# Enhancing Bicycle Safety Through Immersive Experiences Using Virtual Reality Technologies

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**Abstract.** A bicycle is a fundamental means of transportation for citizens in a modern urban city. However, many traffic accidents have caused by bicycle riding. In this study, our aim is to make people learn desirable riding manners of a bicycle, and to improve their skills towards safer riding for bicycle riders by using a bicycle riding training systems based on virtual reality technologies. The system takes into account the following four issues. The first issue is improving the effectiveness of bicycle riding training by improving the reality of the training system. The second issue is the improvement of the awareness of bicycle riding safety by experiencing traffic accidents in the virtual space. The third issue is to introduce a proper feedback system to a user of the training system. The fourth issue is to introduce gamification-based rewards in the training system. We have developed a prototype system to validate our approach, and present some results from user studies to investigate the feasibility of the prototype training system.

**Keywords:** Augmented cognition technologies · Virtual reality
Bicycle riding · Avoiding physical risks

## 1 Introduction

A bicycle is a fundamental means of transportation for citizens in a modern urban city. However, many traffic accidents have caused by bicycle riding, for example, in Tokyo over 10,000 bicycle traffic injuries occurred in 2016 [6].

Our aim in this study is to make people learn desirable riding manners of a bicycle, and to improve their skills towards safer riding for bicycle riders by using virtual reality technologies.

One of advantages of using virtual reality technologies in the bicycle training system is to improve the training effect by offering immersive experiences about dangerous situations in a virtual space [1, 2]. In terms of offering the experience of dangerous situations, another advantage is that a user can experience traffic accidents without actual physical risks. The approach allows a user to experience more realistic experience, but makes it possible to make him/her predict dangerous situations without increasing real physical risks. For improving the bicycle training effect, the road condition offered in a virtual space should be close to the actual road condition as much


D. D. Schmorrow and C. M. Fidopiastis (Eds.): AC 2018, LNAI 10915, pp. 444–456, 2018.
https://doi.org/10.1007/978-3-319-91470-1_35

as possible, and his/her actual riding skills to ride on a bicycle should be improved in the virtual space.

In this paper, we first describe previous work on training system using virtual reality technologies in Sect. 2. Section 3 describes the design of the proposed training system developed in this study that focuses on four issues that we take into account in the design, and Sect. 4 explains the implementation of the prototype system. In Sect. 5, we present some observations of the initial prototype system that are necessary for designing the current version of the prototype system, then, Sect. 6 describes how this prototype system actually affects a user's safety riding consciousness, and finally in Sect. 6, we will present the conclusion of the paper.

## 2 Related Work

The effectiveness of driving Simulators has been reported in many studies[4, 5, 10]. Past researches like Psotka [7] showed that virtual reality technologies for education and training are very effective. They said that there are many difficulties in learning in terms of existing visual representations and simulations. Virtual reality technologies offer some possibilities to relieve these difficulties.

De Winter et al. claimed that a driving simulator has some advantages and disadvantages [3]. They said that driving simulators are advantageous in terms of reproducibility, standardization, the ease of data collection, and the possibility of encountering dangerous driving conditions without real physical risks to a user's body. On the other hand, low fidelity simulators can produce unrealistic driving and incorrect research results.

In our research, we introduce virtual reality technologies into a bicycle riding simulator and focus on the reality of user experiences, in a simulator, thus we believe that the main disadvantage of using a bicycle riding simulator to train people will be solved.

Schewebel and McClure [9] conducted children street-crossing training in a validated, interactive, and immersive virtual street environment. In this research, children received computer-generated feedbacks concerning safety are immediately as following every street-crossing. They said that virtual reality enables desirable training without the risk of physical injuries, and it provides a fun and an appealing environment for training.

Also, Wang et al. [11] introduced virtual reality technologies to improve the safety of bicycle riders. In the system used in their study, a user wears a head mounted display, and answers questions about his/her bicycle riding manners at each decision point in routes. This study concluded that training systems using virtual reality technologies are useful for children who are not familiar with bicycles.

On the other hand, in the bicycle training system we have developed, we especially focus on the reality of training in the system. For example, a user cannot move freely in a virtual space as shown in [11], whereas in our system, the user can move freely in the virtual space like real bicycle riding.

## 3 System Design

In this study, we consider the following four issues to build a more advanced virtual reality bicycle riding training system for improving a user's awareness on the safety of bicycle riders and for reducing bicycle accidents.

### 3.1 Improving the Reality of the Training System

The first issue is improving the effectiveness of bicycle training by improving the reality of the training system. We especially focus on the following two points.

***Improve the Reality of Bicycle Operation***

We created a bicycle training system with physical pedals and a bicycle handle bar. The system simply recognizes the movement of the pedals and the bicycle handle bar by using sensors. The system monitors the accelerations of the pedals, and the position of the bicycle handle bar, then the data are retrieved by a virtual bicycle in a virtual space, and the system allows a user to feel the reality to ride an actual bicycle.

More specifically, the moving speed of a bicycle in the virtual space is determined from the acceleration of its pedal obtained by an acceleration sensor and the current moving speed. Even if the pedal's rotation speed is the same, a way of the speed changes depends on the speed of the bicycle.

