Mobile Information Systems

Virtual Reality Based Education with Mobile Device Platform

Lead Guest Editor: Sang-Youn Kim
Guest Editors: Byeong-Seok Shin and Heejin Choi

Virtual Reality Based Education with Mobile Device Platform

Mobile Information Systems

Virtual Reality Based Education with Mobile Device Platform

Lead Guest Editor: Sang-Youn Kim
Guest Editors: Byeong-Seok Shin and Heejin Choi

Editorial Board

Contents

Hindawi
Mobile Information Systems
Volume 2019, Article ID 6971319, 1 page
https://doi.org/10.1155/2019/6971319

Editorial

Virtual Reality Based Education with Mobile Device Platform

Sang-Youn Kim,[1] Byeong-Seok Shin,[2] and Heejin Choi[3]

[1]*Department of Computer Science and Engineering, Korea University of Technology and Education, Cheonan City, Chungnam Province, Republic of Korea*
[2]*Department of Computer Science and Engineering, Inha University, Incheon, Republic of Korea*
[3]*Department Institute for Medical Engineering & Science, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA*

Correspondence should be addressed to Sang-Youn Kim; sykim@kut.ac.kr

Received 6 November 2018; Accepted 5 December 2018; Published 21 January 2019

The objective of this special issue is to address the virtual reality based education system in the enhancement of learners' motivation, engagement, immersion, satisfaction, and transfer of learning. Many papers were submitted, and after a thorough peer-review process, five papers were selected to be included in this special issue. These research studies provide invaluable insights into understanding and applying virtual reality from a multidisciplinary point of view. This special issue includes high-quality and original research papers addressing research achievements, practices, theoretical framework, and challenges for virtual reality based education platform with mobile devices. We believe that the published papers in this special issue introduce readers to the latest advances in the field.

The paper by M. Hernández-Ordoñez et al. presents an education platform consisting of a homemade robotic arm, a control system, and the RAR@pp for teaching robotic arm manipulation concepts. In the paper, they apply augmented reality technology for the visualization of the articulation arm angles.

The paper by H. Kim et al. proposes a novel, virtual reality based cyber-physical education system for efficient education in virtual reality on a mobile platform which can integrate the real world into virtual reality using cyber-physical systems technology.

The paper by S. Jeon designed a user-adaptive tactile keyboard on mobile device and then investigated how tactile feedback intensity of the virtual keyboard in mobile devices affects typing speed and user preference.

The paper by K. Choi et al. developed a multilayer 360° VR representation with image-based interactions such as mesh deformation and water simulation, which enables users to realistically interact with 360° panoramic contents without consuming excessive computational resources. On the basis of this representation, they designed and implemented play-based learning scenarios to increase the interactivity and immersion of users.

The paper by M. K. Jin presents an evaluation tool for VR-training contents based on mobile environments. After categorizing VR-training contents in the field of tech education into structure comprehension type, procedure learning type, and equipment experiment type contents, they constructed items for each evaluation area.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

Acknowledgments

We would like to thank all the authors who contributed to this special issue. This publication would not be possible without the participation of our expert reviewers, who provided vital constructive feedback and criticism throughout the review process.

Sang-Youn Kim
Byeong-Seok Shin
Heejin Choi

Hindawi
Mobile Information Systems
Volume 2018, Article ID 6126140, 12 pages
https://doi.org/10.1155/2018/6126140

Research Article

User-Adaptive Key Click Vibration on Virtual Keyboard

Seokhee Jeon,[1] Hongchae Lee,[1] Jiyoung Jung,[1] and Jin Ryong Kim [2]

[1]*Department of Computer Engineering, Kyung Hee University, Yongin 17104, Republic of Korea*
[2]*Smart UI/UX Device Laboratory, ETRI, Daejeon 34129, Republic of Korea*

Correspondence should be addressed to Jin Ryong Kim; jessekim@etri.re.kr

Received 11 May 2018; Accepted 28 August 2018; Published 14 October 2018

Academic Editor: Byeong-Seok Shin

This study focuses on design of user-adaptive tactile keyboard on mobile device. We are particularly interested in its feasibility of user-adaptive keyboard in mobile environment. Study 1 investigates how tactile feedback intensity of the virtual keyboard in mobile devices affects typing speed and user preference. We report how different levels of feedback intensity affect user preferences in terms of typing speed and accuracy in different user groups with different typing performance. Study 2 investigates different tactile feedback modes (i.e., whether feedback intensity is linearly increased, linearly decreased, or constant from the centroid of the key, and whether tactile feedback is delivered when a key is pressed, released, or both pressed and released). We finally design and implement user-adaptive tactile keyboards on mobile device to explore the design space of our keyboards. We close by discussing the benefits of our design along with its future work.

1. Introduction

Touchscreen-based mobile devices are pervasive, and a number of smartphone users prefer typing on a virtual keyboard in mobile phone as they spend more time on it [1]. Mobile-based text entry system using virtual keyboards has many benefits. Its portability allows people not to carry on their own keyboards, and it does not require significant learning effort from users since it sometimes adapts the training-free QWERTY layout. Due to this, it is even possible to perform eyes-free typing on mobile device [2]. Such benefits of text entry with mobile device can bring another opportunity in other computing areas such as virtual reality (VR).

A good example that effectively takes these benefits is VR. Typing in VR is becoming more important as it gradually replaces conventional communication media. In this sense, typing is required in a broad range of areas in VR such as education, media consumption, gaming, and training. However, typing in VR is still difficult due to many technical challenges such as poor hand and finger tracking, lack of tactile feedback, limitation of vertical field of view, and so on. Since user's typing fingers are invisible in HMD-based VR, there is a need for alternative ways to achieve typing in VR. One good approach would be text entry on virtual keyboard using mobile device in VR. Since text entry on mobile device can provide portability, convenient, and even eyes-free typing, it can be a good match with VR as today's VR focuses more on the interactive aspects of VR. In fact, a number of studies [3–5] showed the great benefits and promising results for using mobile device as text input.

In this study, we focus more on how to improve the typing performance and final user experience to the level of conventional mechanical keyboard typing scenario. Assuming that one of the important missing cues in current virtual keyboard typing is the absence of proper tactile feedback, we investigate the effect of various factors in the key click vibration on the final user experience. Two tactile cues during typing are essential for typing experience: (1) mechanical click feeling to provide a user confirmation of pressing and (2) the feeling of valley among keys to help a user navigating the fingers to locate a specific key. In virtual keyboard, the former is partly provided by playing vibrotactile feedback when clicking, but there are huge variations in individual preference on this virtual click feedback due to low fidelity of the feedback. In addition, the latter cue, while this significantly affects the typing accuracy, is not usually provided in virtual keyboard typing scenario.

To overcome these shortcomings, we proposed two new techniques to improve the quality of user's typing experience. First, in order to cope with various demands of the users about the virtual key click, the relationship between the user's expertise on typing and user's preference on the strength of the virtual click feedback is experimentally investigated. This idea is based on our initial hypothesis that expert users do not rely on the feedback since they already have confidence on their typing skill, while novice users like to have feedback to strengthen their internal confidence. Using this relationship, we designed an adaptive key click strength control scheme. This scheme predicts user's typing expertise in real time based on his or her typing speed and adaptively controls the strength of the feedback to provide optimum experience.

Our second approach is an initial investigation on providing cue equivalent to the valley among keys using vibrotactile feedback. To achieve this goal, vibrotactile feedback is designed in a way that its strength is systematically altered when a user clicks the edge of the key so that he or she can notice the edge of keys. Two different algorithms are provided, and the effect of these is investigated through user experiment.

We finally integrate all the proposed techniques in one virtual tactile keyboard and test the significance of the approaches by observing user's workload using a TLX questionnaire.

The main contributions of the paper are as follows:

(1) New algorithm to adaptively control the amplitude of key click vibration through user preference estimation based on his/her typing expertise

(2) New key click vibration rendering technique to deliver virtual keys' edge information

(3) Experimental validations on the new above algorithms

2. Related Works

There exists a broad range of research works focusing on user experience improvement in virtual keyboard using sensory modality. Auditory feedback [6–8] can be a good solution to improve the user experience on virtual keyboards, but it has clear limitation in noisy environment. Visual feedback is the most commonly used modality for user experience and usability of virtual keyboard [9–27]. Sears [24] investigated the palm-style QWERTY keyboard, and they changed their keyboard size and location to investigate the user performance. Even though the size does not affect the user's typing performance, they revealed that there is a difference in user performance between numeric type keyboard and QWERTY keyboard. Nakagawa and Uwano proved the relationship between location of keyboard and user's performance such as typing error rate and typing speed. This clearly showed that the location of keyboard is also important factor for the user experience [21]. Mackenzie and Zhang [18] designed the new soft keyboard and their keyboard design improved the user's text entry speed. Kim et al. [19] developed one key keyboard that can be worn on the wrist. Their keyboard could increase the input speed of users and accelerate their text entry learning ability.

Tactile feedback is another sensory modality that is available on virtual keyboards [8, 28–36]. Brewster et al. [28] found that typing with tactile feedback improves typing performance on mobile device. Users were able to enter more texts, make fewer errors, and correct more errors with tactile feedback. They demonstrated that tactile feedback is important role in touchscreen devices. Rabin and Gordon [29] studied the role of tactile feedback. They analysed kinematics of the right index finger with and without tactile feedback with special gloves and sensors. Their results suggested that tactile cues can provide information about the start location of the finger in which it is necessary to perform finger movement more accurately. Hoffmann et al. [30] developed a new tactile device for text entry. They used tactile feedback as a detector to prevent errors during the typing. Basic concept is that if a user types an incorrect key, the resistive force of the key becomes stronger so that the key makes the user to press the incorrect key harder. Kaaresoja et al. [32] used tactile feedback to mobile touchscreen and they demonstrated that tactile feedback is helpful in both usability and user experience. Nishino et al. [33] used tactile feedback as a communication modality. In their study, they used various types of vibration pattern such as strength, length, and effect. As a result, they found out the guidelines for building a practical system for tactile communication. Lylykangas et al. [37] focused on tactile feedback output delay and duration time. In their study, they found out the optimal duration and delay of tactile feedback when button is pressed. More recently, there exist a number of studies that are focused on perception [38] and performance [39–41] using tactile feedback in mobile and flat keyboard environments.

3. Study 1: Effects of Tactile Feedback Intensity

Study 1 investigates how tactile feedback intensity of the virtual keyboard in the mobile device affects typing speed and how strong user prefers based on their typing speed. We classified four levels of different feedback intensity and conducted a user study to observe the typing speed along with a follow-up questionnaire.

3.1. Apparatus. We built an Android-based typing program application with Mackenzie and Soukoreff phrase set [42]. In this program, a phrase is displayed on the top of the screen and the virtual keyboard is located under the phrase display area. The typing application stores typing speed, total elapsed time, and experimental condition. The typing application runs on Samsung Galaxy Note 3 due to its large touchscreen for typing phrases.

The vibration in the experiment is generated by the phone's internal linear resonant actuator (LRA) with 200 Hz resonant frequency and 4.043 m/s^2 maximum acceleration.

3.2. Participants. A total of eighteen university students participated in this study (mean age: 28.34, SD = 3.93). All participants were paid for their participation. They reported no disabilities. They also reported that they had prior experience of typing in English and familiar with virtual keyboards.

3.3. Experimental Design. We have four levels of tactile feedback intensity: *None*, *Low*, *Mid*, and *High*. Each has different intensity of tactile feedback signal of 0, 3.430, 3.798, and 4.043 m/s^2, respectively. The signal frequency was set to 200 Hz for all four levels of signal. We chose four levels of signal intensity because of *JND* of tactile feedback since participants may not be able to distinguish among the levels if the number of level exceeds four. Number of level less than four may not give us enough data to analyse the experiment.

In each level, twenty phrases were randomly assigned. The order of intensity level was selected by Latin square to reduce any ordering effect [43].

3.4. Procedure. A number of preliminary typing trials were conducted prior to the main experiment in order to allow participants to be accustomed to the typing application. In the main experiment, we asked participants to take a seat and naturally hold the touchscreen phone with their two hands (Figure 1). We then asked participants to type as fast and as accurately as they can based on the given phrase using their two thumbs [44]. We kept silence in the room during the experiment to avoid any noise effect. For each session, we recorded typing speed in words per minute (WPM), total elapsed time, and intensity level.

After completing each condition, we asked participants to rate the application for the following three questions on a 7-point Likert-type scale from 1 (strongly disagree) to 7 (strongly agree): *Typing speed*—this tactile feedback is helpful for increasing typing speed; *Typing accuracy*—this tactile feedback is helpful for reducing typing errors; *Preference*—I prefer this feedback. We also had a debrief session to ask more questions about their typing experiences with different intensity levels after the main experiment.

3.5. Data Analysis. We measured several performance metrics for this experiment. We measured typing speed in words per minute (WPM), keystroke per character (KSPC) for measuring typing efficiency, and minimum string distance (MSD) [44] for typing accuracy.

3.6. Results: Feedback Intensity versus Typing Speed. Figure 2 shows typing speed with different intensity levels. It is clearly observed that the WPM increases when the intensity level increases. Although one-way repeated-measure ANOVA shows that there is only a weak difference in typing speed ($F = 2.1$, $p = 0.098$), the trend is well observed.

3.7. Results: Feedback Intensity versus User Type. We further divided the participants into three groups based on their typing speeds—that is, *Beginner*, *Intermediate*, and *Expert*. Participants having average WPM value lower than 25 were categorized in *Beginner* group, and participants who scored average WPM higher than 30 were classified into *Experts*. Rest of the participants were classified as *Intermediates*. These thresholds are decided based on [44] and our observation on the distribution of the WPM. As a result, *Beginner* group and *Expert* group had 5 participants each, and *Intermediate* group had 8 participants.

As can be seen in Figures 3–5, people in each group prefer different intensity levels. *Beginner* group reported that they prefer *Mid* level of feedback intensity, whereas *Intermediate* group reported that they prefer both *Mid* and *High* levels of feedback intensity. *Expert* group reported that they prefer *Low* level of feedback intensity.

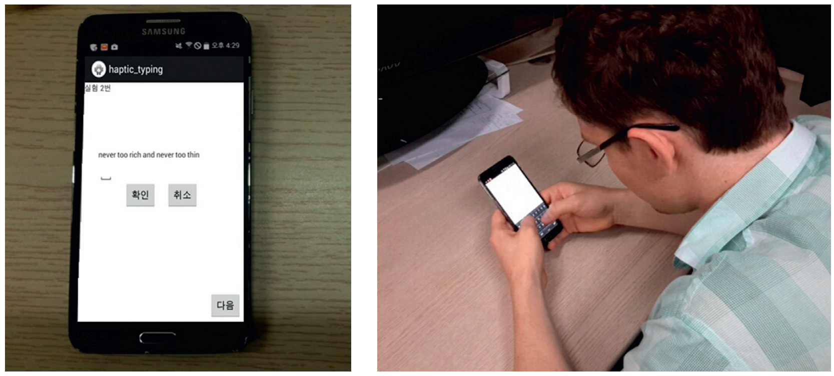
For different expertise groups and different measurements, one-way repeated-measure ANOVA tests were conducted. For all cases, no significant effect was observed. However, weak evidences ($0.05 < p$ value < 0.1) of the effect of feedback intensity on user preferences were captured through a post hoc test (Bonferroni test) in some conditions as shown in the figures as blue lines.

3.8. Discussion. In this study, we first found that increasing feedback intensity is likely to lead to higher typing speed. Although the results were only weakly supported ($0.05 < p$ value < 0.1), we clearly observed a linear trend of performance improvement with increased feedback intensity. We then observed the preference of different user group. Interestingly, people in *Beginner* and *Intermediate* groups preferred comparably higher intensity levels (*Mid* for *Beginner* and *Mid*/*High* for *Intermediate*) than those in *Expert* group (*Low* for *Expert*). It seems that *High* level was too strong for people in *Beginner*. However, they clearly preferred relatively higher intensity as they think that it helped them in increasing the typing speed and accuracy.

For people in *Expert* group, low tactile feedback intensity showed promising results as compared to other expertise groups. It is probably due to the fact that people in *Expert* group are already good at typing on virtual keyboards so that they neither need any strong key click feedback nor no feedback. This can be weak evidence that our initial hypothesis is on the relationship between typing expertise and the preference on feedback strength.

4. Study 2: Effects of Vibrotactile Edge

The goal of this study is to investigate the effect of vibrotactile feedback that encodes information about the keyboard edge. The idea of the encoding is that the distance between the finger and the intended keyboard is linearly mapped to the strength of the click vibration. Two different mapping functions were used: linearly increasing as distance increases, and the other way around. Additionally, we also investigated the effect of the moment when the encoded feedback is provided, at the moment of key



(a) (b)

FIGURE 1: Typing program application (a) and a subject holding a phone during the experiment (b).

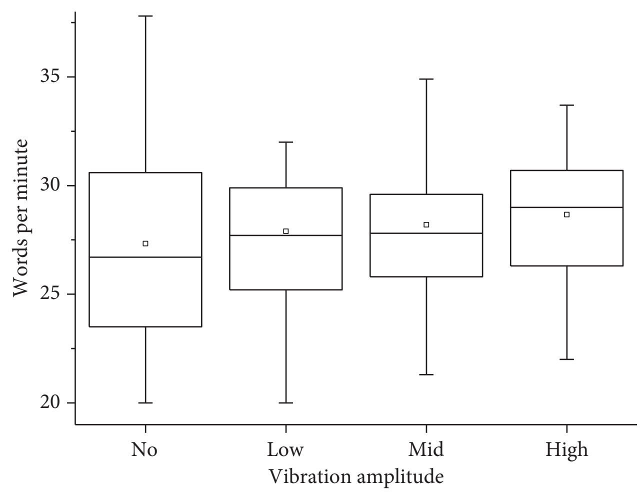


FIGURE 2: Typing speed in words per minute (WPM) for each tactile feedback intensity.

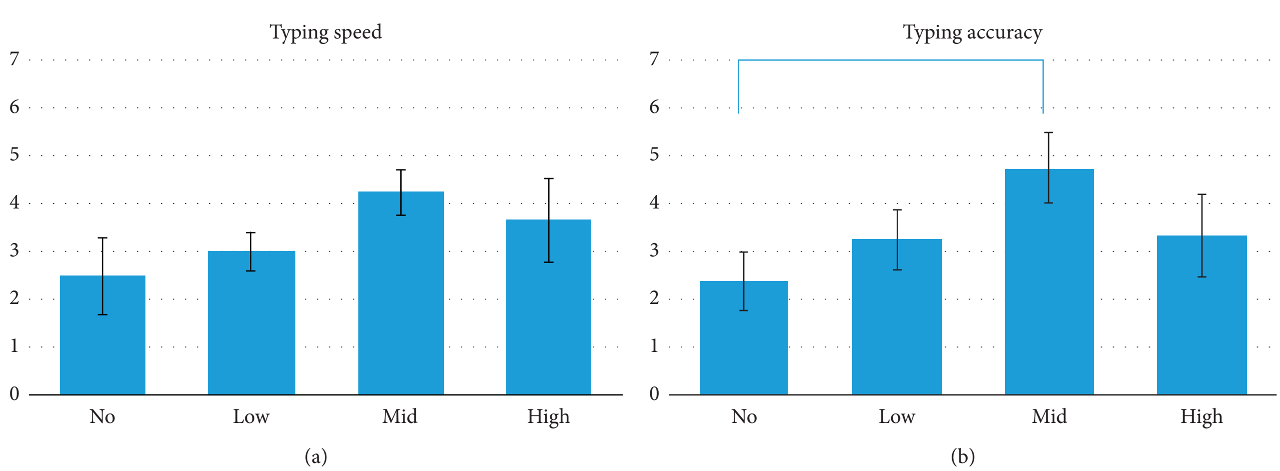


FIGURE 3: Average score for user preference on typing speed (a) and accuracy (b) for each intensity level in *Beginner* group.

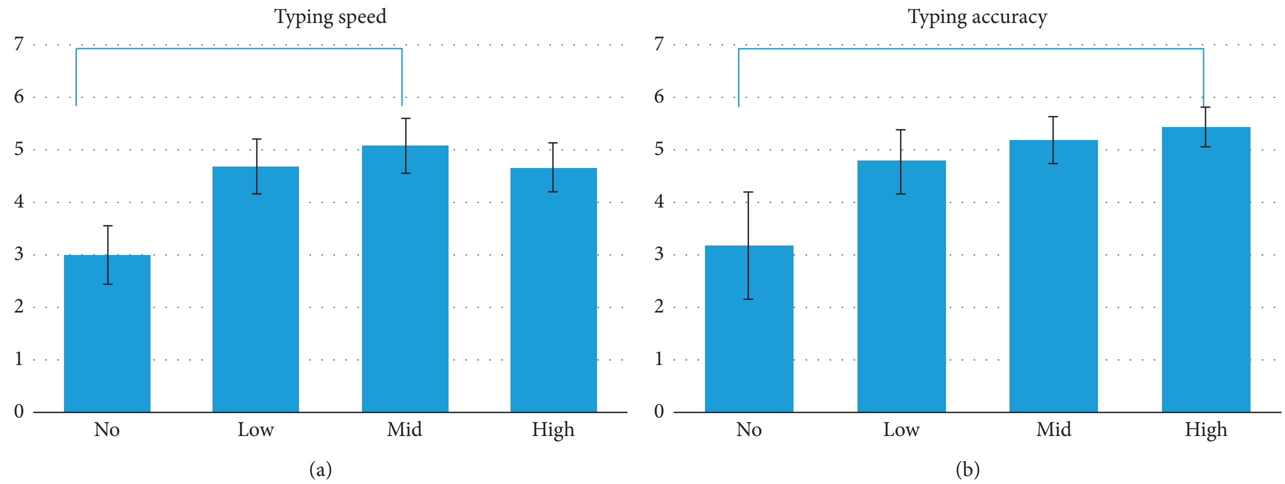


Figure 4: Average score for user preference on typing speed (a) and accuracy (b) for each intensity level in *Intermediate* group.

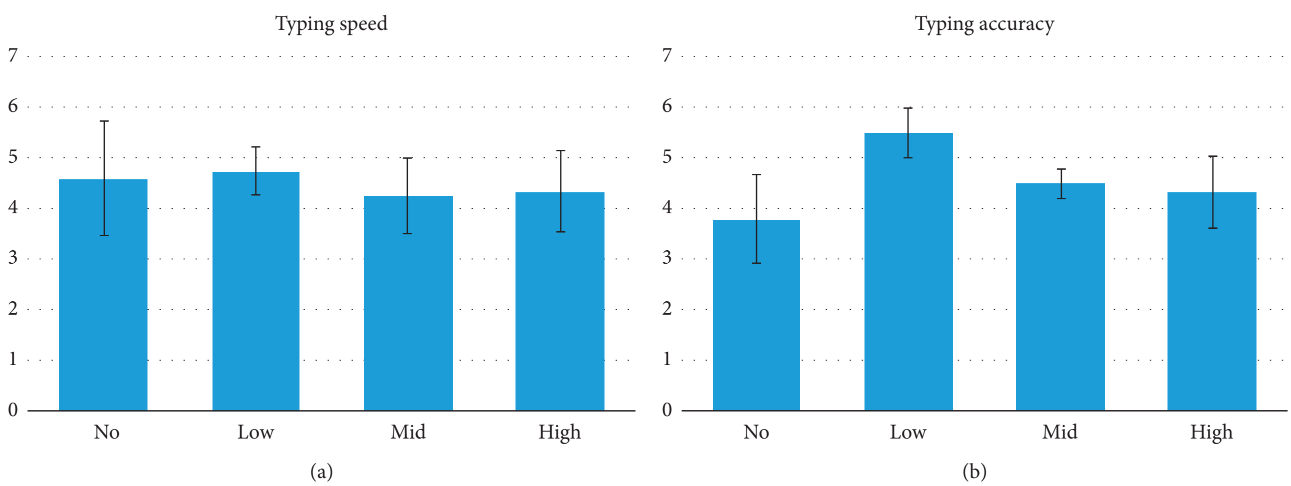


Figure 5: Average score for user preference on typing speed (a) and accuracy (b) for each intensity level in *Expert* group.

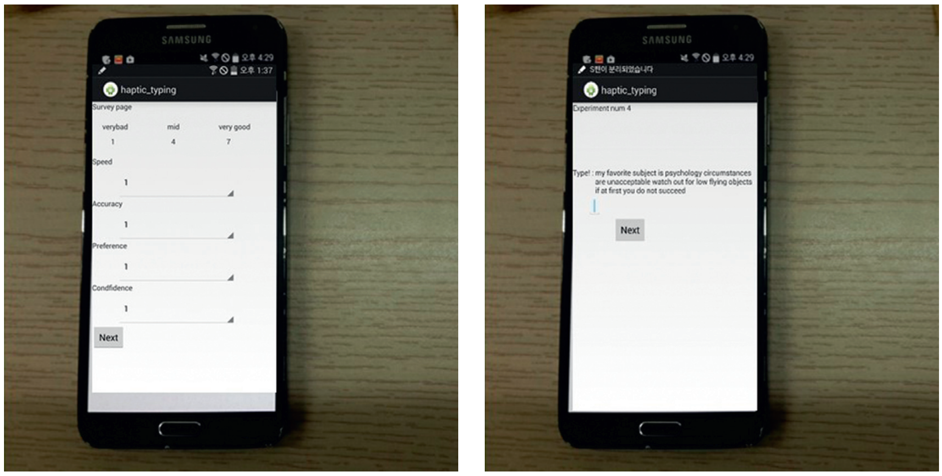
pressing or at the moment of key releasing. In this experiment, we experimentally find the best suitable combination among various combinations of the two mapping functions and two moments of feedback by observing the users' preference on their typing speed, error, and users' confidence.

4.1. Apparatus. We built another Android-based typing program apparatus with customized virtual keyboard (Figure 6). In this keyboard, we provide different intensity of tactile feedback signal based on the location of user's key press on the key. The intensity of signal is determined by the experimental conditions (see the later subsection for further explanation). This keyboard further supports temporal feedback conditions in which tactile feedback is delivered based on key's touch state. For example, tactile feedback is delivered when key is pressed, released, or both pressed and released. The typing application stores user's typing speed in WPM, number of key pressed, and the position of finger touched on the key.

4.2. Participants. A total of ten university students who did not participate in Study 1 participated in this study (mean = 25.34, SD = 1.92). Participants were paid for their participation. They reported that they are healthy and have no disabilities. They also reported that they had prior experience of typing in English and familiar with virtual keyboards.

4.3. Experimental Conditions. Table 1 shows the combinations of spatial-temporal feedback conditions—we call this tactile feedback mode.

As shown in Figures 7 and 8, and Table 1, we have three spatial tactile feedback conditions for this experiment: *Linear Feedback*, *Reversed Feedback*, and *Constant Feedback*. In *Linear Feedback*, tactile feedback intensity is linearly increased in regard to the distance of the touched location from the centroid of the key. Stronger tactile feedback is delivered when touched point is relatively farther from the centroid of the key. In *Reversed Feedback*, tactile feedback intensity is linearly decreased in regard to the touched point

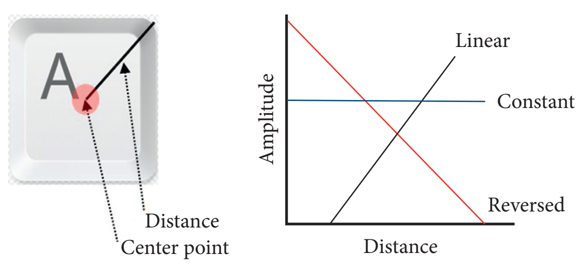


(a) (b)

Figure 6: A phone with a survey page (a) and a typing application (b).

Table 1: Tactile feedback mode based on spatial-temporal feedback conditions.

	Linear	Reversed	Constant
Attached	AL	AR	AC
Detached	DL	DR	DC
Both ways	BL	BR	BC



(a) (b)

Figure 7: A key showing the distance from the centroid to its corner (a) and a chart showing three tactile feedback conditions—*Linear*, *Reversed*, and *Constant* based on the distance from the centroid (b).

(a) (b)

Figure 8: A finger is attached to a key (a) and detached from a key (b).

from the centroid of the key. In *Constant Feedback*, the constant intensity of tactile feedback is delivered no matter which area is touched within a key. We also provide no feedback when the centroid of key is touched, providing confidence to the users that they touched the centroid of the key—we call this *Dead Zone*.

We also have three temporal tactile feedback conditions: *Pressed*, *Released*, and *Pressed-Released*. In *Pressed*, tactile feedback is delivered when key is being pressed (touched). In *Released*, tactile feedback is delivered when key is being released. In *Pressed-Released*, tactile feedback is delivered when key is being pressed and being released.

