone (approximately 0.2 kg) 2. A set of VR virtual glasses (approximately 0.5 kg)	The total weight: 0.2 kg. Description: 1. A mobile phone (approximately 0.2 kg)	The total weight: 0.2 kg. Description: 1. Resusci Anne QCPR kit (approximately 20 kg)
Action feedback	Yes. Description: Feedback of the pressing frequency and depth.	Yes. Description: Feedback of the pressing frequency and depth.	Yes. Description: Feedback of the pressing frequency.	No.	No.	Yes. Description: Data feedback of pressing depth frequency, ventilation volume, operation time and rebound.
Somatosensory equipment	Yes. Description: The parameters will be detected through the pressure sensing and control module.	Yes. Description: The parameters will be detected through a somatosensory controller.	Yes. Description: The parameters will be detected through a somatosensory controller.	No.	No.	Yes. Description: The parameters will be detected through chest spring to simulate the press.
VR equipment	Yes. Description: The press under immersive learning guide with virtual glasses.	Yes. Description: To simulate virtual situations with the HTC Vive kit.	Yes. Description: To simulate virtual situations with Oculus Rift kits.	Yes. Description: The virtual glasses play video to direct the pressing.	No.	No.

[a]: https://www.oculus.com/experiences/rift/1696889327052846/?locale=zh_TW
[b]: https://www.youtube.com/watch?v=QuUavS3WSAI
[c]: https://play.google.com/store/apps/details?id=edu.hku.resus&hl=zh_TW
[d]: https://www.youtube.com/watch?v=OdZe3L9DboM

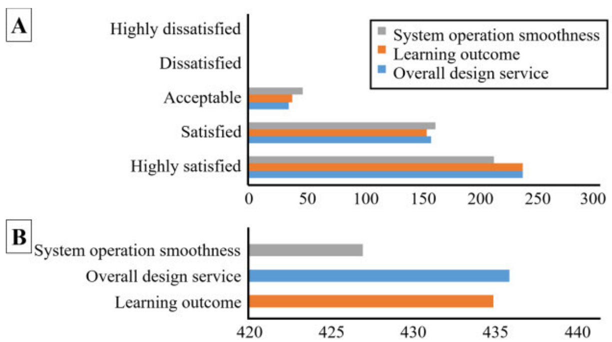

FIGURE 6. (A) VR-CPRs satisfaction questionnaire stats. (B) VR-CPRs satisfaction score stats.

patient was successfully rescued, the successful CPR screen was shown. For chest compression, CPR failed when the requirement of 200 compressions per 120 seconds (a round) was not met. Moreover, when CPR was interrupted for more than 10 seconds, it was also deemed a failure.

C. CPR PERFORMANCE RESULT COMPARISON

First, the 100 participants completed the (A) pretest questionnaire and performed CPR on the force-sensitive model to assess their learning outcome before introducing the VR-CPRs. Next, the 100 participants put on the VR-CPRs interactive learning support system for CPR training. The learning outcome was assessed, and the participants were asked to complete the posttest questionnaire (B). When performing CPR on the force-sensitive model, 10 participants (10%) (6 male and 4 female participants) performed the CPR successfully, whereas 90 participants (90%) failed. After implementing VR-CPRs training, 85 participants (85%) performed CPR simulation successfully (52 male and 33 female participants), and 15 participants (15%) failed. The results revealed that using the VR-CPRs can enhance CPR learning outcomes for 85% of learners (Table 3).The standard deviation was 0.24 preintervention and 0.20 postintervention, indicating a smaller difference after the intervention than before (Table 3). The postintervention scores were significantly higher than the preintervention scores ($t = -16.43$, $P < 0.001$).

After the participants used the VR-CPRs for learning, their chest compression frequency errors were significantly reduced. The percentage of participants applying insufficient compression frequency was reduced from 37.5% to 5% for women and from 30% to 1.7% for men. Insufficient compression force (i.e., to a depth less than 2 in) was reduced from 22.5% to 10% for women and from 25% to 0% for men. Because women are generally not physically strong enough, the VR-CPRs could not completely correct insufficient compression force for women. Because men are sufficiently physically strong, insufficient compression force was completely eliminated using the VR-CPRs learning support system.

D. QUESTIONNAIRE RESULT COMPARISON

Satisfaction questionnaire statistical results: For the level of satisfaction of the VR-CPRs learning system, 48 people were highly satisfied, 39 were satisfied, 13 responded with acceptable, and 0 were dissatisfied or highly dissatisfied. The total score of learning outcome satisfaction was 435 points. In terms of the overall design service satisfaction, 48 people were highly satisfied, 40 were satisfied, 12 responded with acceptable, and 0 were dissatisfied or highly dissatisfied. The total score of design service satisfaction was 436 points. For smoothness of system operation, 43 people were highly satisfied, 41 were satisfied, 16 responded with acceptable,

TABLE 4. Rates of correct chest compression before and after VR-CPRs learning.