4.4. Data Analysis. We measured several performance metrics for this experiment. We measured typing speed in words per minute (WPM), keystroke per character (KSPC) for measuring typing efficiency, and minimum string distance (MSD) [44] for typing accuracy. We also measured key distance ratio for typing accuracy. Given that $P(x, y)$ is user's touch point on the key, we divided the touched key into four regions using two diagonal lines to obtain a distance ratio from the centroid to user's touch point $P(x, y)$ (Figure 9).

If $P(x, y)$ is in *Surface* 1 or 3, we calculate the ratio by the following equation:

$$\text{Ratio}R = \frac{((P(y) - (\text{height}/2) \times 100)}{(\text{height}/2)}, \quad \text{if } P(y) > \frac{\text{height}}{2},$$

$$\text{Ratio}R = \frac{(P(y) \times 100)}{\text{height}/2}, \quad \text{if } P(y) < \frac{\text{height}}{2}. \tag{1}$$

And if $P(x, y)$ is in *Surface* 2 or 4, then:

$$\text{Ratio}R = \frac{((P(x) - (\text{width}/2)) \times 100)}{\text{width}/2}, \quad \text{if } P(x) > \frac{\text{width}}{2},$$

$$\text{Ratio}R = \frac{(P(x) \times 100)}{(\text{width}/2)}, \quad \text{if } P(y) < \frac{\text{width}}{2}, \tag{2}$$

where height and width are the sizes of actual virtual key.

4.5. Procedure. We conducted a typing test experiment to measure the typing performance on a virtual keyboard apparatus as shown in Figure 6. Similar to Study 1, we asked participants to type as fast and accurately as possible using their two thumbs while holding the touchscreen phone.

Combinations of three feedback intensity conditions (i.e., *Linear*, *Reversed*, and *Constant*) and three feedback delivery time conditions (i.e., *Pressed*, *Released*, and *Pressed-Released*) were used for this experiment. No feedback was also used for the comparison. Each session was composed of 10 lines of phrases and the session is repeated three times, yielding thirty tasks in total. Latin square was used to reduce the ordering effect.

After completing each session, we asked participants to rate their typing experiences based on the following questions on a 7-point Likert-type scale from 1 (strongly disagree) to 7 (strongly agree): *Typing speed*—this tactile feedback is helpful for increasing typing speed; *Typing accuracy*—this tactile feedback is helpful for reducing typing errors; *Preference*—I prefer this feedback; and *Confidence*—this tactile feedback gives me the confidence of key click. We added this *Confidence* question to find out whether degradation of confidence is caused by spatial or temporal feedback.

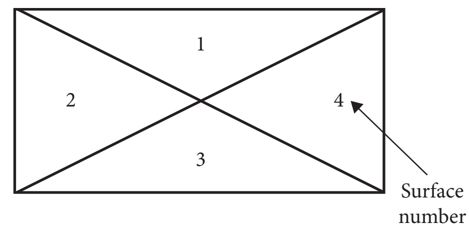


Figure 9: A key with four regions and their surface numbers. The key is divided using two diagonal lines.

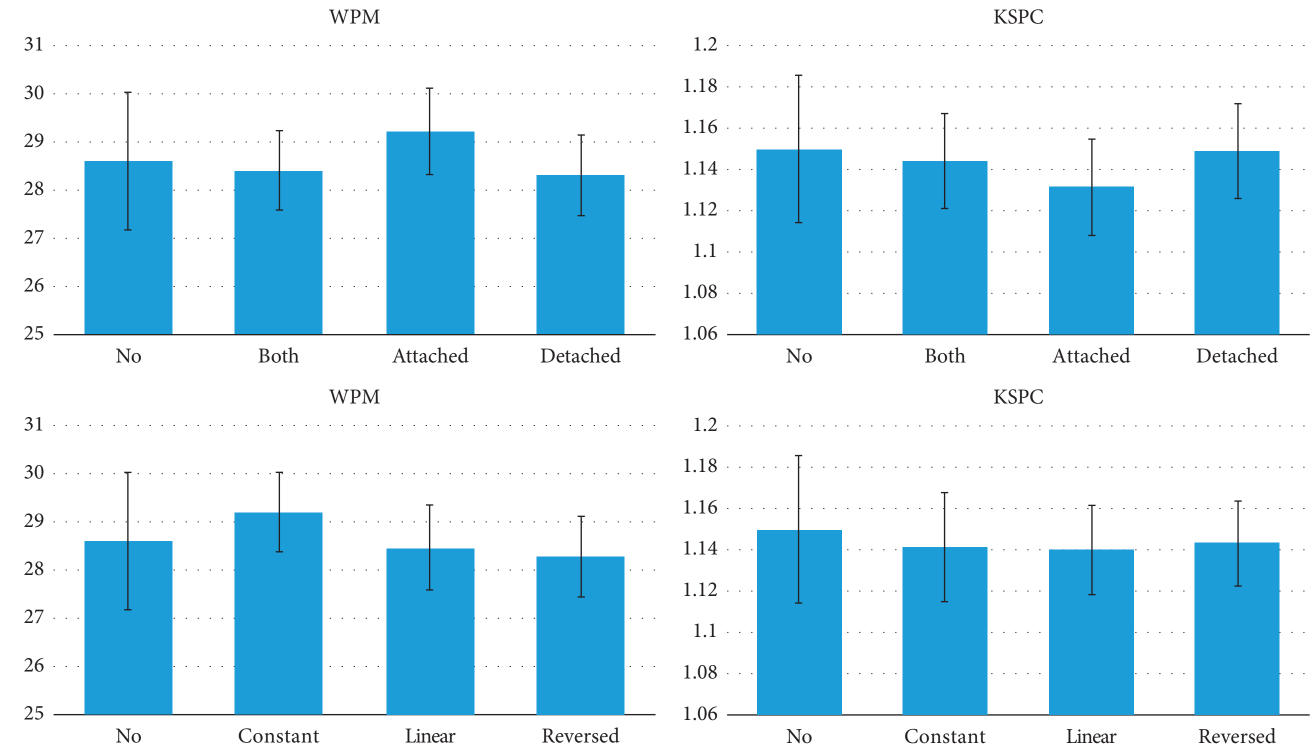
4.6. Results: Typing Speed and KSPC. Figure 10(a) shows typing speed in WPM. As observed in this figure, the feedback condition of the "Attached" and "Constant" feedback reached the highest. Figure 10(b) shows typing efficiency in KSPC. We observed that the lowest KSPC (meaning highest efficiency) was observed in the "Attached" and "Linear" condition and second lowest KSPC was observed in "Attached" and "Constant" condition. A two-way repeated-measure ANOVA confirmed that feedback condition was not a significant factor for typing speed ($F = 0.276$, $p = 0.981$) or typing efficiency ($F = 0.45$, $p = 1.00$).

4.7. Results: Different Ratio. We also measured the calculated ratio used in the data analysis section. This value can be an indicator of how close user's key press is to the centroid of a key. Figure 11 shows the ratio for each experimental condition. As illustrated in this figure, the lowest ratio was observed in AC (Attached and Constant) condition, meaning highest typing accuracy.

4.8. Results: User Preference. Figure 12 shows the results of user preference on *Accuracy, Speed, Comfort,* and *Confidence* for temporal feedback conditions (*Attached*, *Detached*, *Both*, or *None*), respectively. It is clearly showed that participants preferred tactile feedback that is provided when key is attached (pressed) in terms of accuracy, but preferred feedback that is provided when key is detached (released) in terms of confidence.

Figure 13 shows the results of user preferences for spatial feedback conditions (*No*, *Linear*, *Reversed*, or *Constant*), respectively. It is clearly shown that participants preferred *Reversed Feedback* condition to provide key click confidence. However, participants preferred *Constant Feedback* condition in terms of typing speed.

A two-way repeated-measure ANOVA showed that there was a significant effect of both temporal conditions and spatial conditions for *Confidence* measurement ($F(2, 90) = 3.326$, $p = 0.05$ for temporal condition and $F(2, 90) = 4.122$, $p = 0.02$ for spatial conditions), but not for other measurements. Post hoc Tukey tests on both spatial and temporal feedback conditions showed the significantly



(a) (b)

Figure 10: Simple Effects. Typing speed in words per minute (a) and typing efficiency in KSPC (b) for each condition. Upper images are for temporal encoding factors, and the lower images are for edge encoding factors.

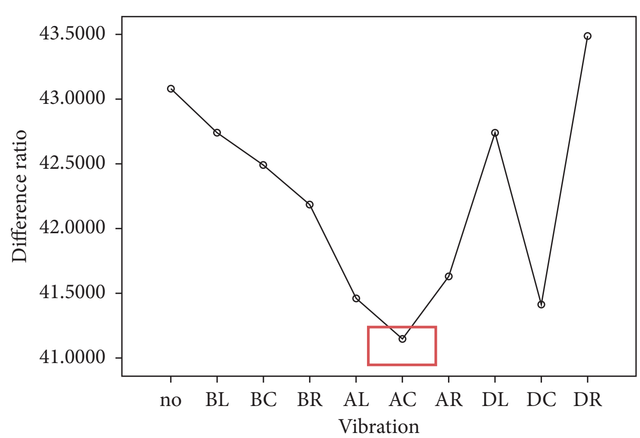


Figure 11: Ratio for each condition.

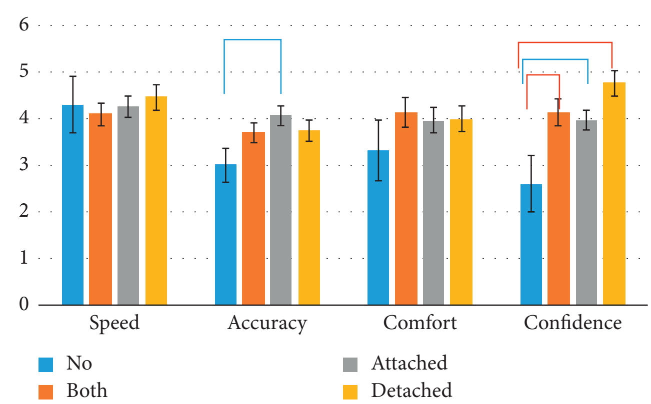


Figure 12: User preference on *Accuracy* (a) and *Confidence* (b) for temporal feedback conditions.

different pairs (see red connecting lines in Figures 12 and 13 for p value less than 0.05 and blue connecting lines for $p$value less than 0.1).

4.9. Discussion. In this study, we confirmed that the spatial and temporal modifications on the vibration feedback did not give us a physical performance enhancement as shown in Figure 10. In addition, spatial modification of the feedback did not show significant effect on the user's preference compared to the *Constant Feedback* case, while the feedback itself was clearly advantageous on giving a user confidence. Temporal modification on the feedback also did not have clear effect on user's preference. This result indicates that the proposed temporal and spatial modification techniques are not very effective on physical performance and on user preference.

We presume that these results are due to the fact that participants are naïve to the information embedded on the feedback, so they did not successfully utilize the feedback. This can lead to the need of more intensive experiment that involves prolonged usage of the interface.

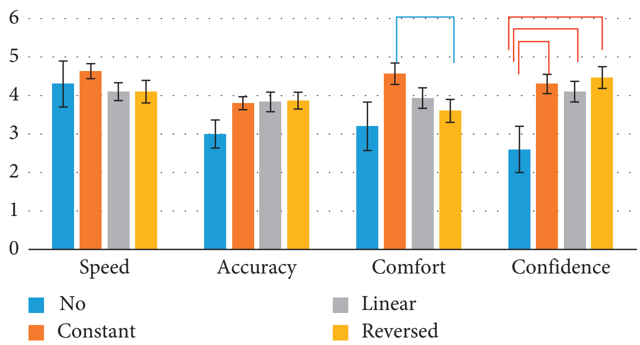


Figure 13: User preference on *Confidence* (a) and *Typing Speed* (b) for spatial feedback conditions.

In next section, in order to partially avoid this problem, we examined the user's workload when using a virtual keyboard with new feedback techniques. This time, participants were aware of the meaning of difference in the feedback.

5. User Evaluation: Work Load Analysis

Based on the findings from our first study, we learned that there exist different preferences of tactile feedback for different groups of users. We first discovered that people with higher typing performance (i.e., people who type fast with mobile keyboard) prefer comparably reduced intensity of tactile feedback, whereas beginner and intermediate-level users prefer comparably higher intensity of tactile feedback. From the second study, although there was no statistical meaning, we also had evidences that people prefer *Attached* with *Constant* tactile feedback to increase typing speed and provide confidence for their key click confirmation. Based on these findings, we propose a user-adaptive tactile keyboard on mobile device and compare it with the existing keyboard to explore the feasibility of our work (Figure 14).

5.1. Development of User-Adaptive Tactile Keyboards. We developed two different versions of user-adaptive tactile keyboards for this study. First one is feedback mode change-based keyboard. Basically, it measures the user's typing speed in real time and adaptively changes its feedback mode based on user's typing performance—we call this keyboard *Feedback Mode Change Keyboard*. For example, if typing speed is slow, the mode becomes DR (Detached-Reversed—meaning feedback is delivered when key is detached, and tactile feedback intensity is linearly decreased in regard to the touched point from the centroid of the key (Table 1)). If typing speed is increased up to intermediate level, the mode becomes BL (Attached/Detached-Linear—meaning feedback is delivered when key is attached and also detached, and tactile feedback intensity is linearly increased in regard to the touched point from the centroid of the key). If typing speed is further increased up to expert level, the mode is changed to AC (Attached-Constant—meaning feedback is delivered when key is attached, and tactile feedback intensity is constantly provided).

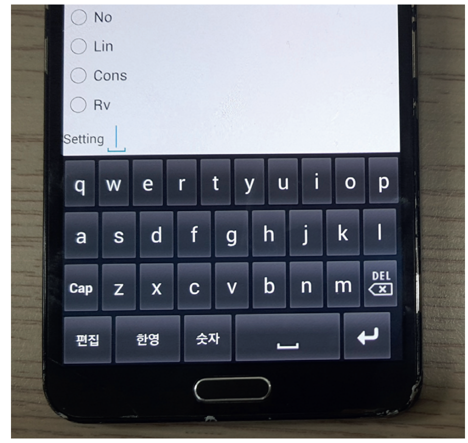


Figure 14: Adaptive keyboard design.

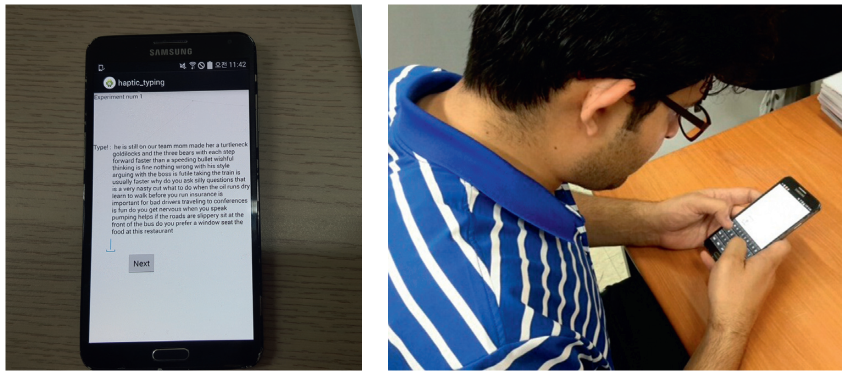
We also developed another keyboard that changes its tactile feedback intensity based on user's typing speed but does not consider the feedback mode—we call this keyboard *Feedback Intensity Change Keyboard*. In this keyboard, we set a number of intensity levels and only allowed the level to change one level at a time. This is due to the fact that people felt uncomfortable when the tactile feedback intensity changed dramatically during our pilot study.

For the baseline of this experiment, we also used an ordinary virtual keyboard in which tactile feedback intensity is fixed and constant at all times. We set the size of all keys to the same size and added tactile feedback for space bar and delete key. We stored user's typing speed and all the characters of the keys that they typed.

5.2. Participants. A total of ten university students who did not participate in Study 1 or Study 2 participated in this study. Participants were paid for their participation. They reported that they are healthy and have no disabilities. They also reported that they had prior experience of typing in English and familiar with virtual keyboards.

5.3. Procedure. Similar to studies 1 and 2, we asked participants to take a seat and naturally hold the touchscreen phone with their two hands for thumb typing (Figure 15). However, instead of asking them to type as fast and as accurately as they can, we asked them to type as comfortable as they can just like they perform the typing task during ordinary days. Since the goal of this study is to find the feasibility of our user-adaptive tactile keyboard in daily life setting, we focus more on comfort use of user-adaptive tactile keyboard than typing performance. For this reason, we provided 10 lines of multiple sentences to simulate real-world scenarios of daily text entry on mobile phone. Three sessions with three different keyboard types (*Feedback Mode Change Keyboard*, *Feedback Intensity Change Keyboard*, and baseline) were provided for each user.

After each session, we asked participants to evaluate the workload by providing a questionnaire based on NASA-TLX [45]. A total of six questions were asked: mental demand, physical demand, temporal demand, overall performance, frustration level, and effort (Figure 16).



(a) (b)

Figure 15: Typing application (a) and a user conducting a typing task (b).

Mental demand	How much focus on or effect while typing?
Physical demand	How much physical activity was required? (finger or arm?)
Temporal demand	How much time did you spend to finish the task?
Performance	How successful were you in performing the task?
Effort	How annoyed were you due to vibration?
Frustration	How hard did you have to type the key affected by vibration?

Figure 16: Six questions based on NASA-TLX.

In order to calculate the final workload of the conditions, we used analytic hierarchy process (AHP) to objectify the subjective response from the participants by assigning a weight to subjective response from NASA-TLX [45].

5.4. Results and Discussion: NASA-TLX. Based on the weight from AHP, we calculated the workload with each keyboard condition. The workload for *Feedback Mode Change Keyboard* and *Feedback Intensity Change Keyboard* is 31.44 and 38.72, respectively. The workload for baseline was 36.98. Compared to the baseline, the *Feedback Mode Change Keyboard* reduced the workload by 17%. This is notable since the feedback modes did not have statistical effect in study 2. From this, we can speculate that the feedback modes have positive effect to reduce user's mental load, although the users do not have preference.

6. General Discussion

This work focuses on feasibility of user-adaptive tactile keyboard on mobile touchscreen. We noticed that there exists a number of tactile feedback that mobile device can provide. We also noticed that not every user likes the same and simple tactile feedback. We hypothesized that there exists a relationship between feedback intensity and users, and we further hypothesized that these users can be grouped by a factor—such as typing speed. We also believed that we can build a user-adaptive tactile keyboard for better usability and performance, and this can be extended to virtual and augmented reality.

We first observed how mobile users behave based on tactile feedback intensity and what intensity level that different user group prefers. We then studied if different tactile feedback mode affects the user preference based on user's typing speed. Interestingly, we discovered that users preferred tactile feedback that is provided when key is attached (pressed) in terms of accuracy, but preferred feedback that is provided when key is detached (released) in terms of confidence. We also discovered that people in *Beginner* and *Intermediate* groups preferred comparably higher levels of feedback intensity (*Mid* for *Beginner* and *Mid/High* for *Intermediate*) than those in *Expert* group (*Low* for *Expert*).

Based on our findings, we built two different versions of user-adaptive tactile keyboard on mobile phone. We conducted a user study to investigate the feasibility of the keyboards by analysing the workload. As results, *Feedback Mode Change Keyboard* reduced the workload by 17 percent. We believe that this achievement will shed light on the development of user-adaptive tactile keyboard on mobile platform. Our future work will extend the present study by considering the use of adaptive keyboard in VR setting as typing is one of most challengeable tasks in VR and user-adaptive keyboard can be a good solution to address this issue.

7. Conclusions

This work investigates the effects of user-adaptive tactile keyboard on mobile touchscreen. We performed two studies to investigate the relationship between tactile feedback intensity and user preference. We then implemented user-adaptive tactile keyboards on mobile platform to verify their feasibility. We performed a user study to evaluate the workload of our proposed keyboard and showed the improvement in workload.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the NRF of Korea through the Basic Research Program (NRF-2017R1D1A1B03031272) and by the MSIP through IITP (no. 2017-0-00179) (HD Haptic Technology for Hyper Reality Contents).

References

[1] Pew Research Center, *Smartphone Ownership and Internet Usage Continues to Climb in Emerging Economies*, Pew Research Center, Washington, DC, USA, 2016.

[2] S. Zhu, T. Luo, X. Bi, and S. Zhai, “Typing on an invisible keyboard,” in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems (CHI 2018)*, pp. 1–13, ACM, Montreal, QC, Canada, April 2018.

[3] J. Gugenheimer, D. Dobbelstein, C. Winkler, G. Haas, and E. Rukzio, “FaceTouch: enabling touch interaction in display fixed UIs for mobile virtual reality,” in *Proceeding of Annual Symposium on User Interface Software and Technology (UIST 2016)*, pp. 49–60, ACM, Tokyo, Japan, October 2016.

[4] Y. Kim and G. J. Kim, “HoVR-Type: smartphone as a typing interface in VR using hovering,” in *Proceeding of ACM Conference on Virtual Reality Software and Technology*, pp. 333-334, ACM, Munich, Germany, November 2016.

[5] J. Gugenheimer, “Nomadic virtual reality: exploring new interaction concepts for mobile virtual reality head mounted displays,” in *Proceeding of Annual Symposium on User Interface Software and Technology (UIST 2016 Adjunct)*, pp. 9–12, ACM, Tokyo, Japan, October 2016.

[6] E. Hoggan, A. Crossan, S. Brewster, and T. Kaaresoja, “Audio or tactile feedback: which modality and when?,” in *Proceeding of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2009)*, pp. 2253–2256, ACM, New York, NY, USA, April 2009.

[7] H. Korhonen, “Audio feedback on a mobile phone for number dialling,” in *Proceeding of the 7th International Conference on Human Computer Interaction with Mobile Devices & Services*, pp. 345-346, ACM, Salzburg, Austria, September 2005.

[8] T. Noguchi, Y. Fukushima, and I. Yairi, “Evaluating information support system for visually impaired people with mobile touch screens and vibration,” in *Proceeding of the 13th International ACM SIGACCESS Conference on Computers and Accessibility*, pp. 243-244, ACM, Dundee, Scotland, UK, October 2011.

[9] E. Matias, I. S. MacKenzie, and W. Buxton, “One-handed touch typing on a QWERTY keyboard,” *Human-Computer Interaction*, vol. 11, no. 1, pp. 1–27, 1996.

[10] N. Green, J. Kruger, C. Faldu, and R. Amant, “A reduced QWERTY keyboard for mobile text entry,” in *Proceeding of CHI Extended Abstracts on Human Factors in Computing Systems*, pp. 1429–1432, ACM, Vienna, Austria, April 2004.

[11] S. Hwang and G. Lee, “Qwerty-like 3×4 keypad layouts for mobile phone,” in *Proceeding of CHI Extended Abstracts on Human Factors in Computing Systems*, pp. 1479–1482, ACM, Portland, Oregon, April 2005.

[12] A. Chang and C. O’Sullivan, “Audio-haptic feedback in mobile phones,” in *Proceeding of CHI Extended Abstracts on Human Factors in Computing Systems*, pp. 1264–1267, ACM, Portland, Oregon, April 2005.

[13] H. Chen, J. Santos, M. Graves, K. Kim, and H. Tan, “Tactor localization at the wrist,” in *Proceeding of Haptics: Perception, Devices and Scenarios*, pp. 209–218, Springer, Madrid, Spain, June 2008.

[14] K. B. Perry and J. P. Hourcade, “Evaluating one handed thumb tapping on mobile touchscreen devices,” in *Proceeding of Graphics Interface 2008*, pp. 57–64, Canadian Information Processing Society, Windsor, Canada, May 2008.

[15] M. Silfverberg, I. S. MacKenzie, and P. Korhonen, “Predicting text entry speed on mobile phones,” in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems (CHI 2000)*, pp. 9–16, ACM, Hague, The Netherlands, April 2000.

[16] Y.-S. Jeong, T.-K. Yeom, J. S. Park, and J. H. Park, “Efficient model of Korean graphemes based on a smartphone keyboard,” *Electronic Commerce Research*, vol. 13, no. 3, pp. 357–377, 2013.

[17] K. Lyons, D. Plaisted, and T. Starner, “Expert chording text entry on the twiddler one-handed keyboard,” in *Proceeding of Eighth International Symposium on Wearable Computers, 2004. ISWC 2004*, vol. 1, pp. 94–101, IEEE, Arlington, VA, October 2004.

[18] I. S. MacKenzie and S. X. Zhang, “The design and evaluation of a high performance soft keyboard,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 25–31, ACM, Pittsburgh, Pennsylvania, USA, May, 1999.

[19] S. Kim, M. Sohn, J. Pak, and W. Lee, “One-key keyboard: a very small QWERTY keyboard supporting text entry for wearable computing,” in *Proceeding of 18th Australia Conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments*, pp. 305–308, ACM, Sydney, Australia, November 2006.

[20] A. Karlson, “Interface design for single-handed use of small devices,” in *Proceeding of Annual ACM Symposium on User Interface Software and Technology (UIST 2008)*, pp. 27–30, ACM, Monterey, CA, USA, October 2008.

[21] T. Nakagawa and H. Uwano, “Usability differential in positions of software keyboard on smartphone,” in *Proceeding of IEEE Global Conference on Consumer Electronics (GCCE 2012)*, pp. 304–308, Tokyo, Japan, October 2012.

[22] L. Findlater, J. O. Wobbrock, and D. Wigdor, “Typing on flat glass: examining ten-finger expert typing patterns on touch surfaces,” in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems*, pp. 2453–2462, ACM, Vancouver, Canada, 2011.

[23] T.-B. Ryu, "Performance analysis of text entry with preferred one hand using smart phone touch-keyboard," *Journal of the Ergonomics Society of Korea*, vol. 30, no. 1, pp. 259–264, 2011.

[24] A. Sears, "Improving touchscreen keyboards: design issues and a comparison with other devices," *Interacting with Computers*, vol. 3, no. 3, pp. 253–269, 1991.

[25] A. Sears, D. Revis, J. Swatski, R. Crittenden, and B. Shneiderman, "Investigating touchscreen typing: the effect of keyboard size on typing speed," *Behaviour and Information Technology*, vol. 12, no. 1, pp. 17–22, 1993.

[26] T. Page, "Usability of text input interfaces in smartphones," *Journal of Design Research*, vol. 11, no. 1, pp. 39–56, 2013.

[27] A. Sears and Y. Zha, "Data entry for mobile devices using soft keyboards: understanding the effects of keyboard size and user tasks," *International Journal of Human-Computer Interaction*, vol. 16, no. 2, pp. 163–184, 2003.

[28] S. Brewster, F. Chohan, and L. Brown, "Tactile feedback for mobile interactions," in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems (CHI 2007)*, pp. 159–162, ACM, San Jose, CA, USA, April 2007.

[29] E. Rabin and A. M. Gordon, "Tactile feedback contributes to consistency of finger movements during typing," *Experimental Brain Research*, vol. 155, no. 3, pp. 362–369, 2004.

[30] A. Hoffmann, D. Spelmezan, and J. Borchers, "Typeright: a keyboard with tactile error prevention," in *Proceedings of SIGCHI Conference On Human Factors In Computing Systems*, pp. 2265–2268, ACM, Boston, MA, USA, April 2009.

[31] D. Rudchenko, T. Paek, and E. Badger, "Text revolution: a game that improves text entry on mobile touchscreen keyboards," in *Proceeding of Pervasive Computing*, pp. 206–213, Springer, San Francisco, CA, USA, June 2011.

[32] T. Kaaresoja, L. M. Brown, and J. Linjama, "Snap-crackle-pop: tactile feedback for mobile touch screens," in *Proceedings of Eurohaptics*, pp. 565-566, Paris, France, July 2006.

[33] H. Nishino, R. Goto, T. Kagawa et al., "A touch screen interface design with tactile feedback," in *Proceeding of IEEE International Conference on Complex, Intelligent and Software Intensive Systems (CISIS 2011)*, pp. 53–60, Seoul, South Korea, June 2011.

[34] J. Luk, J. Pasquero, S. Little, K. MacLean, V. Levesque, and V. Hayward, "A role for haptics in mobile interaction: initial design using a handheld tactile display prototype," in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems*, pp. 171–180, ACM, Montréal, Québec, Canada, April 2006.

[35] J. R. Kim and H. Z. Tan, "A study of touch typing performance with keyclick feedback," in *Proceeding of IEEE Haptics Symposium (HAPTICS 2014)*, pp. 227–233, Houston, TX, USA, February 2014.

[36] S. Brewster and A. King, "An investigation into the use of tactons to present progress information," in *Proceeding of Human-Computer Interaction (INTERACT 2005)*, pp. 6–17, Springer, Rome, Italy, September 2005.

[37] J. Lylykangas, V. Surakka, K. Salminen et al., "Designing tactile feedback for piezo buttons," in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems (CHI 2011)*, pp. 3281–3284, ACM, Boston, MA, USA, 2011.

[38] K. Kim, "Perception-based tactile soft keyboard for the touchscreen of tablets," *Mobile Information Systems*, vol. 2018, Article ID 4237346, 9 pages, 2018.

[39] B. Han, K. Kim, K. Yatani, and H. Z. Tan, "Text entry performance evaluation of haptic soft QWERTY keyboard on a tablet device," in *Proceeding of the EuroHaptics 2014*, pp. 325–332, Springer, Versailles, France, June 2014.

[40] J. R. Kim and H. Z. Tan, "Haptic feedback intensity affects touch typing performance on a flat keyboard," in *Proceeding of EuroHaptics 2014*, pp. 369–375, Springer, Versailles, France, June 2014.

[41] J. R. Kim and H. Z. Tan, "Effect of information content in sensory feedback on typing performance using a flat keyboard," in *Proceeding of IEEE World Haptics Conference 2015*, pp. 228–234, Chicago, Illinois, June 2015.

[42] I. S. MacKenzie and R. W. Soukoreff, "Phrase sets for evaluating text entry techniques," in *Proceeding of Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 754-755, ACM, 2003.

[43] D. A. Grant, "The Latin square principle in the design and analysis of psychological experiments," *Psychological Bulletin*, vol. 45, no. 5, p. 427, 1948.

[44] R. W. Soukoreff and I. S. MacKenzie, "Metrics for text entry research: an evaluation of MSD and KSPC, and a new unified error metric," in *Proceeding of SIGCHI Conference on Human Factors in Computing Systems (CHI 2003)*, pp. 113–120, ACM, Lauderdale, Florida, USA, April 2003.

[45] S. G. Hart and L. E. Stavenland, "Development of NASA-TLX (Task Load Index): results of empirical and theoretical research," in *Human Mental Workload*, P. A. Hancock and N. Meshkati, Eds., NASA Ames Research Center, Mountain View, CA, USA, 1988.

Hindawi
Mobile Information Systems
Volume 2018, Article ID 2306031, 12 pages
https://doi.org/10.1155/2018/2306031

Research Article

Interactive and Immersive Learning Using 360° Virtual Reality Contents on Mobile Platforms

Kanghyun Choi,[1] **Yeo-Jin Yoon**,[1,2] **Oh-Young Song**,[3] **and Soo-Mi Choi**[1,2]

[1]*Department of Computer Science and Engineering, Sejong University, Seoul, Republic of Korea*
[2]*Mobile Virtual Reality Research Center, Sejong University, Seoul, Republic of Korea*
[3]*Department of Software, Sejong University, Seoul, Republic of Korea*

Correspondence should be addressed to Soo-Mi Choi; smchoi@sejong.ac.kr

Received 11 May 2018; Accepted 26 July 2018; Published 11 October 2018

Academic Editor: Sang-Youn Kim

Recent advances in mobile virtual reality (VR) devices have paved the way for various VR applications in education. This paper presents a novel authoring framework for mobile VR contents and a play-based learning model for marine biology education. For interactive and immersive mobile VR contents, we develop a multilayer 360° VR representation with image-based interactions such as mesh deformation and water simulation, which enable users to realistically interact with 360° panoramic contents without consuming excessive computational resources. On the basis of this representation, we design and implement play-based learning scenarios to increase the interactivity and immersion of users. Then, we verify the effectiveness of our educational scenarios using a user study in terms of user-created VR contents, interactivity, and immersion. The results show that more experienced elements in VR contents improve the immersion of users and make them more actively involved.

1. Introduction

Following the development of consumer virtual reality (VR) devices using smartphones and tablets, the demand for mobile VR contents in various fields such as games, movies, and education has increased. Recently, user-created VR contents have been rapidly increasing with the advancement in low-cost image or video-capturing equipment for mobile VR. However, VR contents that use images or videos suffer from limitations with the lack of interactivity by only providing passive information; thus, the contents cannot draw active involvement of users. In education, we know that VR encourages learners to become more active through immersive experience [1]. Learning with real-time interactions provides learners instant results and helps in the decision making to reach their goals. To achieve a higher level of immersion and maximize educational effects, more engaging interactions between the learners and mobile VR contents are essential.

We aim to satisfy the interactive and immersive experience using the following criteria in terms of education.

(i) *Environment*. We target mobile VR platforms. Compared with the desktop-based VR, the cost of mobile VR hardware such as smartphones and mobile headsets is affordable, making it suitable for production and distribution of educational contents for a large number of users.

(ii) *Engagement*. We allow users to navigate in the environment and perform appropriate interactions according to the educational purpose within the VR environment, providing natural adaption to the virtual learning environment.

(iii) *Immersion*. We provide a personalized learning environment to maximize the educational effect by increasing the immersion and participation in virtual space compared with traditional teaching methods.

This paper presents a novel authoring framework for mobile VR contents using 360° photographs or videos. To create engaging interactions in the surrounding scenes, we introduce a multilayer representation where each layer can have different interaction types or properties such as deformable objects, moving objects, and water simulation. On the basis of the proposed representation, we develop play-based learning scenarios on a mobile VR platform for education in marine biology and conduct a user study on the interactivity and immersion of the scenarios. The overall pipeline of our play-based learning is shown in Figure 1.

The main contributions of this paper are summarized as follows:

(i) For interactive 360° VR contents, we introduced a multilayer representation using image-based interactions that are effective on mobile devices with limited performance.

(ii) We designed a learning model to increase the interactivity and immersion of users, which includes viewer-directed immersive forms, layers for interactivity, achievements, and engaging contents.

(iii) We verified our learning framework where we employed a user study in terms of user-created VR contents, interactivity, and immersion.

The remainder of this paper is structured as follows: Section 2 provides an overview of related works, and Section 3 describes our multilayer representation using different interactions and immersive experience in mobile VR. We present our active learning model in Section 4 and evaluate the developed learning scenarios through a user study in Section 5. Finally, we discuss our conclusions and future work directions in Section 6.

2. Related Work

The 360° VR contents for mobile platforms are usually created by including panoramic photographs or videos. This image-based content generation can reduce the time and cost of building a virtual space compared with the same process using three-dimensional (3D) graphics in traditional VR such as games. In addition, real-time manipulation is possible on mobile devices because it consumes a small amount of memory. The main advantage of using image-based techniques is that anyone can use their own images; thus, learner-driven personalized education is possible with the use of user-created VR contents.

2.1. Mobile VR in Education. In recent years, mobile VR education has been shown to provide more interactive learning with fully immersive contents than traditional education approaches [1, 2] A study on motivational active learning methods of several subjects that make learners quickly lose interest, such as Science, Technology, Engineering, and Mathematics [3], measured the level of immersion of learners using the Game Engagement Questionnaire (GEQ) to evaluate the ability of these learning methods. To create VR contents using synthetic 3D graphics, special skills, and extensive efforts are required. Furthermore, delivering user personalized experience and recreating virtual spaces according to the change in the learning context are difficult. The study in [4] provided a conceptual framework for user-generated VR learning across three contexts such as paramedicine, journalism, and new media production. In that study, an active learning environment using student-created 360° videos was proposed where the students could share the videos on social networks to collaborate together. Although 360° contents are more realistic than synthetic 3D VR, limitations on the interactions with the contents have been identified to exist.

2.2. Interactivity in 360° Contents. The 360° contents, which are called 360° photographs or videos, are captured by several wide-angle cameras, which are stitched and mapped in a spherical or hemispherical space to observe the surrounding scenes based on the camera [2]. Most research works for 360° content creation focus on accurate stitching for spherical mapping [5, 6], image-based lighting effects [7–9], resolution improvement, and distortion correction of images from wide-angle cameras [10]. Some researchers investigated methods to improve the interactivity in image-based VR contents by adding URLs to 360° images [11], changing scenes using button clicks [12, 13], and adding special effects to reduce the differences between composite boundaries [14]. The study in [8] recently presented an immersive system using powerful PC-tethered VR headsets that provide interactive mixed reality experiences by compositing 3D virtual objects into a live 360° video. However, there are few studies on interactive 360° contents for mobile VR headsets, such as the Samsung Gear VR and Google Daydream View, where all of the processing is done on mobile phones.

2.3. Immersive Experience in Mobile VR. Immersion comes from the feeling that a user actually exists in a virtual space reproduced by a computer [15, 16]. Unlike the existing computer-based environment, the mobile VR environment can create more immersive feelings owing to the development of VR devices such as head-mounted displays and tracked controllers [17]. The immersion in VR is not only created by elements such as visual, auditory, and haptic information [15] but also by content resolutions, stereo cues, behavioral fidelity of what is being simulated, and system latency [18]. Mobile VR is especially affected by factors such as resolutions and latency because of low-power constraints. Therefore, to increase the immersive experience in mobile VR, visual quality, sound quality, and intuitive interactions can be considered without consuming excessive computational resources [19]. To improve the immersion in mobile VR in terms of user interaction, a few methods to synchronize the virtual and physical spaces have been presented. The methods enable users to navigate the virtual world by mapping the user movement in the physical space to the virtual space [20–22]. In addition, interactive devices that use hand-gesture recognitions have been developed [23, 24]. However, only a few studies have been conducted on the optimization of visual quality or 3D sounds that consider mobile VR platforms.

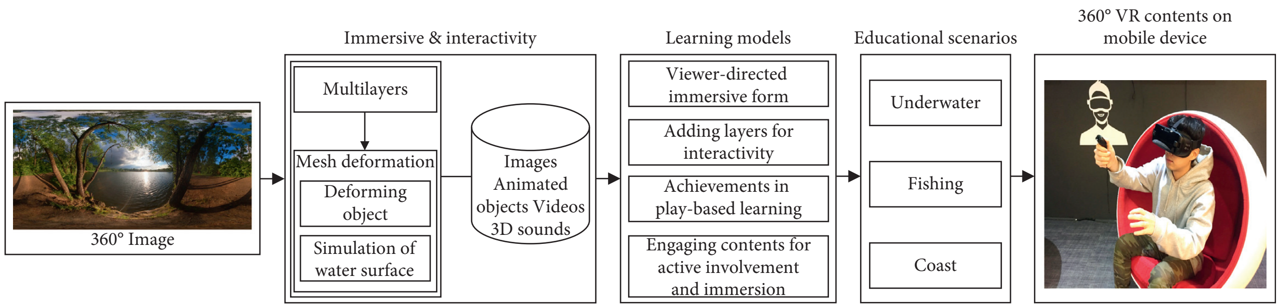


FIGURE 1: Overall pipeline of our play-based learning for education in marine biology.

2.4. Measurement of Immersive Experience. The measurement of immersion in virtual environments has been studied for a long time, mainly in the field of games [25]. GEQ [26] has been widely used as a method for measuring user engagement in games. Recently, a more accurate method to measure immersion in a virtual environment has been proposed in which 10 rating scales and 87 questions are used to show the reliability of the questionnaire [27]. We verify the effectiveness of our framework using the questions corresponding to the flow, immersion, presence, emotion, and judgment among the presented 10 scales.

3. Interactivity and Immersion of 360° VR Contents

In this section, we present methods to improve the interactivity and immersion of mobile VR contents using 360° photographs and videos for education in marine biology.

3.1. Interactive 360° VR Contents with Multiple Layers. Watching 360° contents using a VR headset replaces the user real environment with a simulated one and makes the user feel like he or she is actually there. Thus, 360° panoramic contents create a more immersive experience than regular photographs or videos. However, the viewers can usually look around by moving their head without engaging any interactions because the panoramic contents are generally mapped on a spherical surface as a single layer.

To create more engaging contents, we propose interactive 360° VR contents with multiple layers, as shown in Figure 2. The original input image can be manually segmented by its context such as sky, water, and land by using image tools, and the segmented regions are assigned to different layers. Then, images, animated images, and videos can be added to the original image as separate layers. Images and animated images are usually used for foreground objects, while videos are used for backgrounds. Different interaction properties can be assigned to these multiple layers based on image semantics or user intention. Finally, all the layers are mapped onto each individual sphere. The presented method uses a multilayer representation not only for image composition but also for different types of interactions that enable users to more realistically interact with the 360° panoramic contents.

3.2. Creating Deformable Objects. In our education scenarios for marine biology, interactive image deformation is used to create animation for some objects such as seaweeds and starfish based on transformation of the vertices of a 2D mesh on a particular layer. The resulting visual quality depends on the geometric resolution of the mesh, but mobile devices with limited computational power reduce the maximum achievable quality. Moreover, computationally expensive deformation techniques cause increased latency when the user interacts with the objects within a mobile VR environment. Therefore, we adopt a force-based approach to deform a mesh on a spherical surface, as shown in Figure 3.

The force is attenuated using the inverse proportion of the square of the distance from the center of the force, for example, user picking point p. Attenuated force F_{v} is defined by dividing original force F by one plus the square of the distance, i.e., $1 + d^2$, to ensure that the force is at full strength when the distance is zero.

$$F_{\mathrm{v}} = \frac{F}{1 + d^2}. \tag{1}$$

The force can be converted into acceleration via $a = F/m$, where m is the mass. To simplify, we set mass $m = 1$ for each vertex. Therefore, m is ignored as $a = F$. Then, the change in velocity Δv is defined by Equation (2), where Δt is the time difference:

$$\Delta v = F\Delta t. \tag{2}$$

Vertex velocity V_{v} is computed using Equation (3), where the direction is derived by normalizing the vector that points from the center of the force to the vertex position. The vertices are moved to new positions via $\Delta p = v\Delta t$.

$$V_{v} = \frac{d}{\|d\|}\Delta v. \tag{3}$$

3.3. Realistic Simulation of Water Surface. In our virtual marine contents, realistic simulation of the water surface is an essential method to increase immersion. Real-time performance of the simulation is also required to work with various user interactions in the mobile-based VR environment. To satisfy these requirements, we adopt a physics-based approach to simulate water surface waves by deforming a 2D ocean mesh and implementing it on a graphics processing unit (GPU) hardware. The dynamic

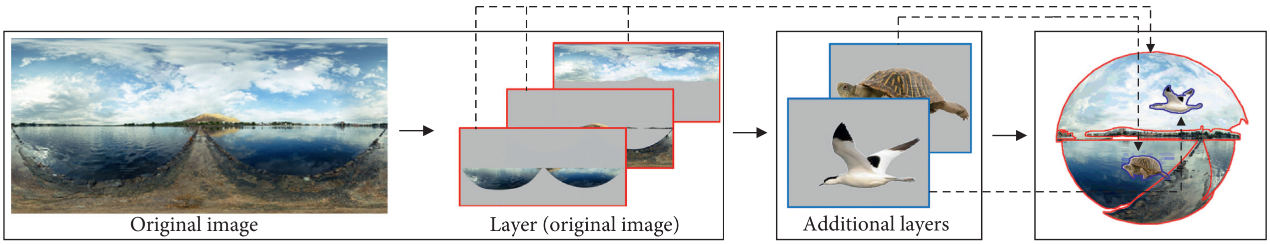


Figure 2: Interactive 360° VR contents with multiple layers.

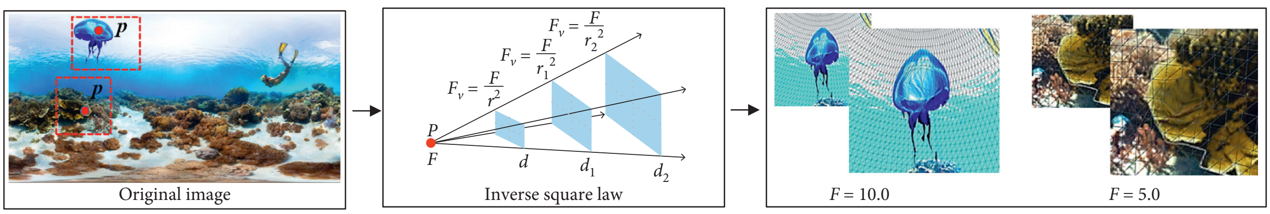


Figure 3: Force-based deformation of a mesh on a spherical surface.

behavior of the water surface, such as the ripple effects, is governed by the following 2D wave equation:

$$\frac{\partial^2 h}{\partial t^2} = c^2\left(\frac{\partial^2 h}{\partial u^2} + \frac{\partial^2 h}{\partial v^2}\right). \tag{4}$$

Equation (4) defines height displacement h on the mesh surface depending on wave speed c. t refers to time, and u and v represent the coordinates of the 2D mesh. To numerically solve this second-order partial differential equation, we discretize it by replacing the partial derivatives with the central differences using a regular spatial grid of spacing ($k = \Delta u = \Delta v$) and a constant time step (Δt), yielding the following equation:

$$\frac{h^{t+1}[i,j] - 2h^t[i,j] + h^{t-1}[i,j]}{\Delta t^2} = c^2\left(\frac{h^t[i+1,j] - 2h^t[i,j] + h^t[i-1,j]}{k^2} + \frac{h^t[i,j+1] - 2h^t[i,j] + h^t[i,j-1]}{k^2}\right). \tag{5}$$

New height displacement h^{t+1} can be explicitly integrated from old displacements h^t and h^{t-1}.

$$h^{t+1}[i,j] = \frac{c^2\Delta t^2}{k^2}\left(h^t[i+1,j] + h^t[i-1,j] + h^t[i,j+1] + h^t[i,j-1] - 4h^t[i,j]\right) + 2h^t[i,j] - h^{t-1}[i,j]. \tag{6}$$

Although this explicit method is fast and easy to implement as a GPU shader, it is only conditionally stable. If the time step becomes very large, the system can become unstable. To increase the stability of the simulation, an artificial attenuation can be added to the new displacement, i.e.,

$$h^{t+1} = \alpha h^{t+1}, \quad \alpha < 1. \tag{7}$$

In our experiments, we set attenuation coefficient α to 0.985 to generate the ripple effects that naturally disappear. Figure 4 shows the results of water simulation in terms of mouse movement and the attenuation coefficients.

3.4. Immersive Experience in Mobile VR Environments. The immersion experience in a mobile VR environment is mainly influenced by the viewing devices and content types, as shown in Figure 5. Because the VR headsets block out all sights of the outside world, watching 360° images or videos using them makes the users more immersed than watching regular photographs or videos. The wide viewing angle of the headset, such as more than 110°, and the higher quality of the visuals, such as more than 4K resolution, as well as the faster and more stable frame rates would result in deeper immersive experience.

Furthermore, wearing headphones makes the users even more immersed by also blocking outside sound. Realistic 3D audio effects on a mobile platform will increase their perception of immersion and reduce the side effects, including headaches and motion sickness. Therefore, the users can focus on the learning objectives in a virtual environment and become active learners.

4. Active Learning Design: Marine Biology Case Study

The learning style of the new generation tends to be more self-directed, engaged, and flexible. Therefore, interactive engagement and active involvement are key elements in digital learning environments for the new generation. The

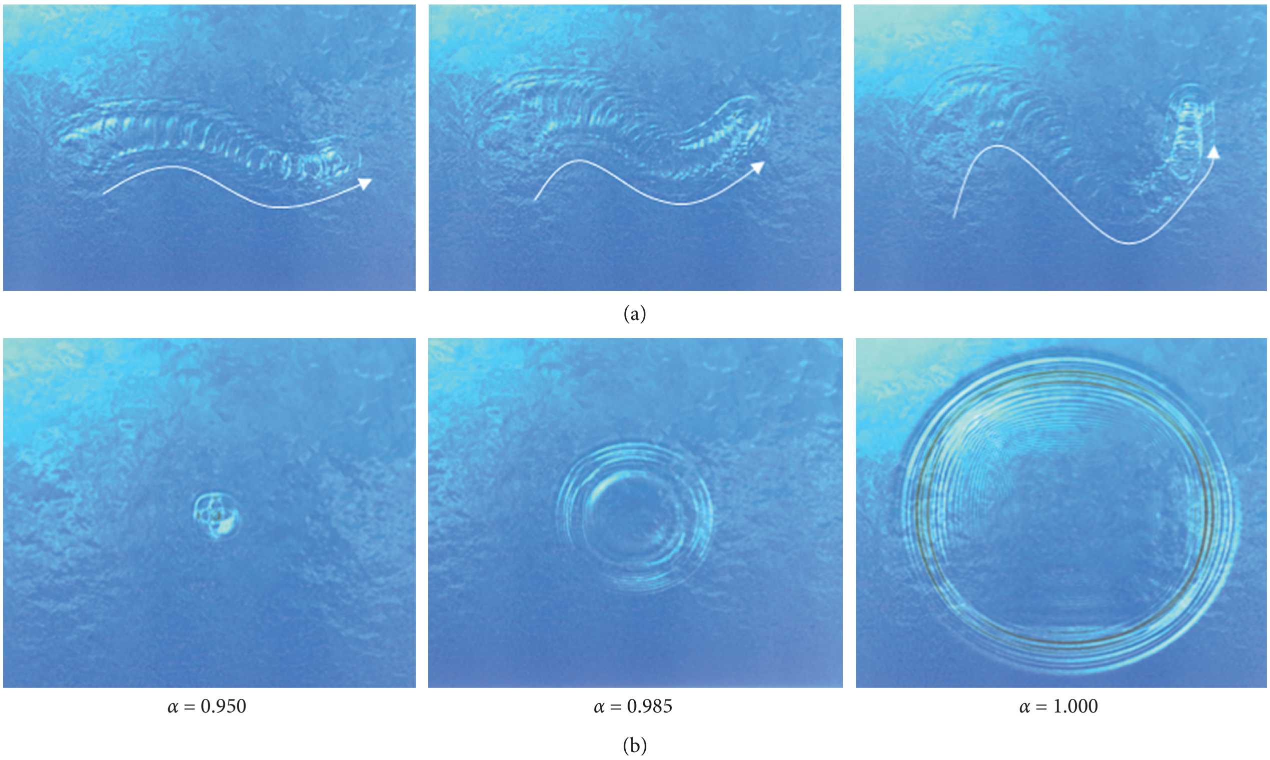


Figure 4: Simulation results of water surface waves in terms of mouse movement (a) and the attenuation coefficients (b).

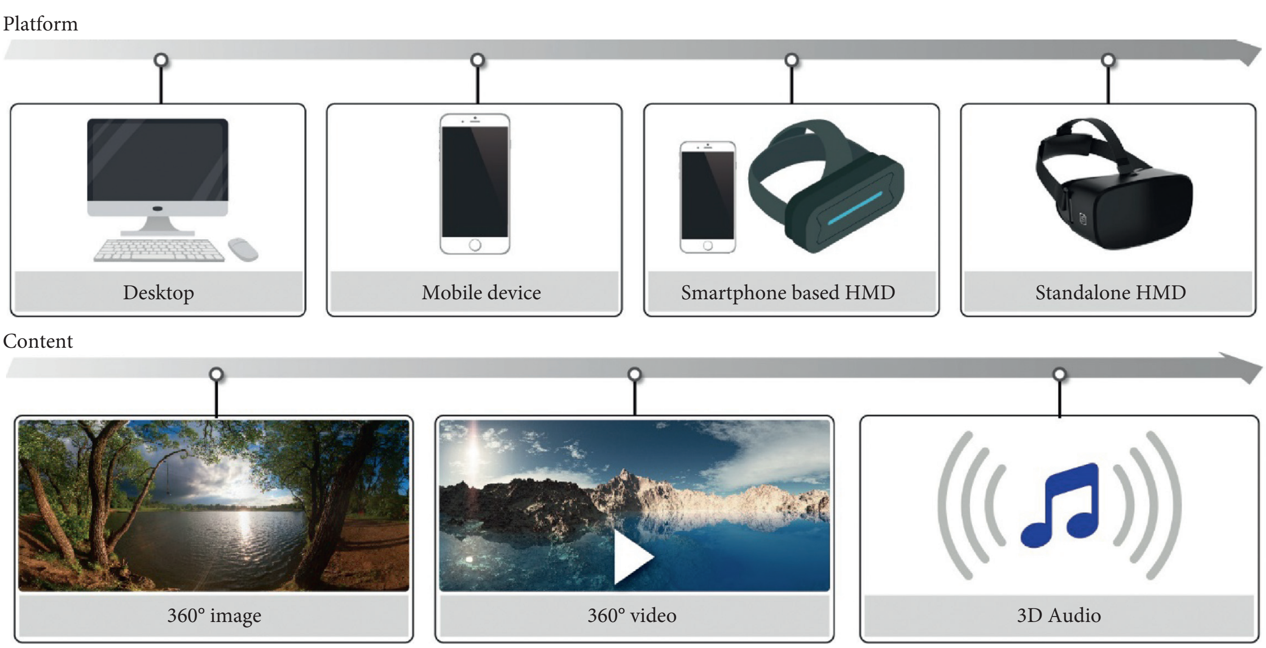


Figure 5: Degree of immersion in terms of viewing devices and content types.

simple forms of mobile VR contents are 360° photographs or videos. When we use the content for educational purpose, lack of interactivity makes the learners become passive in the virtual world. Thus, improvement in the interactivity and immersion in mobile VR contents is crucial to engage learners in the contents and keep them focused and motivated.

For active participant learning, we present play-based learning for education in marine biology. The learning scenarios are designed and implemented as mobile VR environment and allow the users to interact with the immersive mobile VR contents. A low-cost approach to user-created VR contents makes the mobile VR environment potentially learner-centered education to enable learners to create active participant VR contents. The main features of our learning scenarios include viewer-directed immersive form, adding layers for interactivity, achieving play-based learning, and engaging contents for active involvement and immersion.

4.1. Viewer-Directed Immersive Form. The viewer can decide to look at any part of the 360° scenes. The scene can be typically captured from what is around the camera (an outward view) or around an object at different angles (an inward view), as shown in Figure 6. Whereas consumer 360° cameras are mainly focused on outward views, a few apps enable users to capture 360° scenes by having the camera circle around an object. Some cameras simply capture this scene as a hemisphere (a $180° \times 360°$ view), and others can show it as a sphere (a $360° \times 360°$ view). Immersive 360° contents are a valuable tool to create focused learning experience. Figure 7 shows that the user can navigate a 360° marine scene using a VR headset and can control what he or she wishes to view.

4.2. Adding Layers for Interactivity. Layers are a powerful method of creating interactivity and branched stories. For personalized learning, the user can integrate marine plants and animals on additional layers together with animation effects, as shown in Figure 8, which are designed to more engage the learners to the content.

4.3. Achievements in Play-Based Learning. Achievements can be a great means of increasing the learner engagement within the learning content and encourage learners to experiment with features that are not commonly used. In addition, achievements can be a fun way for learners to engage in a light-hearted competition. Figure 9 shows that the adapted picture from [28] illustrates the three zones of marine life according to the depth of the sea, and Figure 10 shows the user interface of our virtual fishing-game scenario. A high score is given to the player when he or she catches the more difficult fish in the deep sea. Table 1 shows the different scoring depending on the marine life zones.

4.4. Engaging Contents for Active Involvement and Immersion. By adding the deformable objects discussed in Section 3.2 on a particular layer or moving objects such as lobsters as shown in Figure 11(a), we can create more interesting contents. During a fishing game, when the player casts a fishing rod, the movement of surface water can be simulated by the method presented in Section 3.3, producing more realistic effects as shown in Figure 11(b). To maximize the immersion, engagement, and learning outcome, we also created marine scenes with head-tracking 3D audio effects and video layers as shown in Figures 11(c) and 11(d).

5. Experiments

We developed the proposed learning framework on a desktop computer using Unity3D engine and then exported the educational scenarios to a mobile VR platform using Samsung Galaxy S7, Gear VR, and a dedicated controller as an interaction tool.

When we created an interactive 360° VR content, the number of vertices in the 3D spherical model for the foreground image layer was very important for realistic mesh deformation. Figure 12 shows that the results using a high-resolution 3D sphere (right) provided smoother interactions than those using a low-resolution 3D sphere (left). Because the realistic interaction methods adopted in this study relatively needed a small amount of computation for mesh processing and used only a simple 3D spherical model compared with the full 3D VR contents, our learning contents were maintained over 60-frame-per-second performance without latency even if we used a 3D spherical model with relatively high resolution.

To verify the effectiveness of the proposed interactive and immersive learning using 360° VR contents, we experimented on three scenarios in marine biology (see scenarios 1–3 in the supplementary materials (available here)), which were created based on the active learning design described in Section 4. In scenario 1, users can explore an underwater environment and interact with diverse marine life on the added deformable image layers. In scenario 2, the users can discover marine life while playing virtual fishing on a boat. In scenario 3, they can learn about the types of fish according to the sea depth while playing a waterside fishing game. When they catch a fish, the detailed information of the fish, such as scientific name and species name, is shown on the billboard, and different scores are given based on the sea depth. Each scenario consisted of three different levels of scenes: (1) simple user-created scenes with multiple layers from different image sources, (2) interactive scenes with animations such as realistic water simulation and deformable objects, and (3) immersive scenes with video layers and 3D audio effects. The participants answered questionnaires on two key VR elements, namely, interactivity and immersion, after finishing their experience in each scenario. Then, we analyzed the response results and evaluated whether the immersion of educational contents increased with the addition of more interactive elements.