CPR outcome	Status	Before learning	Before learning (Female)		Before learning (Male)		After learning	After learning (Female)		After learning (Male)	
		Total	N	%	N	%	Total	N	%	N	%
Success	Success	10	4	10	6	10	85	33	82.5	52	86.7
Fail		90	36	90	54	90	15	7	17.5	8	13.3
Fail	Chest compression interrupted	11	5	12.5	6	10	1	1	2.5	0	0.0
Fail	Chest compression too fast	22	7	17.5	15	25	7	0	0	7	11.7
Fail	Chest compression too slow	33	15	37.5	18	30	3	2	5	1	1.7
Fail	Insufficient chest compression	24	9	22.5	15	25	4	4	10	0	0.0
Fail	Excessive chest compression	0	0	0.0	0	0	0	0	0	0	0.0

* When the 100 participants performed CPR without VR-CPRs, the most frequent type of failure was low chest compression frequency (female 37.5%; male 30%), the second most frequent was insufficient compression force (i.e., not reaching the 2-inch depth) (female 22.5%; male 25%). Also, 25% of male participants applied an excessively high compression frequency.

and 0 were dissatisfied or highly dissatisfied. The total score for smoothness of system operation was 427 points. According to the satisfaction questionnaire results, most people were satisfied with the CPR learning system of this study. For system operation smoothness, the slightly low scores of the first two items may be because of the poor Bluetooth transmission in the network environment.

This study randomly selected 100 undergraduate students who had no CPR training experience to test the effect of VR-CPRs intervention on CPR learning. The VR-CPRs improved CPR learning outcomes for 85% of participants. The questionnaire result revealed a preintervention standard deviation of 0.24 and a postintervention standard deviation of 0.20, suggesting a smaller difference between postintervention scores. Posttest scores were significantly higher ($t = -16.43$, $P < 0.001$) than pretest scores.

V. DISCUSSIONS

Because participants in this study had never received any CPR training, the result suggests that one session of VR-CPRs training is sufficient for improving CPR performance. For example, two common problems, insufficient compression depth and low compression frequency, were significantly improved in this study using the VR-CPRs. This may be because the immersive and guided interactive learning informed the learner s if their compression speed and depth met standards or if adjustment was necessary. In other words, the VR-CPRs makes autonomous CPR practice possible. This study demonstrated that the CPR-VRs system is a useful CPR learning tool. First, the system enables the learner to practice CPR repeatedly to become increasingly familiar with performing CPR. Secondly, the VR-CPRs can also improve the public's CPR competence because the VR somatosensory-based interactive game format helps increase CPR learning motivation, which is crucial for CPR education.

The functions of systems based on various virtual reality (VR) devices on the market are compared in Table 3. The proposed system has the following advantages: (1) low price ($200), so easy to obtain; (2) small size ($21 \times 30 \times 8$ cm^3), so easy to store; (3) light weight (1 kg or less), so portable; (4) an AR + VR gaming experience can increase motivation and interest for learning (similar to Taiko: Drum Master); (5) the user can practice independently and receive instant feedback through pressure sensing—a teacher is not necessary; (6) cloud archives record the results of operation, which facilitates self-evaluation and remote guidance from teachers; (7) easy access to hardware equipment (a $100 mobile phone can be used for operating the application); (8) no dizziness (the operation sight area focuses on the target for approximately 2 min in every course); (9) the system complies with the CPR pressing depth and frequency guidelines set by the American Heart Association; and (10) the CPR license should be retested for every 2 to 3 years. The equipment can help professionals to practice independently and has sustainable global market potential. However, the proposed system has limitations, one of which is that only the C part of ABCD can be simulated; AED cannot be simulated. In addition, we performed the experiment using pre–post data without a comparison group, which may not have provided accurate results. A study with an experimental design is required to demonstrate the benefits and advantages of this training system. Schools and medical departments were the focus of this study. In addition to students and medical professionals, personnel belonging to school departments that focus on VR and somatosensory-related skills were considered. Encouraging innovative students to share ideas can promote cultivation of talent and improve planning, programming, and design related to AR–VR somatosensation. This measure will thus promote development of the AR and VR somatosensory industry. In the study, a learning record cloud system was used for long-term collection of big data, which can be used to optimize the standard operating procedure (SOP) correction and develop precision medicine. Finally, artificial intelligence analysis provides valuable information. The VR CPR somatosensory interactive learning system can not only be employed by medical personnel to perform independent practice but also easily attract the public, students, communities, and organizations through its immersive learning method. Training with the VR learning system of CPR somatosensory interaction would help improve the CPR skill levels of the public.

VI. CONCLUSIONS

Referring to the 2015 revised CPR protocol, this study focused on public health education built an Arduino board–based CPR learning system integrating VR and Bluetooth technology and incorporating a smartphone and VR headset. Related data were displayed by software through hardware operation, and the CPR training provided by the system was designed to guide the learners to perform CPR chest compression accurately by monitoring and correcting the frequency and force (depth) of chest compression. In this case, no CPR instructor is needed for monitoring the CPR performance. In addition to improving the correctness of CPR chest compression, the CPR learning system presented here provides the public with hands-on practice for CPR self-training. According to the questionnaires, students' CPR awareness should be improved. With this study's equipment and software (VR-CPRs) for immersive, game-based and interactive learning in a simulated environment, the learner can concentrate on performing CPR in a lifelike incident in the virtual environment and conduct comprehensive CPR operation and knowledge learning; this can help increase the public's CPR learning motivation and improve learning outcomes. In fact, the VR-CPRs not only enhances public CPR awareness but also polishes CPR skills, one of our objectives for CPR promotion, through repeated practice. Medical personnel can use the autonomous practice feature of the VR-CPRs to improve the correctness of their compression frequency and force and become more familiar with performing CPR. The proposed VR-CPRs should be promoted to as many universities and medical colleges as possible to increase students' CPR knowledge and skills, which is essential for enhancing public CPR competence.

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