For the user study, we used Samsung Galaxy S7, Gear VR, and a dedicated controller. Prior to the user study, the participants were asked about their previous experience in computer usage and VR devices. For a smooth user-study process, the participants used mobile VR devices and controllers for approximately 5 min to adapt to the interaction style. Then, experiments on interactivity and immersion were conducted by randomly choosing two of the three scenarios to keep their concentration on the experiments by limiting the maximum duration to 20 min. Each scenario required approximately 6 min to perform from Levels 1 to 3, and the average time for the experiments took a total of 17 min, including the warm-up time.

In each scenario, Level 1 showed the most basic 360° VR images, whereas Level 2 showed the scene with realistic interactive animation such as moving waves of water and object animation using mesh deformation. In Level 3, the

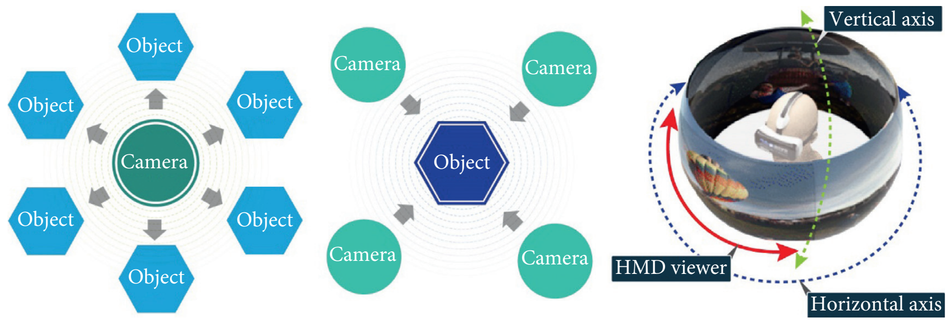


Figure 6: Capture methods for the outward and inward 360° views and navigation of a 360° content.

(a) (b) (c)

Figure 7: The 360° navigation of a boat on the water for virtual fishing.

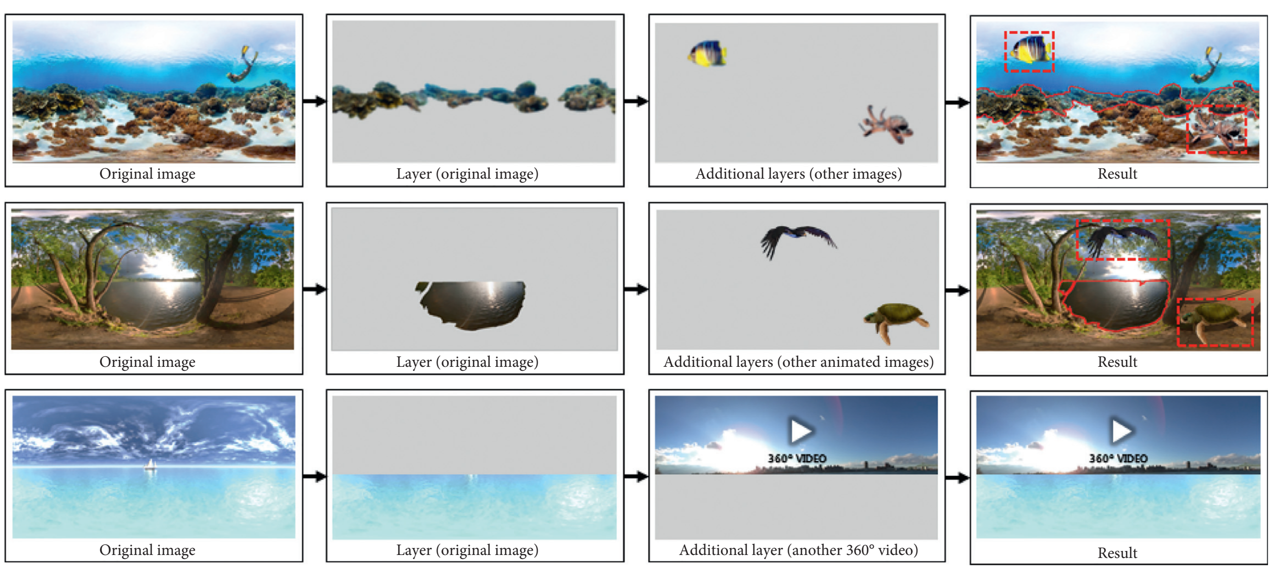


Figure 8: Creating multiple layers for interactive engagement.

scenes could have a video layer as a moving object or background, such as sky and water, and 3D audio effects could be added to enhance the immersive feelings. Table 2 lists the added factors to improve the user-created form, interactivity, and immersion in each learning scenario.

The participants were encouraged to experience the scenes using one or more of the techniques included in each experience category, whichever was selected among the given three scenarios. To compare the interactivity and immersion according to the level of experience, the participants provided points from 1 to 10 (10 is the best) for each experience category after finishing all level experience in each scenario. Then, two different questionnaires in Table 3 were given to measure the interactivity (nine questions) and immersion (17 questions). Twenty-six people who were 14 to 30 years old participated in this user study. We included both, subjects who were familiar with IT and had previous experience in the use of VR and those who were unfamiliar with IT and had no experience of VR, in the user study.

In our experiment, the participants chose Scenario 1 for 20 people, Scenario 2 for 13 people, and Scenario 3 for 19 people. After experiencing the scenarios, they provided score for the interactivity and immersion in each scenario.

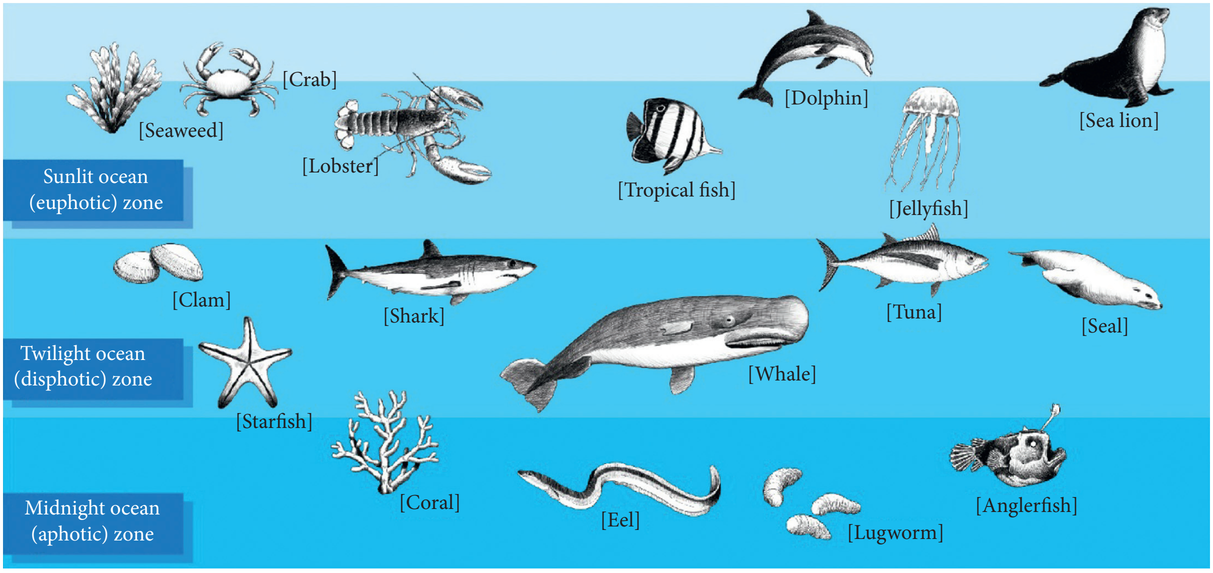


Figure 9: Zones of marine life according to the sea depth.

(a) (b) (c)

Figure 10: Education on marine life through a virtual fishing-game scenario.

Table 1: Different scoring depending on the marine life zones.

Marine organism	Depth	Score
Seaweed, crab, lobster, sea horse, tropical fish, dolphin, jellyfish, and sea lion	Sunlit Ocean (Euphotic) Zone	1
Clam, starfish, shark, whale, tuna, and seal	Twilight Ocean (Disphotic) Zone	3
Coral, eel, lugworm, and anglerfish	Midnight Ocean (Aphotic) Zone	5

Figure 13 shows the results of the average scores and standard deviations according to the level of experience in each scenario. In the interactivity case, the number of immersive elements was shown to increase from Levels 1 to 3. The interactivity also increased in all three scenarios. In the immersion case, Scenario 3 showed the highest scores at Level 1. The reason for this result is that the 3D audio effects were added to Scenario 3 to increase the immersion, and it was not reflected in Scenario 1.

Next, we conducted a survey on the interactivity and immersion for each scenario. The questionnaire for the interactivity consisted of nine questions: four for usability, four for interactivity, and one for immersion. The questionnaire for immersion consisted of 17 questions according to the measurement of user experience in the immersive virtual environment [27]. Our questionnaire consisted of two questions for flow, five for immersion, one for presence, four for emotion, three for judgment, and two for descriptive evaluation of our framework.

We analyzed the response of each participant by calculating the scores. The answers to the positive questions are marked with "P" and the negative questions are marked with "N" in Table 3; we calculated scores according to the 5-point Likert scale (strongly agree = 5, agree = 4, neutral = 3, disagree = 2, and strongly disagree = 1). We also set the scores in the opposite order for the case of negative questions (marked with "N" in Table 3). Thus, we could obtain consistent values from negative and positive responses. The total participant response for each question was calculated as an average score. Then, the average score for each scale was calculated

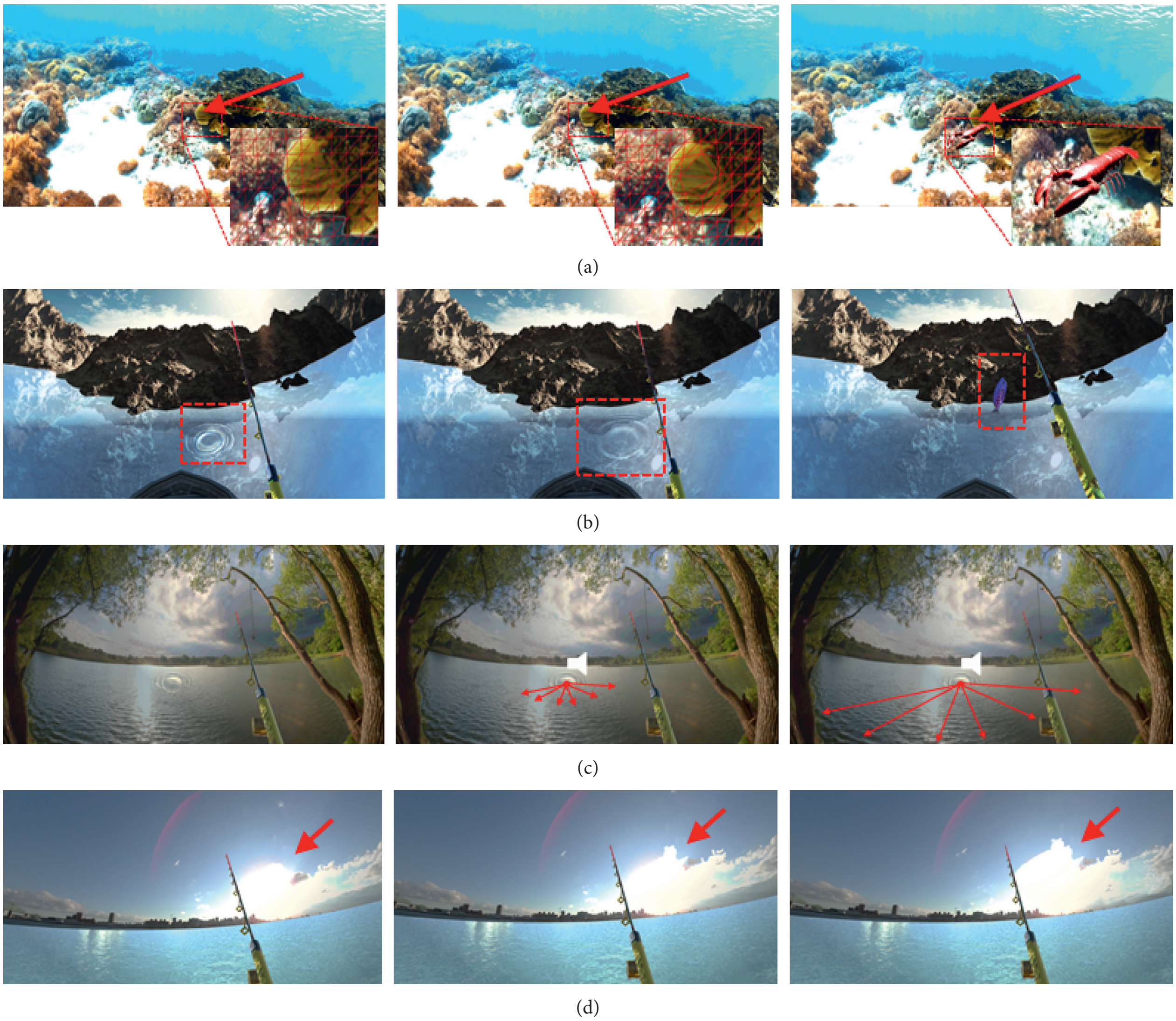


Figure 11: Creating engaging contents. (a) Moving objects, (b) water simulation, (c) 3D audio effects, and (d) video layers.

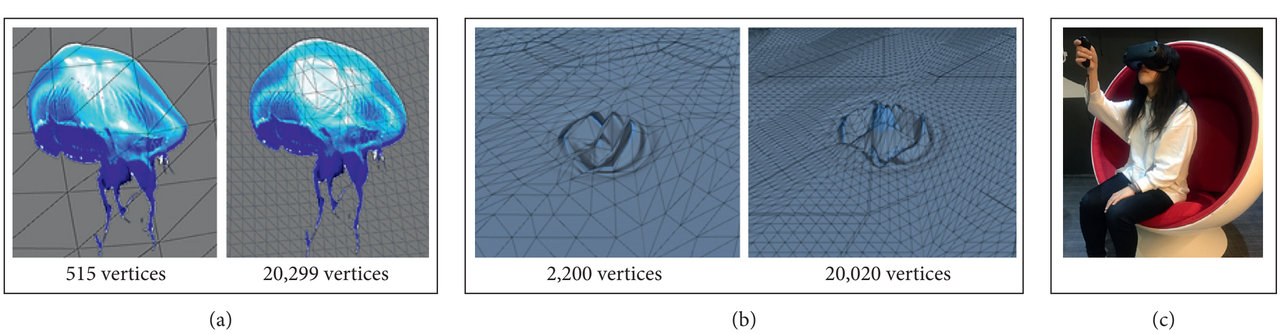


Figure 12: Results of the mesh deformation according to the resolution of spherical models. (a) Deforming objects. (b) Simulation of water surface. (c) VR contents.

according to the number of questions in the scale. Figure 14 shows the evaluation scores and standard deviations of the interactivity and immersion for each scenario according to the different scale, which are marked in Table 3. The reason 'immersion' appears in both interactivity and immersion is that interaction methods or scene elements can affect immersion [27].

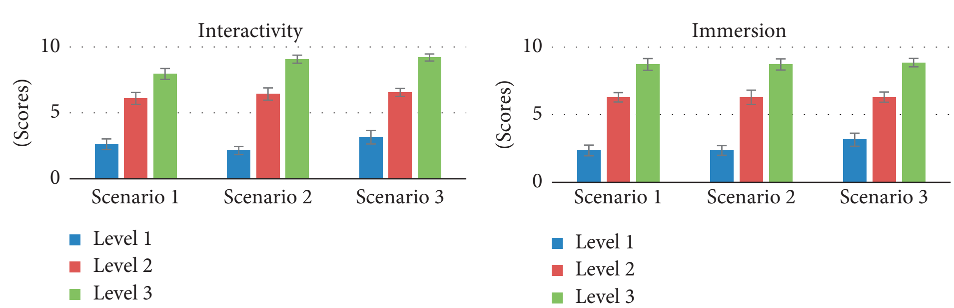
When we analyzed the overall answers, no negative values (less than 3) in all scenarios were obtained that appeared to be a negative response, but standard deviations

Table 2: Techniques for different levels of experience in three scenarios.

Experience	Technique	Scenario 1 (underwater)	Scenario 2 (fishing)	Scenario 3 (coast)
Level 1: user-created scene	Multiple layers	o	o	o
Level 2: interactive scene	Water simulation		o	o
	Physics-based deformation	o		o
Level 3: immersive scene	Image layer (objects)	o	o	o
	Video layer (backgrounds)		o	
	3D audio effects		o	o

Table 3: Questionnaires for interactivity and immersion.

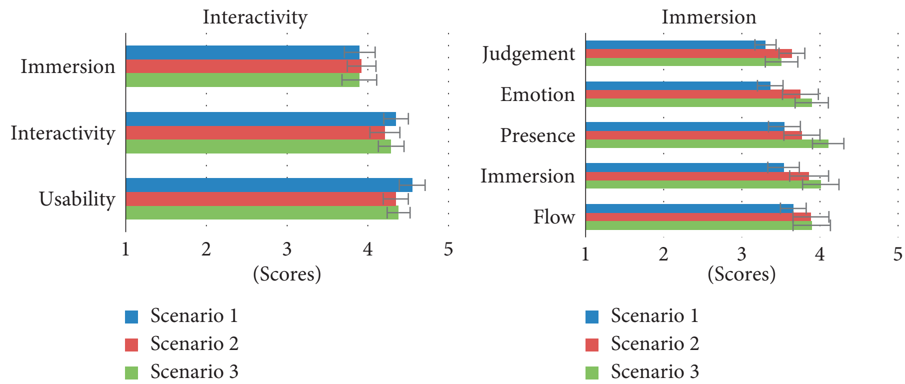
	Scales	
Interactivity		
It was a good time to learn how to control the game	Usability	P
The controller was easy to use	Usability	P
Over time, the controller can be used proficiently	Usability	P
The interaction method was natural	Interactivity	P
The interaction method was clear and easy to understand	Usability	P
It has become possible to interact well over time	Interactivity	P
It was easier to use the controller than traditional input devices (keyboard, mouse, and joystick)	Interactivity	P
Animation (waveform of water, movement of objects) by interaction is reproduced as expected	Interactivity	P
The greater the number of interacting entities, the greater the immersion (depending on the degree of implementation)	Immersion	P
Immersion		
I did not know that the time was running while I was playing the game	Flow	P
After finishing the game play, the time apparently passed faster than expected	Flow	P
I could not figure out what was happening around me while playing the game	Immersion	P
I felt realistic in the configured virtual environment	Presence	P
At some point, I forgot that I had a controller	Immersion	P
I was very immersed in the game	Immersion	P
I needed time to immerse myself in the game	Immersion	N
I tried to get more points (a fishing scenario)	Emotion	P
The game was difficult (a fishing scenario)	Emotion	N
I wanted to stop the game in the middle (a fishing scenario)	Emotion	N
I liked the graphics and images	Emotion	P
Overall, the game was fun	Judgment	P
I want to play the game again	Judgment	P
I would like to recommend it to people	Judgment	P
The sound effect felt like it was real (a scenario with a sound)	Immersion	P
Describe what you liked about the virtual reality content	Description	—
Describe improvements to this content when compared to existing virtual reality content	Description	—



(a) (b)

Figure 13: Average scoring results of the interactivity and immersion for three scenarios according to the different experience levels.

existed among the scenarios depending on the different scale properties. In the questionnaire on interactivity, Scenario 1 showed the highest values in the interactivity and usability scales. We analyzed that Scenario 1 contained a small number of immersive experience elements; thus, it provided a simple interaction style such as touching marine lives



(a) (b)

Figure 14: Average survey results of the interactivity and immersion of three scenarios according to scales.

underwater. From the viewpoint of usability and interactivity, we found that more mixed immersive experience was included, which showed the lower scores in Scenarios 2 and 3, compared to Scenario 1. In the questionnaire about immersion, each scenario was shown to have different characteristics depending on the scale properties. Scenario 2 showed higher judgment and flow, and Scenario 3 exhibited higher scores in the overall scales, except judgment. It shows that as complex immersive experience elements were added, the addition positively influenced the overall scales.

In addition, in the descriptive evaluation, the participants responded that it was good to create realistic user-oriented content and generate natural and realistic animation using mesh deformation. The participants also suggested that the rendering quality in some scenes should be improved and optimized.

6. Conclusions

We have developed an interactive and immersive 360° content-authoring framework for marine biology education. The developed framework is suitable for many students to study using low-cost mobile VR devices because the developed contents can be installed in smartphones or standalone VR equipment. For active participations, we presented user-created forms using additional layers, realistic image-based interactions utilizing elements in the given images, and more immersive contents using animated objects, videos, and 3D audio effects. We conducted a user study to verify the interactivity and immersion of our education scenarios using different levels of experience. As a result, we found that more experience elements improve the immersion of users and make them become more active.

Because the proposed method is processed based on images, creating contents using various low-cost 360° image-capturing devices is easy; thus, it can be utilized not only for educational contents but also for various image-based applications such as marketing and journalism. In the future, the image-based interactions can be improved by applying adaptive mesh deformation to enable more realistic animation depending on the object properties and by automatically segmenting some elements in the images based on the contexts. We will also investigate methods to optimize the presented framework on mobile devices to use more layers and various interactions in an effective manner.

Data Availability

The data used in our paper are 360° images. The 360° images were purchased by a third party license and are applied to "Data Owned by a Third Party" of the Sharing Option. The 360° images data used to support the findings of this study were supplied by Shutterstock under license and so cannot be made freely available. Requests for access to these data should be made to Shutterstock, https://www.shutterstock.com.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2018-2016-0-00312) supervised by the IITP (Institute for Information & communications Technology Promotion).

Supplementary Materials

A video clip including three play-based learning scenarios for marine biology education. (*Supplementary Materials*)

References

[1] J. Martin-Gutiérrez, C. E. Mora, B. Añorbe-Díaz, and A. González-Marrero, "Virtual technologies in education," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 13, no. 2, pp. 469–486, 2017.

[2] H. Hartman and A. Gerard, *User-Generated VR and 360° Imaging—An Overview*, Suite48Analytics, Oakland, CA, USA, 2016.

[3] J. Pirker, "Immersive and engaging forms of virtual learning: new and improved approaches towards engaging and

immersive digital learning," Doctoral dissertation, Graz University of Technology, Graz, Austria, 2017.

[4] T. Cochrane, "Mobile VR in education: from the fringe to the mainstream," *International Journal of Mobile and Blended Learning*, vol. 8, no. 4, pp. 45–60, 2016.

[5] W. T. Lee, H. I. Chen, M. S. Chen, I. C. Shen, and B. Y. Chen, "High-resolution 360 video foveated stitching for real-time VR," *Computer Graphics Forum*, vol. 36, no. 7, pp. 115–123, 2017.

[6] F. Perazzi, A. Sorkine-Hornung, H. Zimmer et al., "Panoramic video from unstructured camera arrays," *Computer Graphics Forum*, vol. 34, no. 2, pp. 57–68, 2015.

[7] J. Kronander, F. Banterle, A. Gardner, E. Miandji, and J. Unger, "Photorealistic rendering of mixed reality scenes," *Computer Graphics Forum*, vol. 34, no. 2, pp. 643–665, 2015.

[8] T. Rhee, L. Petikam, B. Allen, and A. Chalmers, "MR360: mixed reality rendering for 360 panoramic videos," *IEEE Transactions on Visualization and Computer Graphics*, vol. 23, no. 4, pp. 1302–1311, 2017.

[9] K. Rohmer, J. Jendersie, and T. Grosch, "Natural environment illumination: coherent interactive augmented reality for mobile and non-mobile devices," *IEEE Transactions on Visualization and Computer Graphics*, vol. 23, no. 11, pp. 2474–2484, 2017.

[10] J. Lee, B. Kim, K. Kim, Y. Kim, and J. Noh, "Rich360: optimized spherical representation from structured panoramic camera arrays," *ACM Transactions on Graphics (TOG)*, vol. 35, no. 4, pp. 1–11, 2016.

[11] L. A. Neng and T. Chambel, "Get around 360 hypervideo," in *Proceedings of 14th International Academic MindTrek Conference: Envisioning Future Media Environments*, pp. 119–122, ACM, Tampere, Finland, October 2010.

[12] YouTube: https://www.youtube.com/watch?v=-xNN-bJQ4vI&t=42s.

[13] Facebook: https://www.facebook.com/DiscoveryScienceFrance/videos/1369157583160119/.

[14] A. Chalmers, J. J. Choi, and T. Rhee, "Perceptually optimized illumination for seamless composites," in *Proceedings of 22nd Pacific Conference on Computer Graphics and Applications (Pacific Graphics 2014)*, Seoul, South Korea, October 2014.

[15] D. A. Bowman and R. P. McMahan, "Virtual reality: how much immersion is enough?," *Computer*, vol. 40, no. 7, pp. 36–43, 2007.

[16] C. Dede, "Immersive interfaces for engagement and learning," *Science*, vol. 323, no. 5910, pp. 66–69, 2009.

[17] L. Freina and M. Ott, "A literature review on immersive virtual reality in education: state of the art and perspectives," in *Proceedings of International Scientific Conference eLearning and Software for Education (eLSE)*, vol. 1, Bucharest, Romania, 2015.

[18] M. Slater, "A note on presence terminology," *Presence Connect*, vol. 3, no. 3, pp. 1–5, 2003.

[19] Qualcomm, *Making Immersive Virtual Reality Possible in Mobile*, Qualcomm, San Diego, CA, USA, 2016, https://www.qualcomm.com/documents/making-immersive-virtual-reality-possible-mobile.

[20] Q. Sun, L. Y Wei, and A. Kaufman, "Mapping virtual and physical reality," *ACM Transactions on Graphics (TOG)*, vol. 35, no. 4, pp. 1–12, 2016.

[21] Z. C Dong, X. M Fu, C. Zhang, K. Wu, and L. Liu, "Smooth assembled mappings for large-scale real walking," *ACM Transactions on Graphics (TOG)*, vol. 36, no. 6, pp. 1–13, 2017.

[22] S. Tregillus and E. Folmer, "VR-STEP: walking-in-place using inertial sensing for hands free navigation in mobile VR environments," in *Proceedings of CHI Conference on Human Factors in Computing Systems*, pp. 1250–1255, San Jose, CA, USA, May 2016.

[23] Leap Motion: https://www.leapmotion.com/.

[24] Fingo: https://www.usens.com/fingo.

[25] C. Jennett, A. L. Cox, P. Cairns et al., "Measuring and defining the experience of immersion in games," *International Journal of Human Computer Studies*, vol. 66, no. 9, pp. 641–661, 2008.

[26] J. H. Brockmyer, C. M. Fox, K. A. Curtiss, E. McBroom, K. M. Burkhart, and J. N. Pidruzny, "The development of the game engagement questionnaire: a measure of engagement in video game-playing," *Journal of Experimental Social Psychology*, vol. 45, no. 4, pp. 624–634, 2009.

[27] K. Tcha-Tokey, O. Christmann, E. Loup-Escande, and S. Richir, "Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments," *International Journal of Virtual Reality*, vol. 16, no. 1, pp. 33–48, 2016.

[28] W. Kim, *Marine Life: Easy Written Marine Environment and Creatures*, Daewonsa, Sancheong, South Korea, 2014.

Hindawi
Mobile Information Systems
Volume 2018, Article ID 8941241, 10 pages
https://doi.org/10.1155/2018/8941241

Research Article

VR-CPES: A Novel Cyber-Physical Education Systems for Interactive VR Services Based on a Mobile Platform

Hanjin Kim, Heonyeop Shin, Hyeong-su Kim, and Won-Tae Kim

Smart CPS Lab, The Department of Computer Science & Engineering, KOREATECH University, Cheonan, Republic of Korea

Correspondence should be addressed to Won-Tae Kim; wtkim@koreatech.ac.kr

Received 11 May 2018; Revised 7 July 2018; Accepted 6 August 2018; Published 12 September 2018

Academic Editor: Byeong-Seok Shin

The evolution of virtual reality technology allows users to immerse themselves into virtual environments, providing a new experience that is impossible in the real world. The appearance of cyber-physical systems and the Internet of things makes humans to understand and control the real world in detail. The integration of virtual reality into cyber-physical systems and the Internet of things may induce innovative education services in the near future. In this paper, we propose a novel, a virtual reality-based cyber-physical education system for efficient education in a virtual reality on a mobile platform, called VR-CPES. VR-CPES can integrate the real world into virtual reality using cyber-physical systems technology, especially using digital twin. We extract essential service requirements of VR-CPES in terms of delay time in the virtual reality service layer. In order to satisfy the requirements of the network layer, we design a new, real-time network technology interworking software, defined as network and time-sensitive network. A gateway function for the interworking is developed to make protocol level transparency. In addition, a path selection algorithm is proposed to make flexible flow between physical things and cyber things. Finally, a simulation study will be conducted to validate the functionalities and performance in terms of packet loss and delay as defined in the requirements.

1. Introduction

Internet of things (IoT) is a new paradigm that plugs things into the Internet in order to provide various intelligent services to the users. Most of IoT services, such as air conditioning and lighting management, detect the current states of things and environments through sensors and make reasonable decisions based on the data for the specific situations. As the number and functions of the things increase, the relationship between the things has become more complicated. This complexity makes it difficult to monitor and manage the data of things precisely, which leads to difficulties in proper control of things.

Cyber-physical systems (CPS), or *digital twin*, may be a solution for the problem [1]. The digital twin is considered an element of CPS because it means the mirror image of a physical thing. In this paper, we use the term *cyber thing* as the digital twin. CPS has some aspects of IoT in terms of using data of physical things collected through the Internet. The control devices, mechanical body, and corresponding cyber things are connected to fully operate the corresponding physical systems [2]. By virtue of the tight interworking between cyber things and physical things, CPS can be used for many critical applications, including smart city, smart factory, and smart grid, which require accurate analysis and control functionalities based on physical systems and the environments [3–5]. Since cyber things inherit the exact features and states of the physical things, they can be used for accurate estimation, prediction, and control of the physical things by means of dynamics simulations and the other computational means.

The emergence of *virtual reality* (VR) technologies makes it possible to provide services by immersion into computer-generating virtual environments [6]. Currently, most of the VR services are provided in the virtual environment that has no direct relations with the physical environment. Although *augmented reality* (AR) has more information of the real world than VR, it just overlays cyber things or cyber information on the physical things or the physical space. If the cyber thing or space is actually connected to the physical thing or space, users in the cyber space can vividly experience more immersive VR/AR services. Therefore, the integration of CPS and VR/AR empowers the legacy VR/AR services to dramatically enhance the reality and the interactivity with real world [7]. In this paper, we propose a new type of education service called virtual reality-based cyber-physical education system (VR-CPES) to support the VR/AR education services based on CPS.

1.1. Scenario. We introduce a new driver-training service scenario in order to explain, in detail, what VR-CPES can provide for efficient training in wireless/mobile environments. The VR-CPES services are executed on a mobile device, which is a sort of the VR device. A comparison between the advantages of the services implemented in VR-CPES and the existing services execution environments is shown in Table 1.

Figure 1 shows the scenario and architecture of VR-CPES driver-training service. VR-CPES driver training is very safe from risks, such as vehicle accidents. In addition, the constraints of the training caused by the lack of equipment and space are eliminated by virtue of the mobile platform. Subsequently, users can practice in a variety of driving environments, such as where they wanted to practice and where the steering-wheel position changes according to the country. On the physical side, using actual data allows user to practice in a realistic environment because conditions of the vehicle are immediately reflected by temperature, weather, and time changes in the virtual environment. The services listed above require not only generation of the virtual environment, but also interworking of cyber-physical environments. Therefore, the VR-CPES mobile platform needs to satisfy the following requirements.

1.2. Requirements. In this section, we suggest the following requirements to solve the problems shown in the scenario. In VR/AR education services, physical things must be represented in cyber space as cyber things, and the two assets must be interworking. As mentioned above, the cyber things are called the digital twin. A digital twin is a digital replica of a physical thing that conducts all of its functionalities [8]. For example, vehicles, traffic signs, and even people in physical space can be reflected by the digital twin in cyber space. In the general IoT service, the physical things usually gather environment data and use them in mobile devices. However, the physical things in VR-CPES use digital twin models so that monitoring status and management are improved compared with physical things in general IoT [9, 10].

Because VR-CPES uses a digital twin in cyber space, it needs to generate and manage various digital twin models in cyber space, according to various physical spaces. An IoT platform considering a digital twin needs to manage resources of things based on time because physical things should be reflected by the digital twin in real time. A general IoT platform does not sufficiently support such time-based resource management. Moreover, the IoT platform for VR-CPES must consider cloud and edge computing, which is responsible for generating, simulating, and analyzing the digital twin because a single mobile device cannot manage the uncountable resources of the physical thing and digital twin, respectively. In other words, the *quality of experience* (QoE) of a user in VR-CPES is totally related to the interworking of the physical thing and digital twin.

Reliability of VR-CPES increases as the virtual environment and digital twin become more reliable. The reliability of the virtual environment and digital twin is closely related to the seamless interworking of cyber-physical environments. It also depends on a dependable transmission of physical space and physical-thing data. Table 2 shows the network *quality of service* (QoS) requirements for data which is transmitted in VR-CPES. The VR-CPES needs to satisfy QoS requirements for all applications in the cyber-physical environments. Since the main things in our scenario are vehicles and VR devices, we investigated the traffic class based on this [11–13].

In this paper, we propose a novel VR-CPES platform to provide virtual reality contents for efficient education in the mobile environment, as mentioned in the above scenario, and a network framework that can satisfy the requirements for all contents. The remainder of the paper is organized as follows: in Section 2, we summarize IoT platform, SDN, and TSN and describe insufficiency of each technology for the VR-CPES service; in Section 3, we propose the VR-CPES platform by describing each component of the platform and the real-time network framework for seamless VR-CPES service; Section 4 verifies the performance of the proposed real-time network framework; finally, Section 5 concludes this paper.

2. Related Works

2.1. IoT Platform. In order to apply IoT technologies to various domains, such as smart city and health care, IoT platforms are being developed that can adaptively operate in environments where many things need to be monitored and managed [14–16]. In standard organizations, such as oneM2M and OCF design, IoT has standards for the standardized operation of platforms, and these standard-based platforms facilitate the connection of different IoT devices and resource management [17, 18]. Various commercial platforms, such as GE's Predix platform and IBM's Watson IoT platform, are developed as platforms considering the digital twin [19, 20]. They support IoT services for the digital twin using Predix Machine, Asset, and Machine Data Analytics. In addition, multiple technologies have incorporated an IoT platform to replicate physical assets of a digital twin and utilize them [2]. Due to the characteristic of the digital twin that is a digital replica of physical assets, the IoT platforms for the digital twin must consider communication network for seamless data transmission of cyber and physical things.

2.2. Software-Defined Networking. As mentioned above, reliability of VR-CPES is based on dependable data transmission, according to the dynamically changing interconnection of cyber-physical things. *Software-defined*

Table 1: Comparison of driver-training services.

Conditions	Real training	VR simulator	VR-CPES driver training
Safety under training	Low	High	High
Volume of training space	Large	Small	Small
Diversity of training scenario	Low	Middle	High
Reality of training	High	Low	High

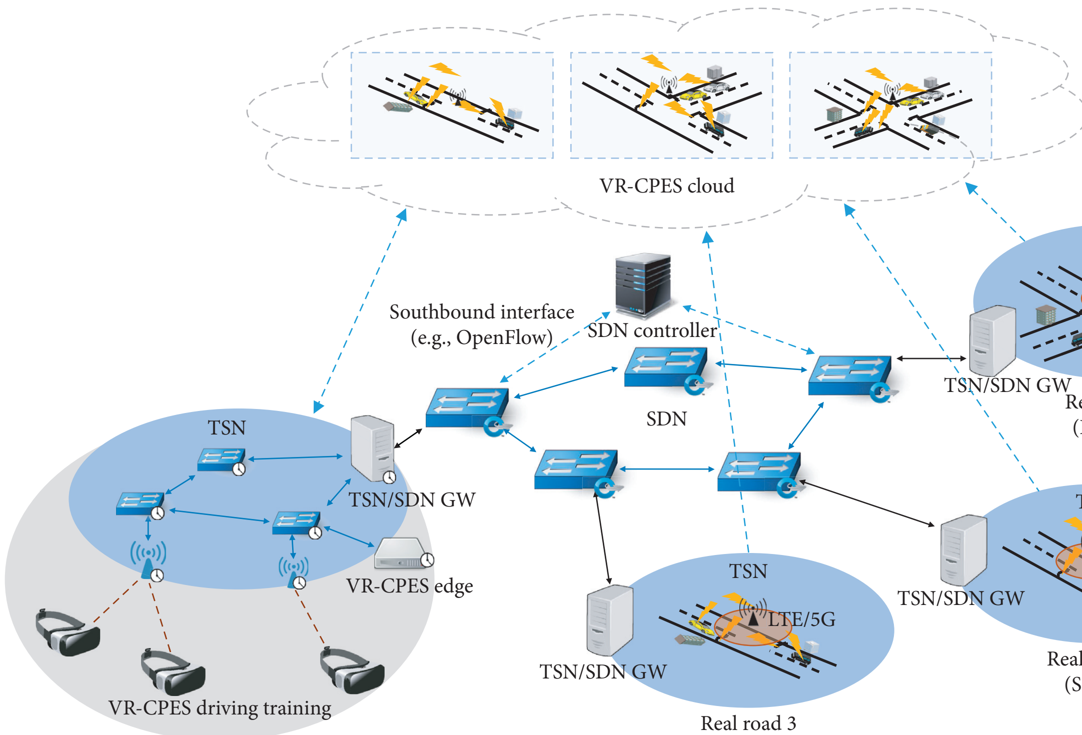


Figure 1: VR-CPES driver-training service.

networking (SDN) is a centralized network technology with a global network view that allows quick and dynamic configuration of the network, depending on the complex quality of service (QoS) of various network applications [21]. The SDN separates the control plane, which determines the network policy, from the data plane, which forwards the actual data. This decoupling of planes abstracts low-level network functionality and higher level service, which facilitates programmable network configuration. This feature is suitable for a large-scale IoT, which, for a network to be configured adaptively, depends on the different network requirements of many things [22]. In the SDN, the control plane receives network information of the data plane from a southbound interface, and the OpenFlow protocol is used dominantly for this operation [23]. The OpenFlow switch can identify all of the layer 2, layer 3, and layer 4 (L2–L4) protocols when configuring the path (i.e., the flow), so the SDN has the advantage of flow configuration in the reconfigurable and heterogeneous network condition [24]. However, it is difficult to calculate proper data transmission paths in systems where control data need to be transmitted with critical network requirements, such as CPS. Various studies have been conducted to extend SDN suitable for these systems [25]. In the network for VR-CPES, it is necessary to transfer data depending on the QoS requirements of different applications, which are simulation for digital twin and VR rendering. In addition, time-based data transmission should be considered for seamless operation of a digital twin and physical thing.

2.3. Time-Sensitive Networking. Time-sensitive networking (TSN) is a set of standards under development by the Time-Sensitive Networking Task Group which is part of the IEEE 802.1 Working Group [26]. In the TSN standard, various technologies, such as time synchronization and frame preemption, are being developed to provide deterministic network service of low latency and low packet loss in ethernet. The predecessor of the TSN standard technology is the audio-video bridging (AVB), which started in the media industry to transmit high-quality audio and video data in real time using a standardized-ethernet network. Subsequently, there has been a requirement to transfer control/management data through the ethernet network in industry domains, such as automotive and factory automation. The standard is being extended to develop a reliable network based on time synchronization for each industry's

Table 2: QoS requirements for applications in VR-CPES.

Traffic class	Bandwidth	End-to-end delay	Jitter
Control data (vehicle)	Low	2.5 ms	Sub-microsecond
Safety data (vehicle)	Medium	45 ms	Sub-microsecond
Infotainment data (vehicle)	High	150 ms	100 ms
Video data (VR)	80 k~50 Mbps	<100~500 ms	<50~150 ms
Audio data (VR)	10~80 kbps	<100 ms	<100 ms

domain network. With the motivations developed to cover the requirements of various industries, TSN is utilized as a network technology in a system that requires transmission of critical control data and high-bandwidth data [27]. In addition, deterministic network technologies of TSN are being applied in the mobile network environment. In particular, the development of a standard for a fronthaul and various studies for mobile networks is in progress to meet the strict reliable low latency communication requirement of 5G network [28]. However, until now, TSN standards have a limitation of local area network due to problems such as time synchronization accuracy. In order to solve it, the IETF is in the process of extending the TSN to the wide-area network under the name DetNet [29], and the VR-CPES service also requires a dynamic and large-scale network environment, so extended technologies of the existing TSN are needed.

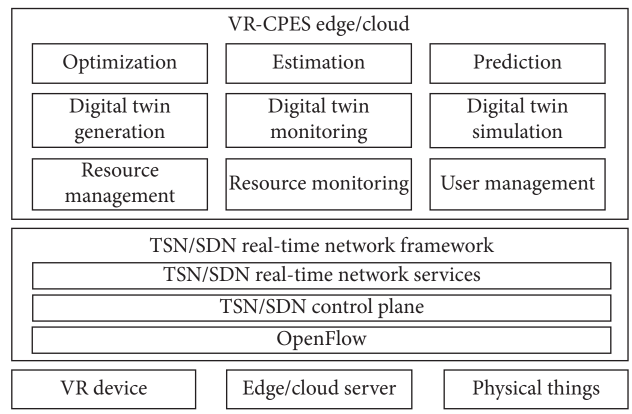


Figure 2: VR-CPES platform.

3. The Proposed VR-CPES Platform

3.1. VR-CPES Platform. The proposed VR-CPES platform is shown in Figure 2. The VR-CPES platform consists of four components: VR device, VR-CPES edge, VR-CPES cloud, and physical things. Each component transmits data through a TSN/SDN real-time network framework, which is described in Section 3.2. For the ease of explanation, we describe the operation of each component of the VR-CPES platform based on the driver-training service scenario in the introduction, as shown in Figure 3.

3.1.1. VR Device. The VR-CPES service should operate by interworking the corresponding vehicle according to the user's operation and the digital twins, which are reflected in the virtual environment from physical space. For this reason, in the VR device, it is very difficult to calculate the results for rendering—such as the perspective view associated with each digital twin according to the user's action—in order to immerse the user in the virtual environment. Therefore, an application that requires high-computing resources, such as a simulation, is operated in the VR-CPES edge and cloud. The VR device transmits only the user's behavior and eye tracking as sensor data and receives external-calculated data of digital twins and the virtual environment and then renders it.

3.1.2. VR-CPES Edge. The VR-CPES edge is a subsimulator for each VR device (i.e., each user). It estimates the commands of the user for the user's digital twin vehicle (DTV), based on the data received from the VR device. Since the VR-CPES training service is intended for the person, it should operate at less than 13 ms, which does not affect human perception [30]. In other words, the control of the corresponding DTV interworking with the movement of the user, which should be executed in real time for the VR experience, needs to be simulated on the VR-CPES edge rather than the cloud. The VR-CPES edge performs simulation by receiving external environment data and previously executed simulation data for the scenario selected by the user in the VR-CPES cloud. The result data of simulation are transmitted back to the VR-CPES cloud and updated for analysis of DTV.

3.1.3. VR-CPES Cloud. The VR-CPES cloud is the main simulator of the VR-CPES platform and performs functions such as management and monitoring of VR-CPES things. In the cloud simulator, virtual environment models and digital twin models are generated based on data collected from physical space. In the VR-CPES cloud, unlike the VR-CPES edge, which considers only the user's DTV, the environment model and other digital twin models must interact with each other in the simulator. Therefore, simulation should be performed in a distributed cosimulation environment, rather than a single simulation environment [31]. Digital twin models are designed and interpreted based on the large amount of physical-space data, so that they can not only optimize the states of the corresponding things, but estimate and predict certain situations for appropriate control. This series of processes requires various analytical techniques, such as stochastic approach, machine learning, AI, and appropriate control theory. The VR-CPES cloud stores these simulated results of each situation, and the data are used as

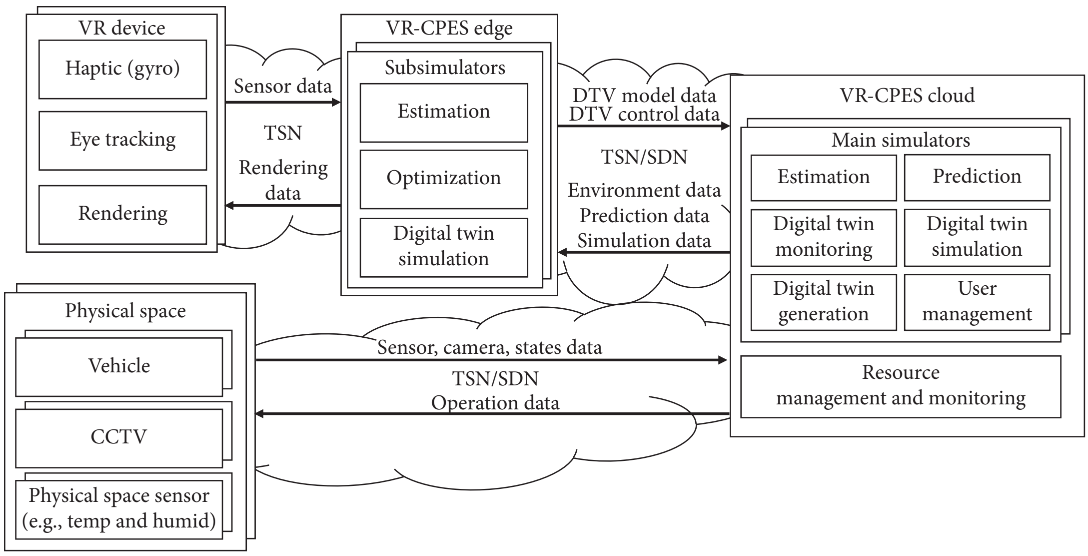


Figure 3: Structure of VR-CPES platform.

external environment input data of the DTV model in VR-CPES edge's subsimulator.

3.1.4. Physical Space. Physical space is a real physical space interworked with virtual reality environments. In a scenario, they are real road environments such as New York, Seoul, and London. Data of physical things that occur in the physical space are transmitted to the VR-CPES cloud and used to generate virtual space. Each physical thing must be utilized as digital twins, not only in the monitoring, but in the simulator. Therefore, unlike legacy IoT platform, real-time data transmission must be considered in VR-CPES platform, and this is supported by TSN/SDN real-time network framework.

3.2. TSN/SDN Real-Time Network Framework (TSRTnet). As mentioned above, the service of the VR-CPES platform requires real-time data transmission for VR experience of users. It can be achieved, not only by resource management according to the QoS of application level in each platform component, but by supporting data transmission according to the QoS of network level. TSN, a standard for real-time data transmission in ethernet networks, transmits data in frame units based on priority. High-priority frames are transmitted in further advance than low-priority frames through a TSN switch, and there are several algorithms to determine how ethernet frames are processed and how priority is assigned. The frames, which require hard real-time data transmission, such as physical states data in the VR-CPES service, are processed based on a time-aware shaper algorithm in TSN [32]. This time-based, scheduled-traffic transmission requires time synchronization between the nodes, which configure the network. The Precision Time Protocol (PTP) is used for time synchronization between nodes under sub-microsecond accuracy by means of hardware timestamps and compensating the time offset considering link delay [33]. In addition, the TSN standards are extended for requirement of time-sensitive applications such as a multiple time domain [34].

The main application for the VR-CPES service runs on the VR-CPES cloud, not on the VR device, which is physically separated from the VR device runtime environment. It means the local network needs to extend to a large-scale network for the user's experience. TSN can guarantee time-sensitive data transmission, but it is limited to less than 7 hops switched network due to the inaccuracy of time synchronization. Although the TSN standard has recently been applied to the factory network considering the connection between TSN nodes based on the centralized network configuration concept in the industrial network, it is still not enough to satisfy the requirements of VR-CPES service [35]. Because it is difficult to practically configure the entire network with homogeneous TSN, we suggest TSN/SDN real-time network framework to plug multiple TSNs into SDN core network.

The structure of TSN/SDN real-time network framework (TSRTnet) for the VR-CPES platform is shown in Figure 4. The architecture consists of TSN/SDN gateways, an SDN controller, and OpenFlow switches. Each TSN is connected to an external SDN through the TSN/SDN gateway, which is managed by the SDN controller.

3.2.1. TSN/SDN Gateway. The TSN/SDN gateway is responsible for connecting the local TSN to the SDN backbone network. In this paper, we assume that the TSN/SDN gateway is capable of processing OpenFlow protocol to communicate with the SDN controller. The TSN nodes register and reserve time-sensitive streams for communication as talker and listener using Stream-Reservation Protocol (SRP). The SRP parameters used for TSN stream management requiring guaranteed QoS are shown in Table 3 [36]. The TSN nodes, such as physical things and the VR device, which need to be communicated with the VR-CPES cloud through SDN, reserve the TSN streams to the

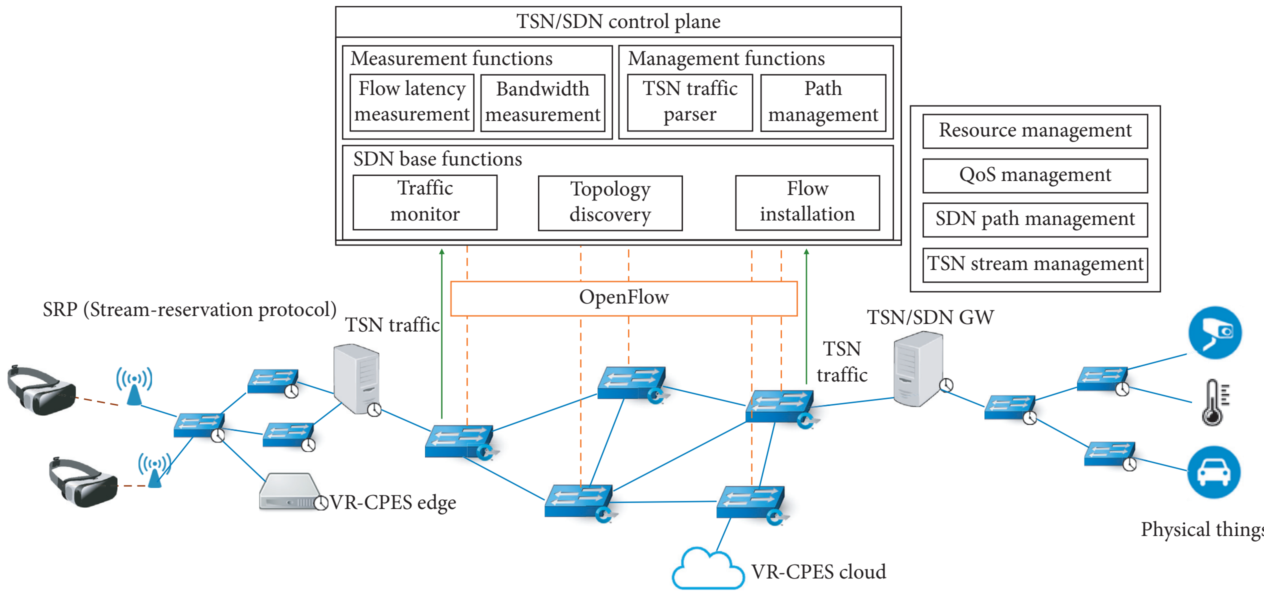


Figure 4: TSN/SDN real-time network framework.

Table 3: Stream-Reservation Protocol parameters.

StreamID	Stream identifier
Stream destination address	Destination address
Stream VLAN ID	VLAN identifier
MaxFrameSize	Traffic specification associated with a stream
MaxIntervalFrames	Traffic specification associated with a stream
Data frame priority	Priority value
AccumulatedLatency	Worst-case latency that a stream can encounter

TSN/SDN gateway by SRP. The TSN/SDN gateway encapsulates the SRP message of the connected node into a packet destined for the VR-CPES cloud. This packet is sent as a packet-in message to the SDN controller, and the SDN controller sets the flow of the SDN by parsing the SRP contained in this message.

3.2.2. SDN Controller. The SDN controller parses the packet-in message received from the TSN/SDN gateway and configures a path to communicate with VR-CPES cloud. The SDN controller has three base functions: traffic monitor, topology discovery, and flow installation. These functions set flows for configuring the path [37]. As the name implies, each function is responsible for monitoring traffic of the data plane, discovering network topology, and installing flow for packet forwarding of the data plane, respectively. Additionally, we designed four SDN functions to forward time-sensitive traffic to SDN core network:

(1) *Flow latency measurement.* This function measures the flow latency of each link to establish a network path according to a requirement of the application's end-to-end delay. The SDN controller has a global view of each flow latency through the latency-measurement function [38]. In this function, the SDN controller measures the latency using Internet Control Message Protocol (ICMP) every second.

(2) *Bandwidth measurement.* This function uses the bandwidth-measurement function to measure available bandwidth (ABW) of i-th link in SDN. Available bandwidth is calculated by the amount of packets forwarding to SDN flow in specific time. The amount of forwarded packets is sent to the controller through FlowStates message, and then the controller calculates available bandwidth using the period time T when the controller receives FlowStates message:

$$b_i(t) = \frac{\text{count}_i(t) - \text{count}_i(t-T)}{T},$$
$$\text{ABW}_i = c_i(1 - b_i). \quad (1)$$

(3) *TSN traffic parser.* This function is parsing the time-sensitive traffic, which is received from TSN/SDN gateway by OpenFlow packet-in message. The SDN controller parses the QoS of applications by checking the SRP parameters and VLAN header. These data are used as QoS information of applications to set a path in a path management function.

(4) *Path management.* Path management function sets path from source to destination based on the calculated latency and bandwidth of flows by measurement functions. Algorithm 1 shows the TSN/SDN path selection algorithm for selecting the candidate path from source to destination. Subsequently, the final path is selected from among the selected paths from Algorithm 1 using a path configuration flowchart. The TSN/SDN path configuration flowchart is shown in Figure 5.

```
Input: N-Network Topology
       S-Source IP
       D-Destination IP
Output: SP-Selected Path List
function PathSelection(N, S, D)
  for i = 1 to A_i do
    P ⟵ DelayCostShortest(N, S, D)
    DeleteList(P, 1)
    DeleteList(P, P_length)
    for i = 1 to P_length do
      RemoveNode(N, P[i])
    end for
    SP[i] ⟵ sort(P)
  end for
  return SP
end function
```

Algorithm 1: Pseudocode of the TSN/SDN path selection algorithm.

3.2.3. TSN/SDN Path Selection Algorithm. The path selection algorithm we propose for TSRTnet is shown in Algorithm 1. In this algorithm, N is the network topology, S is the source IP, and D is the destination IP. The data-stream list to be connected according to application's QoS requirement is represented by A. Again, there are three types of data stream: physical states data, audio data, and video data. The DelayCostShortest function calculates the shortest path from S to D, and N assigns the cost to the link latency [39]. The selected path list as output of algorithm is SP.

3.2.4. TSN/SDN Path Configuration Flowchart. The SDN controller configures the data-stream path as flow in a flow table of SDN core network, using the selected path (SP) list, which is the output of path selection algorithm. DS is a data-stream list, which is the same as A in the path selection algorithm, and it contains the application's QoS requirement. In the VR-CPES service, the TSN data streams are transmitted based on priority, which are identified by VLAN. In the TSN/SDN path configuration, the TSN data stream with highest priority is configured in advance. The SP and DS are ordered according to the highest-priority streams.

3.2.5. OpenFlow Switch Operation by SDN Controller. The SDN controller processes the time-sensitive traffic and management path using OpenFlow protocol. The SDN controller sets the path based on the packet received in the OpenFlow packet-in message, and the path is divided into VLANs. As mentioned above, the QoS requirement of each application is classified by the SRP and VLAN of the TSN in the TSN traffic parser function. We assume that the SDN controller knows the QoS settings of each TSN for path configuration. The SDN controller sets the path, which is chosen from the TSN/SDN path configuration function, as flow using VLAN in the flow table of each OpenFlow switch. If the QoS of the application cannot be satisfied in the network, the SDN controller sends the corresponding fail message to the TSN/SDN gateway.

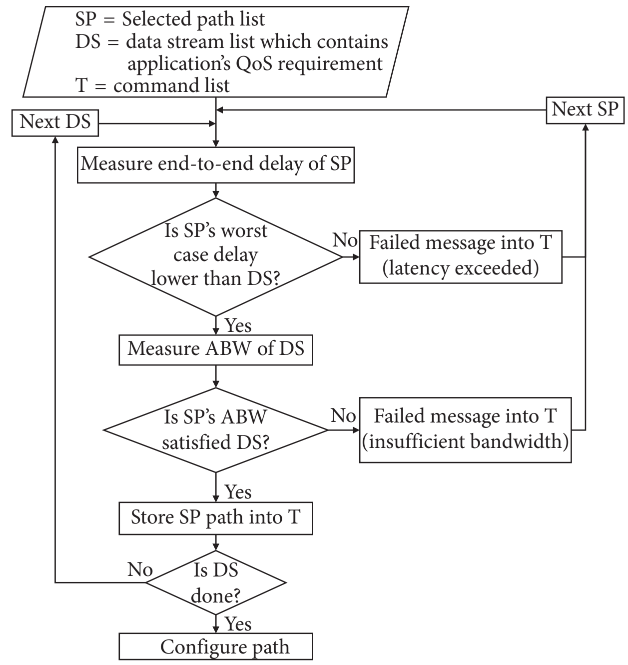


Figure 5: TSN/SDN path configuration.

4. Experiments and Evaluation

In VR-CPES driver-training service, physical states data, audio data, and video data require transmitting in real time, and all QoS requirements in network are mentioned above. To verify the real-time data transmission on the VR-CPES platform, we compared TSRTnet traffic with best-effort traffic. The experiment is performed under the Mininet emulator [40]. Figure 6 shows the network topology of the experiment. In the topology, each link bandwidth is 10 Mbps, and latency is 3 ms. Host 1 (H1) and Host 2 (H2) are the sources, and Host 3 (H3) is the receiver. We consider sources as the TSN/SDN gateways, and the receiver as the VR-CPES cloud of the VR-CPES driver-training service. Both H1 and H2 transmit 6 Mbps TSN streams to H3, which consists of 0.8 Mbps physical states data, 0.2 Mbps audio data, and 5 Mbps video data, respectively.

Figure 7 shows the packet loss of TSRTnet traffic and best-effort traffic. A packet loss that we measured is the sum of the loss packets in all three types of data delivered from the sources H1 and H2 to the receiver H3. In the proposed TSRTnet, the packet loss occurred almost 0% in both H1 (0.4%) and H2 (0.5%), but in the best-effort traffic case, a packet loss of 7% in H1 and 18% in H2 occurred. In the method of TSRTnet, packet loss scarcely occurred in all three data streams because the path is set by comparing the priority and reserving the bandwidth. On the contrary, in the case of best effort, all data are delivered with the same condition, which means they do not consider the QoS requirement. Therefore, the data with the highest bandwidth, such as video data, cause overhead on a certain link, and it incurs a large

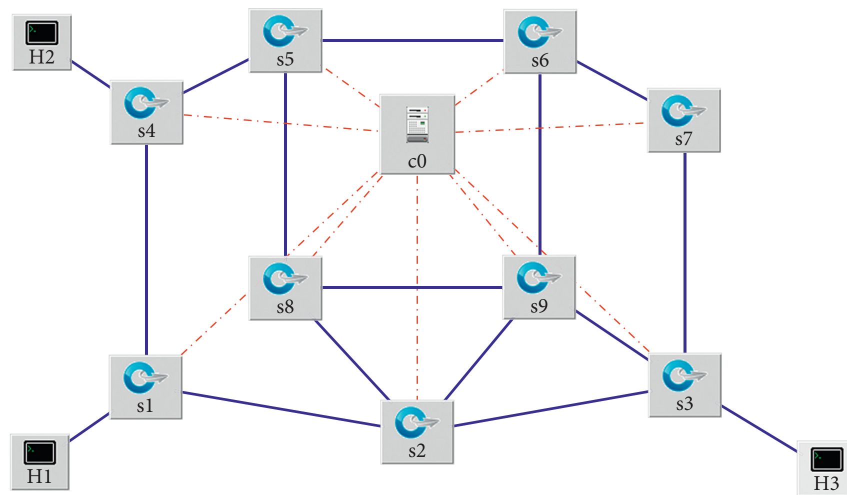


Figure 6: Network topology.

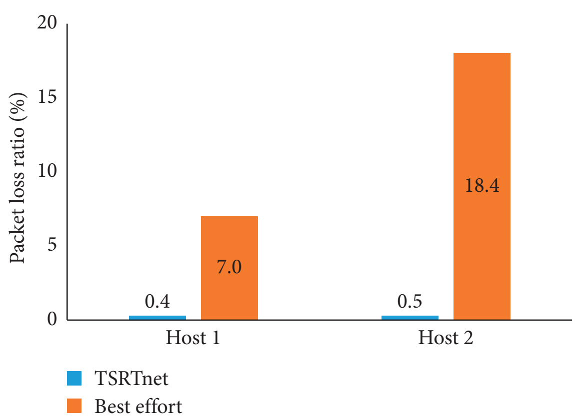


Figure 7: Packet loss of TSRTnet traffic and best-effort traffic.

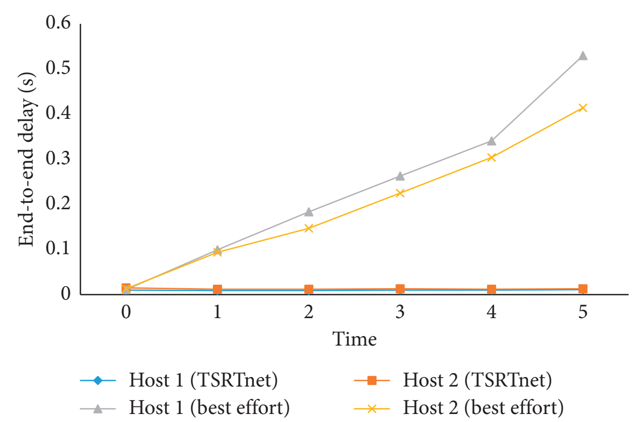


Figure 8: End-to-end delay of TSRTnet traffic and best-effort traffic.

amount of packet loss. The reason why the packet loss of H1 is lower than H2 is because the hop count of H1 is less than H2.

Figure 8 shows the comparison end-to-end delay between TSRTnet and best-effort traffic. In particular, we measured physical states traffic because it is highest priority traffic in our experiment. Both end-to-end delay variations of physical states traffic from H1 and H2 are constant in TSRTnet. Except for the delay due to the initial path configuration, it represents that the delay variation is less than 2 ms. On the contrary, the end-to-end delay of best-effort traffic increases continuously compared with the results from TSRTnet traffic. Until 0.2 seconds before packet loss, the end-to-end delay of best-effort was stable, as with TSRTnet traffic. Since then, however, the best-effort traffic delay for the three types of streams exceeded 100 ms in 1.1 seconds, which means it does not meet the requirements of the video stream with the highest end-to-end delay requirements. In addition, since H1 is close to the receiver, the traffic of H2 caused congestion in the same paths of H1. Consequently, the end-to-end delay of H1 is increased faster than H2.

The results show that the TSRTnet framework is more suitable for the VR-CPES service than the conventional network. As mentioned above, for seamless VR-CPES service, physical-state data, audio data, and video data are transmitted together, which means that data transmission according to complex QoS should be guaranteed in the network. TSRTnet shows almost zero packet loss compared to the conventional network, which transmits data with best effort. Packet loss is closely related to VR service interruption, which has a fatal impact on the user's VR experience. In addition, the constant latency variation of TSRTnet can satisfy the transmission of physical states data for time-critical simulation in VR-CPES.

5. Conclusion

In this paper, we proposed a VR-CPES platform that can provide novel VR-based educational services. VR-CPES platform solves the QoE problem of users caused by delay and loss of data transmission based on TSN/SDN real-time network, which makes time-critical data transmission between cyber things and physical things. Since VR-CPES services require strict time requirements, as well as bandwidth of multimedia and states data of physical things, the time-sensitive network services over the entire network, including core networks and local networks, are essential. The proposed TSN/SDN real-time network framework, called TSRTnet, effectively supports the requirements in terms of packet-loss ratio and end-to-end delay. TSRTnet includes a gateway function for the interworking between SDN core networks and TSN local networks, as well as a path selection algorithm for selecting candidate paths. As a result, TSRTnet showed stable performance of end-to-end delay variation within 2 ms and fewer packet losses compared to conventional best-effort network, which experienced very large delays and higher rates of packet loss.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This paper is partially supported by the Institute for Information and Communications Technology Promotion (IITP) funded by the Ministry of Science and ICT (MSIT) (2015-0-00816-004) and by the National Research Foundation of Korea (NRF) grant (no. 2017010875) from the Korea government.

References

[1] E. A. Lee, “CPS foundations,” in *Proceedings of 47th ACM/IEEE Design Automation Conference on-DAC’10*, pp. 737–742, Anaheim, CA, USA, June 2010.

[2] M. Schluse, M. Priggemeyer, L. Atorf, and J. Rossmann, “Experimentable digital twins—streamlining simulation-based systems engineering for industry 4.0,” *IEEE Transactions on Industrial Informatics*, vol. 14, no. 6, pp. 1722–1731, 2018.

[3] J. Lee, B. Bagheri, and H. A. Kao, “A cyber-physical systems architecture for industry 4.0-based manufacturing systems,” *Manufacturing Letters*, vol. 3, pp. 18–23, 2015.

[4] F. Salim and U. Haque, “Urban computing in the wild: a survey on large scale participation and citizen engagement with ubiquitous computing, cyber physical systems, and internet of things,” *International Journal of Human-Computer Studies*, vol. 81, pp. 31–48, 2015.

[5] X. Yu and Y. Xue, “Smart grids: a cyber–physical systems perspective,” *Proceedings of the IEEE*, vol. 104, no. 5, pp. 1058–1070, 2016.

[6] N. Gavish, T. Gutiérrez, S. Webel et al., “Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks,” *Interactive Learning Environments*, vol. 23, no. 6, pp. 778–798, 2015.

[7] U. H. Govindarajan, A. J. C. Trappey, and C. V. Trappey, “Immersive technology for human-centric cyberphysical systems in complex manufacturing processes: a comprehensive overview of the global patent profile using collective intelligence,” *Complexity*, vol. 2018, Article ID 4283634, 17 pages, 2018.

[8] T. H. J. Uhlemann, C. Lehmann, and R. Steinhilper, “The digital twin: realizing the cyber-physical production system for industry 4.0,” *Procedia CIRP*, vol. 61, pp. 335–340, 2017.

[9] S. Weyer, T. Meyer, M. Ohmer, D. Gorecky, and D. Zühlke, “Future modeling and simulation of CPS-based factories: an example from the automotive industry,” *IFAC-PapersOnLine*, vol. 49, no. 31, pp. 97–102, 2016.

[10] K. M. Alam and A. E. Saddik, “C2PS: A digital twin architecture reference model for the cloud-based cyber-physical systems,” *IEEE Access*, vol. 5, pp. 2050–2062, 2017.

[11] L. Skorin-Kapov, D. Huljenic, D. Mikic, and D. Vilendecic, “Analysis of end-to-end QoS for networked virtual reality services in UMTS,” *IEEE Communications Magazine*, vol. 42, no. 4, pp. 49–55, 2004.

[12] S. Tuohy, M. Glavin, C. Hughes, E. Jones, M. Trivedi, and L. Kilmartin, “Intra-vehicle networks: a review,” *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 2, pp. 534–545, 2015.

[13] Y. Chen, T. Farley, and N. Ye, “QoS requirements of network applications on the Internet,” *Information Knowledge Systems Management*, vol. 4, no. 1, pp. 55–76, 2004.

[14] G. Yang, L. Xie, M. Mäntysalo et al., “A health-IoT platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box,” *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2180–2191, 2014.

[15] R. Lea and M. Blackstock, “City hub: a cloud-based IoT platform for smart cities,” in *Proceedings of 2014 IEEE 6th International Conference on Cloud Computing Technology and Science (CloudCom)*, pp. 799–804, Hong Kong, China, December 2014.

[16] N. H. Motlagh, M. Bagaa, and T. Taleb, “UAV-based IoT platform: a crowd surveillance use case,” *IEEE Communications Magazine*, vol. 55, pp. 128–134, 2017.

[17] oneM2M Standardisation Committee, *oneM2M Release 2 Specifications*, oneM2M, 2016, http://www.onem2m.org/technical/published-drafts.

[18] OIC Specification 1.1, 2016, https://openconnectivity.org/resources/specifications.

[19] GE Predix IoT Platform, 2017, https://www.ge.com/digital/predix.

[20] C. Mercer, *Internet of Things Platforms: Azure, AWS, IBM Watson and More-Which is the Best IoT Platform for Your Business*, Computer World, 2016, https://www.computerworlduk.com/galleries/data/best-internet-of-things-platforms-3635185/.

[21] S. Bera, S. Misra, and A. V. Vasilakos, “Software-defined networking for Internet of things: a survey,” *IEEE Internet of Things Journal*, vol. 4, no. 6, pp. 1994–2008, 2017.

[22] A. Hakiri, P. Berthou, and A. Gokhale, “Publish/subscribe-enabled software defined networking for efficient and scalable IoT communications,” *IEEE Communications Magazine*, vol. 53, no. 3, pp. 48–54, 2015.

[23] ONF, *OpenFlow Switch Specific Version 1.5.1*, Open Networking Foundation, 2015, https://www.opennetworking.org/wp-content/uploads/2014/10/openflow-switch-v1.5.1.pdf.

[24] S. Paris, A. Destounis, L. Maggi, G. S. Paschos, and J. Leguay, “Controlling flow reconfigurations in SDN,” in *Proceedings of IEEE INFOCOM 2016-the 35th Annual IEEE International Conference on Computer Communications*, pp. 1–9, San Francisco, CA, USA, April 2016.

[25] R. W. Skowyra, A. Lapets, A. Bestavros, and A. Kfoury, “Verifiably-safe software-defined networks for CPS,” in *Proceedings of the 2nd ACM International Conference on High*

Confidence Networked Systems, pp. 101–110, Philedelphia, PA, USA, April 2013.
[26] Time-Sensitive Networking Task Group, 2018, http://www.ieee802.org/1/pages/tsn.html.
[27] M. Wollschlaeger, T. Sauter, and J. Jasperneite, "The future of industrial communication: automation networks in the era of the Internet of things and industry 4.0," *IEEE Industrial Electronics Magazine*, vol. 11, no. 1, pp. 17–27, 2017.
[28] D. Chitimalla, K. Kondepu, L. Valcarenghi, M. Tornatore, and B. Mukherjee, "5G fronthaul-latency and jitter studies of CPRI over ethernet," *IEEE/OSA Journal of Optical Communications and Networking*, vol. 9, no. 2, pp. 172–182, 2017.
[29] Deterministic Networking, 2018, https://datatracker.ietf.org/wg/detnet/charter/.
[30] E. Bastug, M. Bennis, M. Médard, and M. Debbah, "Toward interconnected virtual reality: opportunities, challenges, and enablers," *IEEE Communications Magazine*, vol. 55, no. 6, pp. 110–117, 2017.
[31] S. Yun, J. H. Park, and W. Kim, "Data-centric middleware based digital twin platform for dependable cyber-physical systems," in *Proceedings of 2017 Ninth International Conference on Ubiquitous and Future Networks (ICUFN)*, Milan, Italy, July 2017.
[32] IEEE Std. 802.1Qbv, *Standard for Local and Metropolitan Area Networks-Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks Amendment: Enhancements for Scheduled Traffic*, IEEE, Piscataway, NJ, USA, 2016.
[33] IEEE Std. 1588-2008, *Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*, IEEE, Piscataway, NJ, USA, 2008.
[34] IEEE Std. 802.1AS, *IEEE Standard for Local and Metropolitan Area Networks-Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks*, IEEE, Piscataway, NJ, USA, 2010.
[35] IEEE Std. 802.1Qcc, *IEEE Approved Draft Standard for Local and metropolitan Area Networks-Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks Amendment: Stream Reservation Protocol (SRP) Enhancements and Performance Improvements*, IEEE, Piscataway, NJ, USA, 2018.
[36] IEEE. Std 802.1Qat, *IEEE Standard for Local and Metropolitan Area Networks, Virtual Bridged Local Area Networks, Amendment 14: Stream Reservation Protocol*, IEEE, Piscataway, NJ, USA, 2010.
[37] H. S. Kim, S. Yun, H. Kim, H. Shin, and W. Kim, "An efficient SDN multicast architecture for dynamic industrial IoT environments," *Mobile Information Systems*, vol. 2018, Article ID 8482467, 11 pages, 2018.
[38] D. Sinha, K. Haribabu, and S. Balasubramaniam, "Real-time monitoring of network latency in software defined networks," in *Proceedings of 2015 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, pp. 1–3, Kolkata, India, December 2015.
[39] F. Kuipers, T. Korkmaz, M. Krunz, and P. Van Mieghem, "Performance evaluation of constraint-based path selection algorithms," *IEEE Network*, vol. 18, no. 5, pp. 16–23, 2004.
[40] R. L. S. de Oilveira, A. A. Shinoda, C. M. Schweitzer, and L. R. Prete, "Using Mininet for emulation and prototyping software-defined networks," in *Proceedings of the 2014 IEEE Colombian Conference on Communications and Computing (COLCOM)*, pp. 1–6, Bogota, Colombia, June 2014.

Hindawi
Mobile Information Systems
Volume 2018, Article ID 2489149, 9 pages
https://doi.org/10.1155/2018/2489149

Research Article

Design of Evaluation Areas Based on Type of Mobile-Based Virtual Reality Training Content

Mi Kyoung Jin[1] **Hui Jeong Yun,**[2] **and Hye Sun Lee**[3]

[1] *Department of Child Welfare and Studies, Sookmyung Women's University, Seoul, Republic of Korea*
[2] *Center for Teaching and Learning, Sogang University, Seoul, Republic of Korea*
[3] *Department of Education, Sookmyung Women's University, Seoul, Republic of Korea*

Correspondence should be addressed to Mi Kyoung Jin; mkjin12@sookmyung.ac.kr

Received 11 May 2018; Accepted 26 July 2018; Published 19 August 2018

Academic Editor: Sang-Youn Kim

In the field of technology education, virtual reality (VR) training has received significant attention in terms of its efficacy in use. Given its many advantages, there is a specific need to emphasize concrete measures for the implementation of VR training in the field of tech education. VR training based on mobile environments has been touted as a means of not only enhancing presence, flow, and learning authenticity, but also of minimizing spatial and temporal constraints. The present study has developed an evaluation tool for VR training contents, including those based on mobile environments. After categorizing VR training contents in the field of tech education into structure comprehension type, procedure learning type, and equipment experiment type contents, we constructed items for each evaluation area. The considered areas included learning, media, and content quality. By conducting Delphi surveys with a panel of experts, we confirmed that the derived evaluation items differed in number across different types of content. Under the learning area, satisfaction was found to be adequate for all content types. Items such as flow, interactivity, and learning effects were found to be adequate for procedure learning and equipment experiment type contents. The media area indicated marked variability in item adequacy depending on the content type. Usability was found to be adequate only for procedure learning type content. For equipment experiment type content, items such as presence, usability, and manipulability were all found to be adequate. All evaluation items under the content design area were found to be adequate across all content types. Thus, regardless of the type of content, it is necessary to fulfil the basic elements within the content design area in order to establish the efficacy of VR training as educational content in the field of tech education.

1. Introduction

Virtual reality (VR) training has recently been touted as an alternative means of utilizing cutting-edge technology for supplementing/strengthening industrial training. Because of its ability to produce lifelike virtual environments mimicking relevant situations in the fields of manufacturing, defense, health care, and disaster relief, which enables trainees to effectively conduct flow-inducing training/learning within a safer and less expensive setting than actual training, the VR training industry has received attention as a cutting-edge ICT(Information and Communication Technology) convergent industry. Some of the advantages of virtual reality training using cutting-edge ICT technology are cost cutting, enhanced spatial/temporal accessibility, and increase in safety owing to the use of a virtual environment. Furthermore, from the perspective of trainees, VR training has advantages such as participation in actual hands-on training with high on-site relevance and passing down of the experience and know-how of skilled workers. In view of this, VR training has been utilized in diverse industrial fields including medicine, defense, safety, manufacturing/production/construction, education/culture, and sports/leisure. However, the use of VR training in the field of technology education is still in its early stages. In consideration of the multifaceted advantages presented by VR training, there is an urgent need to explore specific methods for increasing the use of VR training in the field of tech education and to improve its effectiveness.

In addition to such technological advances, there is a need to consider methods for designing and utilizing evaluation areas for VR training contents. The evaluation areas and methods of VR training vary depending on the type of industry. For instance, whereas the key evaluation areas in health care and sports/leisure, respectively, are improvement in patient condition and improvement in entertainment or athletic functionality, the key evaluation area in tech industries is improvement in task performance. Therefore, there is a need to consider the unique properties of the tech industry in developing evaluation areas and methods for improving the efficacy of VR training.

In this study, we identify the features that distinguish training via the VR medium from training based on conventional media. By extracting factors that influence the efficacy of training and reflecting them in the development of question items for evaluating the efficacy of VR training, we aim to present an evaluation method for improving the efficacy of VR training contents.

We aim to present evaluation methods for improving the efficacy of VR training contents by developing measures for evaluating their efficacy. Specifically, the purpose of this study is to identify the features of VR training that distinguish it from training based on conventional media and to develop evaluation question items to measure the efficacy of VR training contents by extracting/reflecting upon the factors that influence the efficacy of training.

2. Theoretical Background

2.1. The Mobile Environment and VR Training. VR refers to a new digital environment constituted by digital objects and spaces within a virtual continuum, unlike the real world. The media technology system of VR space is a technological system that allows users the lifelike experience of seeing and interacting with environments that they would seldom experience in everyday life, without having to directly engage with these environments [1].

VR can provide users with a high degree of flow and lifelike presence. Therefore, introducing VR in education and training allows users to achieve higher flow with the training topic, while improving learning efficacy by enabling individualized interactions. It is very effective for providing training for areas that cannot be easily administered via text and 2D materials, for areas with insufficient training materials, or for those involving high-risk/high-cost equipment. Within this context, there has been a rise in the development and adoption of VR training contents for vocational training in the field of technology engineering via experiential/hands-on learning-based training. Due to the nature of technology training, using equipment relevant for actual on-site situations is crucial. However, because such equipment is frequently very expensive and hazardous to handle and operate manually in some cases, they can present numerous risk factors, all of which must be considered during training. VR training has the advantage of allowing trainees to learn repeatedly and safely using actual equipment within lifelike work settings, which enables the trainees to better operate equipment in real-life situations. Furthermore, due to technological changes, the consequent acceleration of the obsolescence cycles of equipment, and the constraints involved in continuously dedicating resources to the provision of new equipment, substituting these with VR training systems can be very effective. In particular, there is a growing demand for experiential/hands-on VR training contents that can replace high-risk/high-cost industrial equipment training [2–4].

The introduction of mobile environments in VR training is also being increasingly emphasized. In particular, because smart learning via mobile environments in learning environments based on 3D-augmented reality technology resolves the spatial/temporal limitations of conventional e-learning while simultaneously providing presence and flow to users, it can open up new possibilities for training services. Other types of training using smart learning include mobile web-based video learning, app-based learning, location-based learning, collaborative learning via social networks, and simulation-type learning via VR and other technologies. In particular, simulation-type learning is seen to improve learners' sense of flow and presence through its emphasis on affinity to on-site learning. VR training via mobile environments has received significant attention due to its ability to enhance authenticity, presence, and flow in learning, as well as its advantages in circumventing spatial and temporal constraints [5, 6].

2.2. The Importance of VR Training Contents in Technology Training. In training situations, VR is a learning tool that can help strengthen immersion and increase the efficacy of education via interaction with objects. It is not only flexible enough to visualize abstract objects beyond realistic constraints, but it also enables learners to gain and share diverse and unique experiences. In particular, in the field of technology training, introducing VR can provide learners with an environment in which they can freely go beyond the constraints of what can be realistically experienced [2].

Some of the expected benefits of introducing VR in technology training are cost saving through the replacement of high-end or high-cost training equipment with VR analogues, enabling online learning via websites, realizing the movements of the internal components of equipment and enabling assembly/disassembly training (differentiated from the training effects of conventional training methods), and enabling trainees to practice equipment maintenance and experience hazardous situations within a safe virtual environment.

2.3. Types of VR Training Contents. In tandem with the growing diversity in the concepts and technological typologies of VR, VR has found applications in a very broad range of fields. In the past, due to its relatively high cost and technologically demanding nature, VR was mainly used in institutes and research labs conducting architectural simulations or military/aerospace experiments and training. More recently, however, due to the diversification of media platforms and the widespread adoption of hardware, the VR market has seen continued growth and a concurrent diversification in the fields that have adopted it. In particular, active discussion is currently being conducted regarding the educational use of simulated 3D VR spaces based on computer and Internet networks that enable interactions between multitudes of users. This draws on the strengths of VR, which enable users to experience high presence and flow.

The development and utilization of VR training contents for experiential/hands-on-based vocational training in the field of technology engineering has seen particularly active growth. Advances in industrial technology have led to the demand for more complex and newer technologies in industrial sites, thus intensifying the importance of tech training.

In response, there has been an increase in the number of studies that review and propose VR training contents suited to the field of technology training. Here, we consider some of the most prominent examples.

First, in a study that aimed to design learning modules in the field of technology training by applying competency-unit elements based on the NCS (National Competency Standards), the types of contents were categorized according to the scope of utilization and manipulation, as well as the characteristics of the VR realization, into the component type, equipment training type, experience type, and simulator type [5]. In another study, previous VR training contents that were developed as specialized coursework for technology training based on the NCS were categorized into three types—the component type, scenario type, and equipment training type [2]. While such content types are meaningful in that they categorize the goals or central functions of VR training contents according to their characteristics, their nomenclature, such as component or scenario type, are not intuitive. Another shortcoming is that their attention is limited to equipment rather than the entirety of the areas pertaining to technology training, such as tools, equipment, and facilities.

Meanwhile, other studies that focused on the types of AR (augmented reality) training contents have categorized the types into tangible AR, mobile AR, and collaborative AR, depending on the realizable characteristics from a technical standpoint. Also, in the present study, we divide AR into general forms of AR and mobile AR, further subdividing the former into the observation/manipulation type and experiment activity type, and the latter into the on-site learning guidance type and the on-site problem solution type [7].

In this study, we present a typology of the VR training contents that are currently in use in vocational training programs (E-KoreaTech, Korea University of Technology and Education) and outlined the characteristics of each type. Through a review of the previous literature [2, 4, 7, 8], we categorized the types of VR training contents for tech education based on their characteristics, meaning how content was utilized for each learning objective. The characteristics of each of the three types of contents are listed below.

2.3.1. Structure Comprehension Type. Through the rendering of precision equipment or facilities, structure comprehension type contents specialize in allowing users to comprehend the internal and external structure of large-scale, microscale, or high-risk equipment. In the case of equipment that is difficult to disassemble, 3D modelling is used to train learners in the role and function of each structure. In this type of content, the most crucial factor is the precision and fidelity with which complex structures are rendered in 3D. Although it is usually impossible to completely disassemble complex equipment, using this type of content enables learners to fully disassemble equipment, thereby facilitating their understanding of equipment structure.

2.3.2. Procedure Learning Type. In the field of tech education, some tasks need to be performed using equipment and in certain sequential steps. Procedure learning type contents enable users to learn the task procedures in sequence with regards to equipment or facilities. By providing content that enables users to learn the steps from equipment startup to shutdown in sequential order, procedure learning type content is useful for the training of equipment functions in each step of the tasks, in addition to providing a safe means of learning how to respond to malfunctions or accident situations. Due to the risks involved, it is often difficult to reenact malfunctions or accident situations in real-life settings. Because of this, trainees usually learn about how to respond to such situations through theoretical learning alone. The use of procedural learning type contents for the training of tasks that require procedural action can be effective in reenacting risky or urgent situations and instructing learners on how to respond to them.

2.3.3. Equipment Experiment Type. Equipment experiment type contents consist of training on how to operate equipment. The greatest strength of such content is that it provides an experimental environment wherein users can operate virtual equipment that may result in various outcomes. Even in the case of high-cost or complex equipment, which often present difficulties in conducting real-life operational training, users of the equipment experiment type VR training contents are able to learn how to properly operate such equipment. Thus, in this type of content, the crucial factor is the realization of the simulative functions so that the virtual equipment will react appropriately to the user's actions in operating them.

2.4. The Evaluation Areas of VR Training Contents. Most studies on the evaluation of VR-based education and training tend to use levels of achievement and satisfaction as indices for measuring learning efficacy. However, considering the characteristics of VR training in the field of tech education, there is a need to supplement measures of knowledge acquisition with behavioral indices such as mastery (i.e., performative proficiency) and applicability to real-life situations. Additionally, satisfaction with education or training refers to a positive affective state that is experienced by the learners as a result of participating in the overall training activity. It is an important index because it is a representative measure of training efficacy while also being a key influencing factor of overall learning outcomes. As subfactors of satisfaction, satisfaction with training in addition to the intention to recommend it to others should be included.

Meanwhile, media characteristics, presence, and flow were found to have significant impacts on learning efficacy [9–13]. In consideration of the unique characteristics of VR-based education and training, we shall include media characteristics, presence, and flow as key evaluative indices. In constructing evaluation items for improving the efficacy of VR training contents in the field of tech education, there is a need to explore the existing literature regarding the contents and evaluation items with respect to the use of online education or VR in general education/training in various fields. Simultaneously, it will also be necessary to emphasize the unique characteristics of VR training in the field of tech education.

To set up the evaluation items regarding VR contents for tech training, it is necessary to consider whether the training has contributed to change or improvement in learner satisfaction or the achievement of learning objectives (Learning Area), whether the characteristics of VR were adequately realized to contribute to better training outcomes (Media Area), and whether adequate consideration was given to the training's unique characteristics content-wise (Content Quality Area).

Thus, in this study, we devised the following three evaluation areas for VR training contents, along with subitems for each area. In order to set up the evaluation items for each area, we searched both domestic and international sources for thesis and academic articles, using VR training and technology education as key words. We extracted evaluation areas that were discussed by previous studies into evaluation item pools. First, for the Learning Area, we reviewed the list of previous studies that evaluated the learning effects of VR-based education [14–16] to establish five evaluation items—Activeness, Learning Satisfaction, Flow, Interactivity, and Learning Effects. For the Media Area, we reviewed previous studies regarding the evaluation of VR media [9, 12, 17–20]. We also broadly reviewed evaluation indices, such as the Igroup Presence Questionnaires (IPQ) [21], Flow State Scale [22], Suitability Evaluation Questionnaire (SEQ) [23], Virtual Experience Test [24], and the User Satisfaction Evaluation Questionnaire (USEQ) [25]. Based on this review, we drew up six evaluation items for the Media Area—Sensory Immersion, Usability, (Media) Satisfaction, Manipulability, Navigability, and Presence. For the final area, the Contents Area, we established three evaluation items—Instructional Design, Teaching and Learning Strategies, and Learning Contents—based on the "Guideline for E-Learning Quality Management" [26].

The concepts regarding these subitems are summarized in Table 1 below.

3. Results and Discussion

3.1. Construction of Evaluation Areas and Items. The evaluation areas of the VR training contents were derived based on the analysis of existing literature.

First, the learning area was constructed to include items for the evaluation of the "training" aspect of the contents. Second, the media area included items relevant to the characteristics of VR as a medium, in order to verify the aspect of "virtuality." Finally, the content quality area included quality management items for e-learning contents [26] that were deemed relevant for this study's purposes, in order to assess the "content" characteristics.

The composition of the evaluation areas and items that were compiled by the authors of this study via literature analysis is presented in Table 2. Specifically, the learning area consists of 5 items, namely, activeness, satisfaction, flow, interactivity, and learning effects. The media area consists of 6 items, namely, sensory immersion, usability, (media) satisfaction, manipulability, navigability, and presence. The content quality area consists of 3 items, namely, instructional design, teaching/learning strategies, and learning contents.

3.2. Evaluation of the Evaluation Items via the Delphi Method. In order to assess the validity of the evaluation items for the VR training contents, analysis was conducted with a 20-person panel of experts using the Delphi method. In accordance with the content validity ratio (CVR) [34], defined here as the ratio of positive responses—4 (adequate) and 5 (very adequate)—on a 5-point scale, values of 0.42 or higher were considered as adequate.

3.2.1. Composition of Expert Panel and Survey Design. The composition of the expert panel reflected the characteristics of the VR training contents. In order to broadly consider matters such as the training goals, the unique properties of virtual training, and the characteristics of the content, the panel consisted of twenty experts from various fields, including five experts in technology engineering, four practitioners in the field of technology, two instructors of content operation, five experts in educational technology, and four experts in educational contents.

The process undertaken in the Delphi study was as follows: The panel of experts, who were selected based on their previous consent, were asked to assess the adequacy of the evaluation areas and items for the VR training contents. The panel also provided suggestions regarding possible modifications to be made to the areas and items. The experts on the panel were presented with the types of VR training contents derived in this study (along with their characteristics and examples), in addition to explanations of the concepts of the evaluation items for each area so as to minimize discrepancies in perception between panel members. The Delphi study was conducted over two rounds, during which experts were asked to suggest modifications for the evaluation areas and items based on their assessment of the adequacy of the question items with which they were presented.

3.2.2. Results of the 1st Round Delphi Study. Results of the 1st round of the Delphi study conducted for assessing the adequacy of the evaluation items indicated different levels of adequacy across content types. The detailed analysis results are presented in Table 3. First, in the case of structure comprehension type contents, the only items that were found to be adequate were satisfaction ($CVR = 0.47$) under

Table 1: Concepts of evaluation items for VR training contents by evaluation area.

Item	Concept
Learning area: items relevant to the learning and/or learner of VR training	
Activeness	Refers to the degree to which the learner is able to take actions by oneself within the realized VR [27].
Learning satisfaction	The most universally used index for measuring learning efficacy. It reflects the extent to which positive educational experiences, such as concentration, relevance, and confidence, were experienced by the learner [11, 12].
Flow	Flow is a psychological state wherein one becomes completely absorbed in a task, to the extent that one loses one's sense of time, space, or even self [28]. The positive sensation wherein a learner is completely immersed in the VR-based learning activity and is thus experiencing it in an optimal manner [18].
Interactivity	The degree to which the learner is permitted to use the system to acquire or access information from the contents [29, 30].
Learning effects	Refers to task applicability (the degree to which the learner applies what they have learned when performing real-life tasks [31]) and mastery (the degree to which VR has contributed to the learner's proficiency in the training subject).
Media area: items relevant to the media characteristics of VR training	
Sensory Immersion	Sensory immersion refers to the degree to which the learner experiences the visual/auditory simulation, namely the degree of virtuality as perceived by the learner [9].
Usability	The ease with which the learner can use the system [32], reflecting the degree of use satisfaction, efficiency, and efficacy conveyed by the experience of the VR environment [20].
(Media) Satisfaction	Satisfaction with the medium is sometimes included as a component of usability. Specifically, it refers to the degree of satisfaction and enjoyment felt upon using a system [33].
Manipulability	Manipulability refers to the learner's ability to manipulate the VR environment. The perceptual state where the learner feels that one is able to freely move and "manipulate" VR objects [9].
Navigability	This refers to the learner's ability to freely explore and interact with the VR space. Navigability reflects the perceptual state where the learner feels that they are able to freely explore and "navigate" within the VR space [9].
Presence	Presence refers to the user's subjective perception of a sense of "being there" within virtual space [10]. It may also refer to the subjective psychological state wherein the user is unaware of experiencing things within a virtual environment [11].
Content quality area: key items relevant to the management of contents utilized in e-learning	
Instructional design	Whether by-level learning, selection of learning elements and materials, screen composition and layout, interface, and session implementation were adequately done [26].
Teaching and learning strategies	Whether teaching/learning strategies, elements of self-directed learning, and motivational strategies were adequately selected [26].
Learning contents	Whether the learning contents, organization, level of difficulty, and study load were adequately selected [26]

Table 2: Composition of evaluation areas and items as derived through literature analysis.

Area	Learning	Media	Content quality
Items	(i) Activeness (ii) Satisfaction (iii) Flow (iv) Interactivity (v) Learning effects	(i) Sensory Immersion (ii) Usability (iii) Satisfaction (iv) Manipulability (v) Navigability (vi) Presence	(i) Instructional design (ii) Teaching/learning strategies (iii) Learning contents

the learning area and usability (CVR = 0.58) under the media area. On the other hand, under the content quality area, all items including instructional design, teaching/learning strategies, and learning contents were found to be adequate for content evaluation. Procedure learning type contents were found to have more adequate evaluation items than the learning area. Thus, all items under the learning area excluding activeness (CVR = 0.26) and sensory immersion (CVR = 0.26), navigability (CVR = −0.05), and presence (CVR = 0.16) under the media items were found to be adequate for evaluation. Finally, in the case of equipment experiment type contents, all evaluation areas and items were found to be adequate for evaluation.

While collecting the views of experts during the 1st round Delphi study for assessing the adequacy of the evaluation items, many experts expressed the need to modify the items of the media area. To prevent overlap between items and improve conciseness, items that shared similarities under the media area, such as sensory immersion and presence, usability and satisfaction, and navigability and manipulability needed to be merged or modified. Furthermore, given the aim of this study, namely, the evaluation of VR training contents, the wording of items under the content quality area were modified from "quality" to "design" and from "instructional" to "content." The list of evaluation areas and items after the modifications suggested by the experts that were incorporated

Table 3: Results of the 1st round Delphi study on the adequacy of the evaluation items by content type.

Category		Structure comprehension			Procedure learning			Equipment experiment		
Area	Item	M	CVR	N	M	CVR	N	M	CVR	N
Learning area	Activeness	3.05	**−0.47**	5 (19)	3.68	**0.26**	12 (19)	4.79	1.00	19 (19)
	Satisfaction	3.89	0.47	14 (19)	3.84	0.47	14 (19)	4.26	0.79	17 (19)
	Flow	3.63	**0.37**	13 (19)	4.06	0.67	15 (18)	4.68	0.89	18 (19)
	Interactivity	3.68	**0.26**	12 (19)	4.11	0.58	15 (19)	4.63	0.79	17 (19)
	Learning effects	4.11	**0.37**	13 (19)	4.32	0.68	16 (19)	4.63	0.89	18 (19)
Media area	Sensory immersion	3.58	**0.26**	12 (19)	3.79	**0.26**	12 (19)	4.63	0.79	17 (19)
	Usability	4.32	0.58	15 (19)	4.37	0.68	16 (19)	4.53	0.79	17 (19)
	Satisfaction	3.95	**0.37**	13 (19)	4.05	0.47	14 (19)	4.42	0.68	16 (19)
	Manipulability	3.47	**−0.05**	9 (19)	4.05	0.47	14 (19)	4.79	1.00	19 (19)
	Navigability	3.89	**0.26**	12 (19)	3.74	**−0.05**	9 (19)	4.11	0.44	13 (18)
	Presence	3.53	**0.16**	11 (19)	3.53	**0.16**	11 (19)	4.42	0.68	16 (19)
Content quality area	Instructional design	4.63	0.89	18 (19)	4.58	0.89	18 (19)	4.63	0.89	18 (19)
	Teaching/learning strategy	4.37	0.68	16 (19)	4.42	0.79	17 (19)	4.47	0.79	17 (19)
	Learning contents	4.37	0.79	17 (19)	4.37	0.79	17 (19)	4.32	0.79	17 (19)

is presented in Table 4, and the newly constructed evaluation areas and concepts for each item are summarized in Table 5.

3.2.3. Results of the 2nd Round Delphi Study. Because some of the evaluation areas and items were modified based on the results of the 1st round Delphi study, in the 2nd round Delphi study, the evaluation items were not discarded based on the content validity values obtained from the 1st round study. However, the content validity values from the 1st round study were presented during the 2nd round Delphi study to inform the responses. The results of the 2nd round Delphi study are presented in Table 6.

Results of the 2nd round Delphi study indicate similar results as those of the 1st round study in terms of structure comprehension type contents. The satisfaction item (CVR = 0.47) under the learning area and the three items under content design, namely, content design (CVR = 0.89), teaching/learning strategies (CVR = 0.68), and learning contents (CVR = 0.68), were found to be adequate for content evaluation. In the case of the media area, all the items that had been found to be adequate in the 1st round Delphi study, including usability, were found to be inadequate. This may be attributable to the fact that because structure comprehension type contents simply aim to convey the structure, role, or function of equipment/facilities, media characteristics such as presence, usability, or manipulability were seen to be relatively less important.

Procedure learning type contents were also found to have similar results to those of the 1st round study. The four items under the learning area, namely, satisfaction, flow, interactivity, and learning effects, except for activeness (CVR = 0) were found to be adequate, while only the usability item (CVR = 0.68) was found to be adequate under the media area. Furthermore, all three items under the content design area were found to be adequate. Thus, given that procedure learning type contents aim to foster proficiency in the operation of equipment/facilities, items such as flow, interactivity, learning effects, and usability were found to be more emphasized than in structure comprehension type contents.

Table 4: Modifications to the evaluation areas and items based on the results of the 1st round Delphi study.

Area	Item	Modified item	Remarks
Learning	Activeness Satisfaction Flow Interactivity Learning effects	*Activeness* *Satisfaction* *Flow* *Interactivity* *Learning effects*	No change
Media	Sensory immersion Presence	*Presence*	Merged
	Usability Satisfaction	*Usability*	Merged
	Manipulability Navigability	*Manipulability*	Merged
Content design	Instructional design	*Content design*	Wording modified
	Teaching/learning strategies Learning contents	*Teaching/learning strategies* *Learning contents*	No change

Finally, in the case of equipment experiment type contents, all evaluation areas and items were found to be adequate. This result is consistent with that of the 1st round Delphi study. Given that equipment experiment type contents aim for mastery rather than comprehension or learning, this result may be interpreted as indicative of the relative importance of the diverse characteristics of VR contents. Thus, based on the results of the Delphi studies conducted over two rounds, we have confirmed differences in the perceived adequacy of evaluation areas and items depending on the type of VR training contents.

4. Construction of Finalized Evaluation Areas and Items by Content Type

Based on the obtained results, we constructed a finalized version of the evaluation areas and items in compliance with the literature analysis and the two rounds of Delphi studies. These are summarized in Table 7. Studying these more

Table 5: Concepts of evaluation items by evaluation area via the Delphi study.

Item	Concept
Learning area	*Items relevant to the learning and/or learner of VR training*
Activeness	Refers to the degree to which the user is able to take actions by oneself within the realized VR.
Satisfaction	The most universally used index for measuring learning efficacy. It reflects the extent to which positive educational experiences, such as concentration, relevance, and confidence, were experienced by the learner.
Flow	The positive sensation wherein a learner is completely immersed in the VR-based learning activity and is thus experiencing it in an optimal manner.
Interactivity	The degree to which the learner is permitted to use the system to acquire or access information from the contents.
Learning effects	Refers to task applicability (the degree to which the learner applies what they have learned in performing real-life tasks) and mastery (the degree to which VR has contributed to the learner's proficiency in the training subject).
Media area	*Items relevant to the media characteristics of VR training*
Presence	The subjective perception where the user experiences a sense of "being there" within virtual space, or the subjective psychological state wherein the user is unaware of experiencing things within a virtual environment.
Usability	The ease with which the learner can use the system, reflecting the degree of use satisfaction, efficiency, and efficacy conveyed by the experience of the VR environment.
Manipulability	The perceptual state where the learner feels that one is able to freely move and "manipulate" VR objects and to freely explore and "navigate" within the VR space.
Content design area	*Key items relevant to the management of contents utilized in e-learning*
Content design	Whether by-level learning, selection of learning elements and materials, screen composition and layout, interface, and session implementation were adequately conducted.
Teaching/learning strategies	Whether teaching/learning strategies, elements of self-directed learning, and motivational strategies were adequately provided.
Learning contents	Whether learning contents, organization, level of difficulty, and study load were adequately selected.

Table 6: Results of the 2nd round Delphi study on the adequacy of evaluation items by content type.

Evaluation area and item		Structure comprehension			Procedure learning			Equipment experiment		
		M	CVR	N	M	CVR	N	M	CVR	N
Learning area	Activeness	2.72	**−0.44**	5 (18)	3.33	**0**	9 (18)	4.89	1	19 (19)
	Satisfaction	4.28	0.56	14 (18)	4.26	0.47	14 (19)	4.58	0.89	18 (19)
	Flow	3.28	**−0.11**	8 (18)	4	0.58	15 (19)	4.63	0.89	18 (19)
	Interactivity	3.28	**0.11**	10 (18)	4.11	0.47	14 (19)	4.79	1	19 (19)
	Learning effects	3.78	**0.22**	11 (18)	4.5	0.78	16 (18)	4.68	0.79	17 (19)
Media area	Presence	3.22	**−0.11**	8 (18)	3.56	**0.22**	11 (18)	4.79	1	19 (19)
	Usability	3.74	**0.37**	13 (19)	4.26	0.68	16 (19)	4.89	1	19 (19)
	Manipulability	3.33	**−0.22**	7 (18)	3.84	**0.37**	13 (19)	4.53	0.79	17 (19)
Content design area	Content design	4.68	0.89	18 (19)	4.68	0.89	18 (19)	4.84	1	19 (19)
	Teaching/learning strategies	4.42	0.68	16 (19)	4.74	1	19 (19)	4.74	0.89	18 (19)
	Learning contents	4.42	0.68	16 (19)	4.47	0.79	17 (19)	4.5	0.89	17 (18)

Table 7: Construction of finalized evaluation areas and items by content type.

Area	Item	Content type		
		Structure comprehension	Procedure learning	Equipment experiment
Learning	Activeness			✓
	Satisfaction	✓	✓	✓
	Flow		✓	✓
	Interactivity		✓	✓
	Learning effects		✓	✓
Media	Presence			✓
	Usability		✓	✓
	Manipulability			✓
Content design	Content design	✓	✓	✓
	Teaching/learning strategies	✓	✓	✓
	Learning contents	✓	✓	✓

closely reveals a marked change in the number of evaluation items that were found to be adequate. First, while only four evaluation items were found to be adequate in the case of structure comprehension type contents, all eleven of the evaluation items for the equipment experiment type contents were found to be adequate.

Reflecting in detail upon the results based on the evaluation items, the satisfaction item under the learning area was found to be adequate for evaluating all types of VR training contents. This indicates that in the case of the learning area, satisfaction is the most basic and representative evaluation item for measuring learners' response to VR training contents. Furthermore, items such as flow, interactivity, and learning effects were found to be adequate for the evaluation of procedure learning type and equipment experiment type contents. On the contrary, the activeness item was found to be adequate only for evaluating equipment experiment type contents, where responses to the operation of contents were emphasized.

The media area demonstrated the most marked variation in adequacy depending on the type of contents. Usability, which was found to be adequate for the evaluation of the most types of contents, included procedure learning type contents and equipment experiment type contents. This highlights the need for media characteristics of VR training contents to crucially consider the ease of use on the part of the learner who will be actually using the contents. On the other hand, items such as presence and manipulability were found to be adequate only for the evaluation of equipment experiment type contents. This suggests that in cases where the aim of VR training extends beyond simple comprehension or experience and includes mastery, there is a need to sufficiently consider factors such as the content's presence or manipulability.

Finally, the three evaluation items under the content design area were found to be adequate for all types of content. This implies that there is a need to consider the basic characteristics of the contents in developing/implementing them, regardless of the type of content.

5. Conclusions

This study was conducted with the aim of developing items for evaluating VR training contents and exploring means for improving their efficacy, by extracting the factors that influence the educational efficacy of mobile-based VR training contents. The adequacy of the evaluation areas and items that were extracted through the analysis of previous literature was assessed through Delphi surveys conducted with experts in each field, and the results thereof were used to derive the evaluation items.

In view of this, some points need to be taken into consideration when utilizing this evaluation tool. First, it should be considered that this tool was constructed such that the items would be selected depending on the type of content to be evaluated. It will be adequately utilized as a tool for assessing the contents' characteristics as a learning tool and for providing feedback. Thus, when utilizing this evaluation tool, it would be appropriate to set it up by selecting evaluation items that suit the type of content.

Second, as a feedback tool for the development and implementation of contents, the evaluation tool presented here could aid in guiding improvements to the contents depending on the evaluation results across each area. By examining the degree of content acceptance across the areas of learning, media, and content design, it would be possible to suggest improvements for each evaluation area.

Third, the results obtained from this evaluation tool may provide guidelines for the design and development of content. For instance, in the case of structure comprehension type content, motivational factors relevant to the experience of learning effects should be prioritized within the learning area, while in the case of equipment experiment type content, consideration must be given to all evaluation items. This is because the virtual experiments may include factors such as structure comprehension as well as procedure learning.

In this study, we assessed the adequacy of evaluation areas and items depending on the type of content. Further studies should extend beyond the assessment of adequacy by also considering the weights assigned to the evaluation areas and items for each type of content. This would allow for the establishment of more concrete standards and evaluation factors for content development.

Data Availability

The statistical data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by Virtual Training Project Grant of the E-KoreaTech in Korea University of Technology and Education (VT-2017-0003). The authors are grateful to a panel of experts who participated for investing time and energy in this project.

References

[1] J.-Y. Han and J.-K. Ahn, "Study on the characteristics of media environment of MRS," *Journal of the Korea Contents Association*, vol. 10, no. 11, pp. 169–179, 2010.

[2] D.-Y. An and H.-K. Park, "Case study on the development and use of technical training contents using virtual reality," *Journal of Practical Engineering Education*, vol. 5, no. 2, pp. 117–122, 2013.

[3] T. Im and S.-Y. Kim, "Virtual reality based total station training content development," *Journal of Digital Contents Society*, vol. 18, no. 4, pp. 631–639, 2017.

[4] E.-J. Song and S.-H. Lee, "A study on NCS-based virtual training content analysis," *Journal of the Korea Institute of Information and Communication Engineering*, vol. 21, no. 3, pp. 651–656, 2017.

[5] J.-Y. Lee, Y.-T. Kim, S.-H. Lee et al., "Mobile augmented reality for smart-learning system," *Journal of Information and Security*, vol. 11, no. 6, pp. 17–23, 2011.

[6] I.-S. Lee, "Proposal on the direction for effective utilization of mobile augmented reality in smart learning," *Journal of Korea Society of Design Forum*, vol. 40, pp. 195–208, 2013.

[7] J.-H. Ryu, I.-H. Jo, H.-O. Heo, J.-H. Kim, and B.-K. Kye, *The Next Generation of Learning Model for Augmented Reality Enhanced in Tangible Interface*, KERIS CR 2006-18, KERIS, Daegu, South Korea, 2006.

[8] C.-D. Koo, H.-S. Yang, and D.-Y. Lee, "The training methods and effectiveness using augmented reality contents system for machine drawings training which is essential in welding practice courses," *Journal of Welding and Joining*, vol. 32, no. 4, pp. 39–45, 2014.

[9] B.-K. Kye, "Investigation on the relationships among media characteristics, presence, flow, and learning effects in augmented reality based learning," Doctoral dissertation, Ewha Women's University, Seoul, South Korea, 2007.

[10] H.-J. Suh, "Relationships among presence, learning flow, attitude toward usability, and learning achievement in an augmented reality interactive learning environment," *Journal of Korean Association for Educational Information and Media*, vol. 14, no. 3, pp. 137–166, 2008.

[11] Y.-H. So, "The impact of academic achievement by presence and flow-mediated variables in a simulation program based on immersive virtual reality," *Journal of Communication Design*, vol. 57, pp. 57–69, 2016.

[12] Y.-H. So, "Relationship with educational effects and medium characteristics in virtual reality learning based on immersion gear VR," *Journal of Communication Design*, vol. 54, pp. 226–237, 2016.

[13] N. Lavroff, *Virtual Reality Playhouse*, Waite Group Press, Corte Madera, CA, USA, 1992.

[14] E.-G. Choi, J.-Y. Kim, S.-H. Shin, and S.-Y. Kim, "A study on the analysis effectiveness of the virtual welding simulator for welding manpower development," *Journal of Welding and Joining*, vol. 33, no. 3, pp. 40–46, 2015.

[15] M. M. Y. Tsang and D. W. K. Man, "A virtual reality-based vocational training system (VRVTS) for people with schizophrenia in vocational rehabilitation," *Schizophrenia Research*, vol. 144, no. 1, pp. 51–62, 2013.

[16] E.-Y. Jung, "Evaluation of practical exercises using an intravenous simulator incorporating virtual reality and haptic technologies," Doctoral dissertation, Ajou University, Suwon, South Korea, 2012.

[17] H.-C. Lee, "The effect of mobile augmented reality application trait on presence, flow experience and consequence," Master's thesis, Sejong University, Seoul, South Korea, 2015.

[18] B.-K. Choi, "Exploring factors of media characteristic influencing flow in virtual worlds based learning," Master's thesis, Korea National University of Education, Cheongju, South Korea, 2011.

[19] H.-M. Eum, "Study of mobile media augmented reality usability evaluation factors for Imaginary fitting experience," Master's thesis, Hongik University, 2015.

[20] J.-W Lee, "(The) attributes of usability test for augmented reality environment," Master's thesis, Hongik University, Seoul, South Korea, 2012.

[21] T. Schubert, F. Friedmann, and H. T. Regenbrecht, "The experience of presence: factor analytic insights," *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 3, pp. 266–281, 2001.

[22] S. A. Jackson and H. Marsh, "Development and validation of a scale to measure optimal experience: The Flow State Scale," *Journal of Sport and Exercise Psychology*, vol. 18, pp. 17–35, 1996.

[23] J. A. Gil-Gómez, H. Gil-Gomez, J. A. Lozano-Quilis, P. Manzano-Hernandez, S. Albiol-Perez, and C. Aula-Valero, "SEQ: suitability evaluation questionnaire for virtual rehabilitation systems. Application in a virtual rehabilitation system for balance rehabilitation," in *Proceedings of 7th International Conference on Pervasive Computing Technologies for Healthcare, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering)*, pp. 335–338, Venice, Italy, May 2013.

[24] D. B. Chertoff, G. Brian, and J. L. Joseph, "Virtual experience test: a virtual environment evaluation questionnaire," in *Proceedings of Virtual Reality Conference (VR)*, pp. 103–110, Waltham, MA, USA, March 2010.

[25] J. A. Gil-Gómez, P. Manzano-Hernández, S. Albiol-Pérez, C. Aula-Valero, H. Gil-Gómez, and J. A. Lozano-Quilis, "USEQ: a short questionnaire for satisfaction evaluation of virtual rehabilitation systems," *Sensors*, vol. 17, no. 7, p. 1589, 2017.

[26] Korea Education and Research Information Service, *E-Learning Quality Management Guidelines for the National e-Learning Quality Assurance Center*, KERIS RR 2006-1, KERIS, Daegu, South South Korea, 2006.

[27] B.-H. Nam and J.-A. Han, "A study on the development of evaluation items for "Sensation of Virtual Reality"," *Archives of Design Research*, vol. 41, pp. 44-45, 2001.

[28] M. Csikszentmihalyi, "Play and intrinsic rewards," *Journal of Humanistic Psychology*, vol. 15, no. 3, pp. 41–63, 1975.

[29] S.-H. Lee, "The effects of ubiquitous attributes of mobile contents on perceived interactivity and behavioral outcome," Doctoral dissertation, Seoul National University, Seoul, South Korea, 2006.

[30] D. R. Fortin and R. R. Dholakia, "Interactivity and vividness effects on social presence and involvement with a web-based advertisement," *Journal of Business Research*, vol. 58, no. 3, pp. 387–396, 2005.

[31] Y.-J. Choi, "A study of the training and development effectiveness for domestic manpower of port using the virtual welding simulator," Master's thesis, Pusan National University, Busan, South Korea, 2014.

[32] J.-H. Choi, "A study on evaluation method of man-machine system usability," Doctoral dissertation, Sungkyunkwan University, Seoul, South Korea, 1997.

[33] J. Nielsen, *Usability Engineering*, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1993.

[34] C. H. Lawshe, "A quantitative approach to content validity," *Personnel Psychology*, vol. 28, no. 4, pp. 563–575, 1975.

Hindawi
Mobile Information Systems
Volume 2018, Article ID 6047034, 8 pages
https://doi.org/10.1155/2018/6047034

Research Article

An Education Application for Teaching Robot Arm Manipulator Concepts Using Augmented Reality

Martín Hernández-Ordoñez,[1,2] **Marco A. Nuño-Maganda**,[3] **Carlos A. Calles-Arriaga**,[3] **Omar Montaño-Rivas**,[4] **and Karla E. Bautista Hernández**[3]

[1]*Instituto Tecnológico Superior de Alvarado, Alvarado, VER, Mexico*
[2]*Instituto Tecnológico de Veracruz, Veracruz, VER, Mexico*
[3]*Universidad Politécnica de Victoria, 87138 Cd. Victoria, TAMPS, Mexico*
[4]*Universidad Politécnica de San Luis Potosí, 78363 San Luis Potosí, SLP, Mexico*

Correspondence should be addressed to Carlos A. Calles-Arriaga; ccallesa@upv.edu.mx

Received 12 May 2018; Accepted 9 July 2018; Published 6 August 2018

Academic Editor: Byeong-Seok Shin

Teaching robotics is a challenge in many universities due to the mathematics concepts used in this area. In recent years, augmented reality has improved learning in several engineering areas. In this paper, a platform for teaching robotic arm manipulation concepts is presented. The system includes a homemade robotic arm, a control system, and the RAR@pp. The RAR@pp is focused on learning robotic arm manipulation algorithms by the detection of markers in the robotic arm and displaying in real time the values based on the data obtained by the control system. Details on the design of the platform are presented, and the related results are discussed. Experimental data about the usability of the application are also shown.

1. Introduction

In the last decade, Information Technologies and Communication (ITC) have spread to all areas of the society. An example of this is the area of learning. The constant changes in the traditional methodology of teaching seek more productive methods, with the goal to improve the learning experience and increase the intellectual level of the students. Currently, the use of mobile devices has continuously been increased. The growth in the demand for cell phones and tablets is due to the evolution of technologies and the implementation of many functionalities. One of the new technologies in development is augmented reality (AR). This technology allows the coexistence of real and virtual objects in the same environment.

Among the different qualities of reality, technology increased its adaptability to a high number of scenarios. Augmented reality, due to its portability and usability, may be implemented in various equipment such as personal computers, mobile devices, and smartphones, among others. Besides, reality technology can be combined with other techniques to enrich the applications, emerging thus a tool to improve the teaching-learning process inside the classroom and laboratories [1]. An area with the potential to implement technology augmented reality is that of robotics since there are issues that require a 3D perception [2]. Nevertheless, traditional teaching methods make use of material didactic in 2D, which makes it difficult to understand these themes. For this reason, the present work shows the implementation of a robotic platform equipped with augmented reality technology. The purpose is to achieve in an educational setting an understanding of robotics topics which are more interactive.

In this work, a platform for teaching robotic arm manipulation concepts is presented. The system includes a homemade robotic arm, a control system, and the RAR@pp (Robotics through Augmented Reality Application). The RAR@pp is focused on learning robotic arm manipulation algorithms by the detection of markers in the robotic arm and the real-time visualization of the angles of each articulation of the homemade robotic arm using augmented reality. These angles are obtained from the robot based on the data obtained by the encoders of each motor and transmitted to the RAR@pp using Bluetooth communication. These applications allow students to send value to the robotic arm and visualize in real time the response of the arm to the com mands using the RAR@pp. This application is specifically designed for mechatronics, information technology, and manufacturing undergraduate programs. The incorporation of augmented reality technology into the mobile application allows real-time viewing of joint angles through virtual objects corresponding to the real angles in the physical platform. The robotic platform is programmed with a reference profile using a desktop application. And by means of a Proportional Integral Derivative controller applied to each joint, it is possible that the robot follows the provided trajectory, allowing the joints to reach the required angles. This paper is structured as follows. In Section 2, a concise review of the state of the art is given. In Section 3, the design and implementation of the proposed system is described. In Section 4, the experimental setup and results are described. Finally, in Section 5, final recalls are established, and future work is outlined.

2. State of the Art

Nowadays, augmented reality represents a potential solution to problems in several areas such as robotics [3], teaching [4], mobile apps [5], or medicine [6]. For instance, Clemente et al. [7] proposed an improvement in sensing feedback of a robotic hand by visual elements. Although other options are typically used as sensors in prostheses such as vibro- or electrotactile stimulations, one advantage of AR implementation is the increase in sensibility resolution and easiness to adapt in the real world. Medical procedures could also be benefited of AR and robotics combination. In [8], a robotic system was proposed for treatment of tumors with the ablation technique. AR implementation helped to increase precision and consistency, which could be reflected in better medical outcomes. Augmented reality can also be used for safety purposes. Quercioli [6] developed a new approach to visualize lasers without any risk to eye damage. The mechanism consists of a modified smartphone camera without the infrared filter and a Google cardboard-type viewer. The system was successfully implemented to obtain real-time images of a Nd:YAG laser and a Ti:sapphire oscillator, both at near-infrared emission which is widely used in medical procedures.

In [2], a desktop application named *Build-A-Robot* was developed to help students to understand the forward kinematics of serial robots arms. The app improves the visualization and configuration of a 3D robotic arm in a controlled (virtual) environment. Jara et al. [9] developed an e-learning system based on a robotic platform and a graphical user interface with an integrated AR module. This platform can be used to control a robot arm through the Internet. The system is capable of planning a path remotely utilizing augmented reality.

In a work oriented to improve students learning, Ibañez et al. [10] developed an electromagnetism experiment using augmented reality (AR). Questions associated with fundamental topics, for example, Coulomb's law, electric field, and Ohm's law, were prepared. A test was carried out in high school students comparing a web-based tool and the AR app in an experimental/control group. Although results showed that the students' outcomes were statistically similar in both cases, the motivation to study was better for the AR app. This factor is also mentioned, along with creativity by Wei at al [4]. This is a very interesting finding since the students' attitude is fundamental during the learning process. Higher education also has a big potential to implement augmented reality as a learning tool. Martín-Gutiérrez et al. [11] developed an app for training students in real electrical labs using AR. One advantage of this work is that it was designed to promote independent as well as collaborative work in laboratories, which could be helpful mainly in engineering environments.

AR has significant growth potential in advanced manufacturing developments; for example, Ni et al. [12] created the haptic robot for programming welding paths. The main advantages of this prototype were a user-friendly interface and the possibility to improve this work through seam tracking sensors. In another work related to programming, Collett and MacDonald [13], design a system to test AR debugging.

Speed of processing is a main concern in mobile applications. Ruan and Jeong [14] proposed and implemented the substitution of traditional markers that elaborated with ARToolkit [15] for the Quick Response (QR) code in an AR system. A related work of applying QR to AR apps was developed by Kan et al. [16]. Barcode has also been used in combination with AR for commercial purposes [17]. AR had also been used for broadcasting enhancement as mentioned by Yan and Hu [18] which in general depends on AR display, AR tracking, and robotic AR broadcast.

3. Proposed System

In this section, the proposed system is described. The system includes three main components: a homemade physical robotic platform, a 2 DoF robotic arm, and the required hardware for moving the robotic arm, including a control module which receives signals from desktop application and sends back the angles obtained by the encoders of the robotic arm. The second component is the desktop application, focused on allowing students to prototype different control algorithms, and the last one is the RAR@pp, for the visualization of the angles in real time.

The dataflow of the proposed system is shown in Figure 1. The details of each component are described below:

(1) The desktop application sends commands to the robotic arm control using a USB serial protocol.

(2) The robotic arm control sends back the angles of each articulation, and these angles are used for plotting a comparison graph between desired and real path. The robotic control generates the

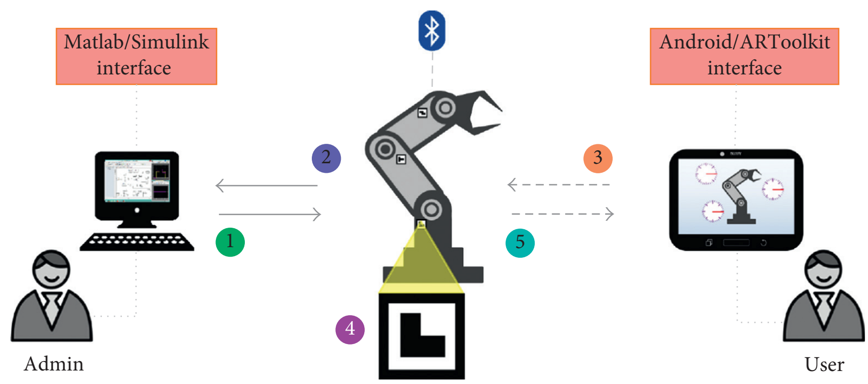


FIGURE 1: Main components and dataflow of the proposed system.

movement commands for each articulation, based on the information obtained from the desktop application.

(3) The mobile application sends a connection request to the robotic arm using a Bluetooth channel. The robotic arm receives this request and grants the connection. Once the connection is established, the mobile application identifies the markers located in the robot arm and sends a request to the robotic arm controller.

(4) Each robot articulation has a marker. In this specific case, due to the design of the robotic arm, only two markers were used, but this design can be extended to robotic arms with more than two articulations.

(5) The mobile application receives the degree of each articulation and displays them using a virtual degree protractor.

3.1. Main Blocks of the Desktop App. The desktop application is designed for sending commands to the control system of the robotic arm using a serial USB connection and gets feedback about the angle of each articulation. This application was developed using Matlab/Simulink®, and the position of each articulation was independently programmed using a proportional-integral-derivative (PID) control. The desktop application also allows the user to perform simulation and generates comparison plots between real and desired trajectory, taking as input the times and angles for each articulation.

3.2. Main Blocks of the Control Module. In Figure 2, a flow diagram including the software routines of the control module is shown. These software modules are hosted on an Arduino board, with an HC-05 Bluetooth shield. Each one of these modules is described below:

(i) *Configuration routine*. This module establishes the configuration parameters of both serial connections (Bluetooth and USB), the transfer speeds, and the pin modes required for external communication.

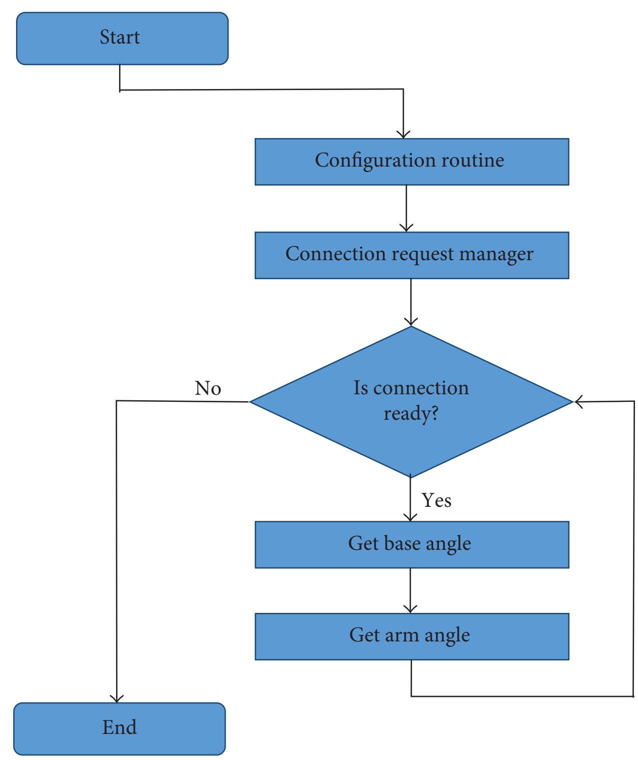


FIGURE 2: Main blocks of the robotic arm control module.

(ii) *Connection request manager*. This module detects if there is at least one connection request by the mobile application or by the desktop application.

(iii) *Get base angle routine*. This module translates the lecture obtained by the encoder located in the base articulation to digital values in order to generate the angle of the base. This angle is sent to the mobile application using the previous Bluetooth connection.

(iv) *Get arm angle routine*. This module translates the lecture obtained by the encoder located in the arm articulation to digital values in order to generate the angle of the arm. This angle is sent to the mobile application using the previous Bluetooth connection.

3.3. Main Blocks of the Mobile App. The main blocks of the mobile application are shown in Figure 3. The details of each block are described below:

(i) *Wireless connection module (WCM)*. This module must allow users to detect if any compatible robot arm Bluetooth connection is available. If it is the first time connection, this module asks the user for linking the device with the platform. Once the platform has been linked, the module is ready to get data from the platform to the application, activating the rest of the application functionalities.

(ii) *Image acquisition module (IAM)*. This module serves as a bridge between the physical sensor and the application. The IAM accesses the camera buffer for accessing the image obtained by the camera sensor.

(iii) *Marker localization module (MLM)*. This module obtains the input video from the IAM and performs the marker localization using the previously obtained data in the training phase for the specific markers located in the platform. Once the marker has been located, then the obtained coordinates are stored and sent to the ARIM.

(iv) *Articulation degree module (ADM)*. This module performs the articulation degree requests depending on the located marker by the MLM. The WCM returns the angles for each located marker and passes to the ARIM.

(v) *Augmented reality integrator module (ARIM)*. This module takes as input the dimensional localization of the marker obtained by the MLM and the degree of each marker obtained by the ADM and generates the final image where the protractor with the obtained angles is overlaid on the image obtained by the IAM. Finally, this image is shown to the user on the device screen.

4. Experimental Setups and Results

4.1. Hardware Tools

(i) Two 12 V DC motors with optical encoders.

(ii) A L298N dual H-bridge motor driver.

(iii) A 12 V 10 A power supply.

(iv) A HC-05 Bluetooth module for communicating Arduino via Bluetooth communication with the AR application.

(v) An Arduino ONE device for hosting the communication modules.

(vi) Homemade robotic arm designed using SolidWorks® and built using material form local providers. The SolidWorks design is shown in Figure 4(a), and the final design is shown in Figure 4(b).

(vii) A mobile device with back camera and Bluetooth adapter. In this device, the developed application is deployed, and several tests were performed in order to validate the localization of the markers and image visualization. The proposed application has been validated on devices with several Android versions. In Table 1, a list of devices used and its specifications used for testing the proposed application are shown. The application worked without problems in the listed devices.

In Figure 5, connections required among the Arduino board, the driver, and the power source are shown. The Arduino board hosts the control module and sends commands to the motor driver, and each motor is connected to the dual motor driver. The Arduino board receives commands for the robot arm from the desktop application through USB connection, and the angles of each arm articulation are sent to the mobile application using Bluetooth USB connection.

4.2. Software Tools. The desktop application was developed using Matlab and Simulink, on a desktop computer with Windows OS.

The mobile application was developed using Android Studio IDE with Android Studio SDK and Java SE Development Kit. The modules of the application were written in Java. In addition, ARToolkit was used for the marker recognition and integration of virtual and real objects in live capture obtained by the camera sensor of the device [15].

4.3. Designed Application. In Figure 6, the base (Figure 6(a)) and arm (Figure 6(b)) markers are shown. These markers were used for training the ARK toolkit classification model for its recognition.

In Figure 7, the desktop application and the mobile application are shown.

In Figure 8, two frames of the obtained angles of each articulation and its visualization in the APP are shown. From the obtained images, it is possible to conclude that the recognition of each marker is performed successfully, and the display of the protractor with the obtained angles is visible in each of the tested angles.

4.4. Time and Angle Results. In order to verify the alignment precision of the two axes (base and shoulder), measurements were carried out using Matlab. Figure 9(a) shows results from base angle trajectories, where the position error ranges from 0.75° to 3.8°. In the case of shoulder axis (Figure 9(b)), variations are from 0.08° to 7.28°. These variations could be reduced by using some control strategies. With respect to time lag between sending the instructions and the display of the response, a delay from 1 to 2 seconds was observed in the experiments.

5. Final Recalls and Future Work

In this paper, an approach for teaching robotic arm manipulator concepts was proposed. The system includes a homemade robotic arm, a control system, and the RAR@pp. The RAR@pp is focused on learning robotic arm manipulation algorithms by the detection of markers in the

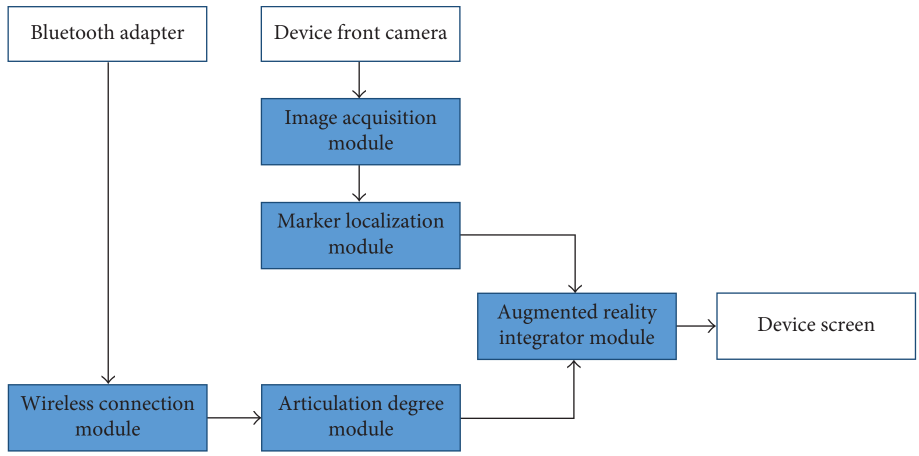
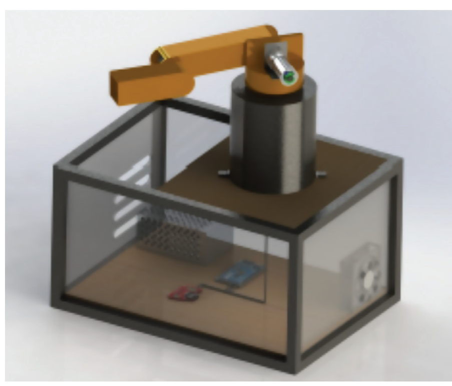
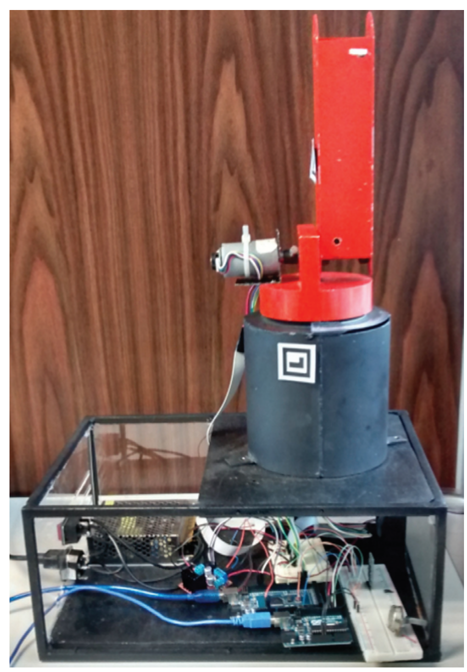


Figure 3: Main blocks of the mobile application.



(a)



(b)

Figure 4: Design and realization of the robotic arm: (a) robotic arm design with SolidWorks; (b) robotic arm prototype.

Table 1: Devices utilized for testing the proposed application.

Device	Processor	RAM	Android version
Galaxy S2	Dual-core 1.2 GHz Cortex-A9	1 GB	4.1
Galaxy S4	Dual-core 1.7 GHz Krait 300	1.5 GB	5.0.1
Polaroid Tab	Dual-core 1.0 GHz Broadcom 21663	1 GB	4.2.2
Galaxy Tab 4	Quad-core 1.2 GHz Marvell PXA1088	3 GB	5.0.2
Galaxy Tab 10.1	Quad-core 2.3 GHz Krait 400	3 GB	5.1.1
LG G3 Stylus	Quad-core 1.3 GHz Cortex-A7	1 GB	5.0.2
Motorola Moto G	Quad-core 1.4 GHz Cortex-A53	1 GB	5.1.1

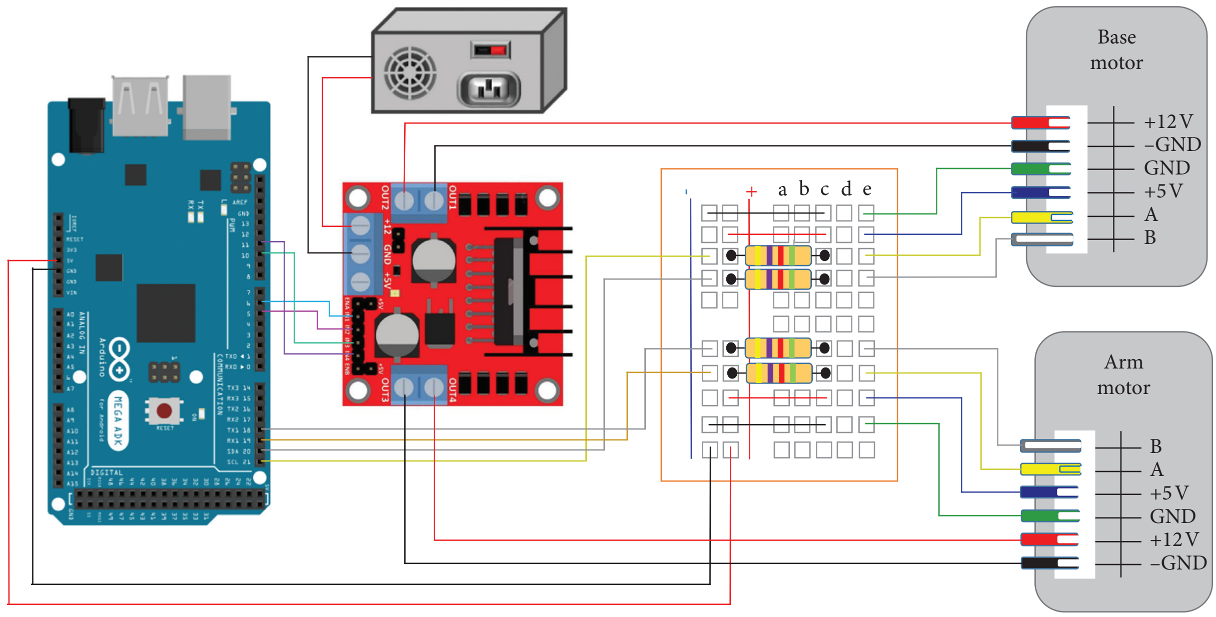


Figure 5: Integration of the components of the control module.

(a) (b)

Figure 6: Marker for the robot arm articulations and localization of each market by the AR demo: (a) base articulation marker; (b) arm articulation marker.

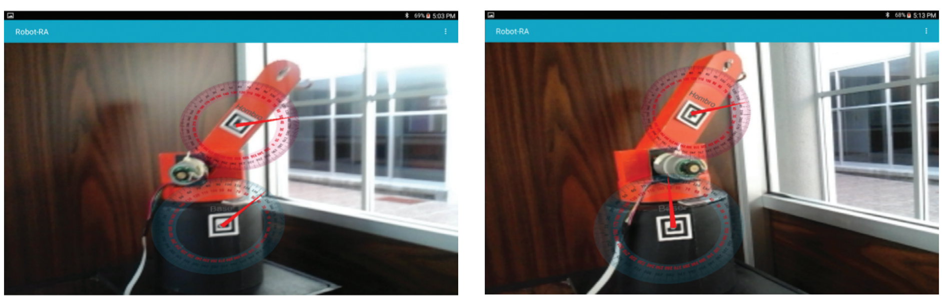
robotic arm and the real-time visualization of the angles of each articulation of the homemade robotic arm using augmented reality. These angles are obtained from the robot based on the data obtained by the encoders of each motor and transmitted to the RAR@pp using Bluetooth communication. This application allows students to send configuration parameters to the robotic arm and visualize in real time the response of the arm to the commands using the RAR@pp. The application was tested in a large number of mobile devices, including smartphones and tablet devices.

The proposed platform allows capturing the student's attention, facilitating the understanding of complex robotics and kinematics concepts. The implementation of a smartphone-based application will allow a large number of students to access to this type of educational resources, improving their performance and their understanding of key concepts of robotics and kinematics.

In this work, basic techniques combining augmented reality have been applied for the visualization of the articulation arm angles. Future work could be oriented to replace the use of markers for the direct recognition of the shape of the object for AR applications. The direct object recognition capabilities could be used for working with different types of arms and for larger degrees of freedom. Moreover, several sensors could be added to the robotic platform in order to expand its capabilities. For example, current sensors could be used to visualize the effect of torque in the axis motors. Implementation of pressure sensors in an end effector or inertial sensor to study the device behavior could also been implemented. It also can be added to the RAR@pp the

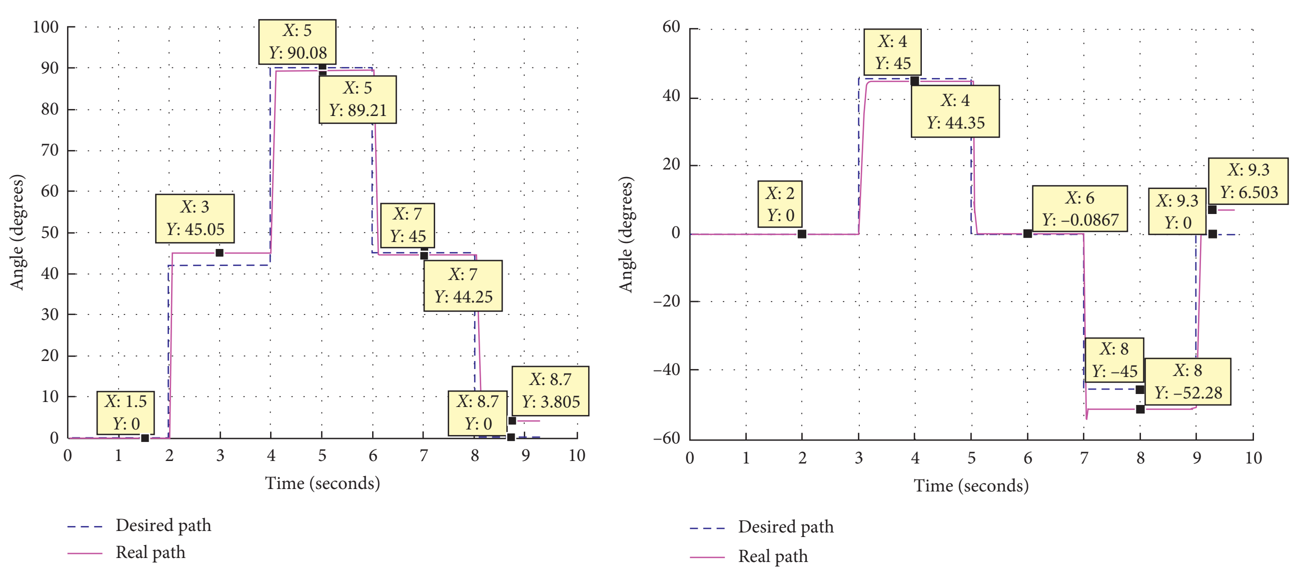
(a) (b)

Figure 7: Integration of the components of the proposed system: (a) robotic arm and desktop application for monitoring; (b) mobile application and its interaction with the robotic arm.



(a) (b)

Figure 8: Robotic arm AR interface: (a) initial position; (b) real-time angle measurements.



(a) (b)

Figure 9: Real and desired paths for robotic arm axes: (a) base axis; (b) shoulder axis.

capability to display information about motor's temperature and the measurement of execution time for a specific task.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The present project was partially funded by the National Council of Science and Technology of Mexico through a scholarship granted to Karla E. Bautista Hernández.

References

[1] G. Akçayır, H. M. Pektaş, and M. A. Ocak, "Augmented reality in science laboratories," *Computers in Human Behavior*, vol. 57, pp. 334–342, 2016.

[2] M. Flanders and R. C. Kavanagh, "Build-a-robot: using virtual reality to visualize the Denavit-Hartenberg parameters," *Computer Applications in Engineering Education*, vol. 23, no. 6, pp. 846–853, 2015.

[3] M. Stilman, P. Michel, J. Chestnutt, K. Nishiwaki, S. Kagami, and J. Kuffner, "Augmented reality for robot development and experimentation," Technical Report, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, USA, 2005.

[4] X. Wei, D. Weng, Y. Liu, and Y. Wang, "Teaching based on augmented reality for a technical creative design course," *Computers and Education*, vol. 81, pp. 221–234, 2015.

[5] W. Tarng, Y.-S. Lin, C.-P. Lin, and K.-L. Ou, "Development of a lunar-phase observation system based on augmented reality and mobile learning technologies," *Mobile Information Systems*, vol. 2016, Article ID 8352791, 12 pages, 2016.

[6] F. Quercioli, "Augmented reality in laser laboratories," *Optics & Laser Technology*, vol. 101, pp. 25–29, 2018.

[7] F. Clemente, S. Dosen, L. Lonini, M. Markovic, D. Farina, and C. Cipriani, "Humans can integrate augmented reality feedback in their sensorimotor control of a robotic hand," *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 4, pp. 583–589, 2015.

[8] L. Yang, C.-K. Chui, and S. Chang, "Design and development of an augmented reality robotic system for large tumor ablation," *International Journal of Virtual Reality*, vol. 8, no. 1, pp. 27–35, 2015.

[9] C. A. Jara, F. A. Candelas-Herías, M. Fernández, and F. Torres, "An Augmented Reality Interface for Training Robotics through the Web," in *Proceedings of the 40th International Symposium on Robotics*, Barcelona, Spain, 2009.

[10] M. B. Ibáñez, Á. D. Serio, D. Villarán, and C. D. Kloos, "Experimenting with electromagnetism using augmented reality: impact on flow student experience and educational effectiveness," *Computers & Education*, vol. 71, pp. 1–13, 2014.

[11] J. Martín-Gutiérrez, P. Fabiani, W. Benesova, M. D. Meneses, and C. E. Mora, "Augmented reality to promote collaborative and autonomous learning in higher education," *Computers in Human Behavior*, vol. 51, pp. 752–761, 2015.

[12] D. Ni, A. W. W. Yew, S. K. Ong, and A. Y. C. Nee, "Haptic and visual augmented reality interface for programming welding robots," *Advances in Manufacturing*, vol. 5, no. 3, pp. 191–198, 2017.

[13] T. H. J. Collett and B. A. MacDonald, "An augmented reality debugging system for mobile robot software engineers," *Journal of Software Engineering for Robotics*, vol. 1, no. 1, pp. 18–32, 2009.

[14] K. Ruan and H. Jeong, *An Augmented Reality System Using QR Code as Marker in Android Smartphone*, IEEE, Piscataway, NJ, USA, 2012.

[15] H. Kato, "ARtoolkit," 2018, http://www.hitl.washington.edu/artoolkit/.

[16] T.-W. Kan, C.-H. Teng, and W.-S. Chou, "Applying QR code in augmented reality applications," in *Proceedings of the 8th International Conference on Virtual Reality Continuum and Its Applications in Industry (VRCAI'09)*, pp. 253–257, Yokohama, Japan, 2009.

[17] J.-C. Chien, H.-Y. Lu, Y.-S. Wu, and L.-C. Liu, "ARtoolkit-based augmented reality system with integrated 1-d barcode: combining colorful markers with remote servers of 3D data for product promotion purposes," in *Proceedings of the Second International Conference on Computational Collective Intelligence: Technologies and Application (ICCCI'10)*, vol. 3, pp. 200–209, Kaohsiung, Taiwan, 2010.

[18] D. Yan and H. Hu, "Application of augmented reality and robotic technology in broadcasting: a survey," *Robotics*, vol. 6, no. 3, p. 18, 2017.