Also, the traveling direction of a bicycle in the virtual space is determined from the direction of the steering wheel and the current traveling direction. The direction of the travel does not reflect the direction of the handle of the bicycle instantaneously but gradually changes towards the direction of the steering wheel. This is because with the actual bicycle there is a time lag between when the handle bar operates the front wheels and when the entire body turns.

***Improving the Reality of Visual Contents***

In our bicycle training system, we used a 3D map that was realistically reproduced using the real city that ZENRIN Co., Ltd. has released by free of charge[1]. In addition, by aligning the scale of the 3D map with the size of the city that was modeled in the training system (for example, the model size and the moving speed with respect to the height of a user's viewpoint), it makes it possible to demonstrate high reality.

Furthermore, as shown in Fig. 1, in order to reproduce an actual traffic situation, our system introduces a traffic light system, so that pedestrians move randomly in the map and basically they follow signals, or make a car travel around the map. The approach makes more sophisticated and realistic training possible.

***Improving the Reality of Auditory Contents***

There is a limitation to feel immersion in a training system through training that relies only on the human vision. Therefore, our system improves the immersion to the training system by also reproducing the running sound of a bicycle, the environmental sounds, and the shock sound at the time of an accident.

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[1] http://www.zenrin.co.jp/product/service/3d/asset/.

**Fig. 1.** Traffic light and pedestrian system

### 3.2 Experiencing Accidents in the Virtual Space

The second issue is the improvement of the awareness of bicycle riding safety by experiencing realistic physical traffic accidents in a virtual space. The important advantage of using virtual reality technologies for bicycle training is to make a user to experience with traffic accidents without real physical injuries. Therefore, in this research, we propose a training system that makes a user strongly recognize potential risks when experiencing traffic accidents in riding a bicycle. The current design considers the following two points

***Creating the Situations that Cause Traffic Accidents***
We prepared two kinds of situations that cause accidents in the system. One is a careless accident experience (an accident experience that can be avoided if a user's care is taken not to cause an accident), and the other is an unavoidable accident experience. The accidental accident experience occurs when a user fails to pay his/her attention to safety. Specifically, it is a mechanism that an accident occurs when colliding with a randomly arranged pedestrians, cars, and others explained in Sect. 3.1. The unavoidable accident experience occurs mainly when a user puts out speed too much. Specifically, when a user enters an intersection at a high speed, a bike or a car collides with the user at such a speed that it cannot be avoided. In addition, as shown in Fig. 2, we also let people recognize the danger when the bike and car are crossing in front of them at a high speed.

***Recognition of a Traffic Accident***
In an accident experience using virtual reality technologies, it is necessary to make a user recognize that an accident has occurred with only the limited feeling without giving a shock to his/her body. We first evaluated the prototype training system that causes to move or rotate a user's field of view when an accident occurs and the user blows off in the virtual space. From the demonstration of the initial prototype system as


**Fig. 2.** A dangerous bike generated in the system

shown in Sect. 5, we found that it was hard to recognize that an accident occurs only by the visual effect, especially when a traffic accident occurred in a training system. Therefore, we modified the training system that makes it easier for a user to recognize his/her situations by adding not only visual expressions but also auditory expressions (ex. the impact noise due to a traffic accident).

### 3.3 Introducing a Proper Feedback System

The third issue is to introduce a proper feedback system. Normally, a bicycle rider cannot recognize whether his/her riding is safe or dangerous unless he/she meets actual accidents. Therefore, in this study, a user presents the moving data that he/she rides a virtual bicycle after he/she finishes his/her ride or when he/she has an accident. The proposed training system makes users understand whether the current traffic manners and riding safety are good or not through appropriate feedbacks.

In this feedback system, a user confirms his/her riding with both the bicycle rider's viewpoint and the bird's-eye viewpoint after riding a bicycle like in Fig. 3. By using the bird's-eye viewpoint, the user can check information on the user's blind spot that he or she often neglects his/her attention while riding a bicycle. Also, if he or she neglects a signal or approaches a pedestrian or a car too close, no alert will be issued during the training, but the feedback system will alert all of them and will lead to a better attention to users for the next time.

### 3.4 Introducing Gamification in the Bicycle Training System

The fourth issue is to introduce game mechanics based on gamification in the bicycle riding training system. We propose a method to implicitly induce a user to ride safely by using a scoring system. It is also intended to make it possible to recognize desirable traffic manners without prior explanation of desirable manners orally or in writing. We take into account the following two points in the current design.


**Fig. 3.** Feedback system window

In this research, we use some factors such as whether bicycle riding speed is not too fast, the distance to surrounding cars is appropriate, and whether signals are correctly observed as the indicator of safe riding. In addition, we use whether to pass the correct position on the road as an index of desirable traffic manners. In order to increase a user's bicycle riding skills, we adopt the scoring system that the score rises when ensuring these rules, and the score decreases when not ensuring these rules, as shown in Fig. 4. In addition, we also introduce a technique to obtain virtual items in a virtual space, like a green cross as shown in Fig. 5, whose scores rise substantially to the points where the scoring system likes to guide a user for navigating him/her towards desirable manners.


**Fig. 4.** Scoring system

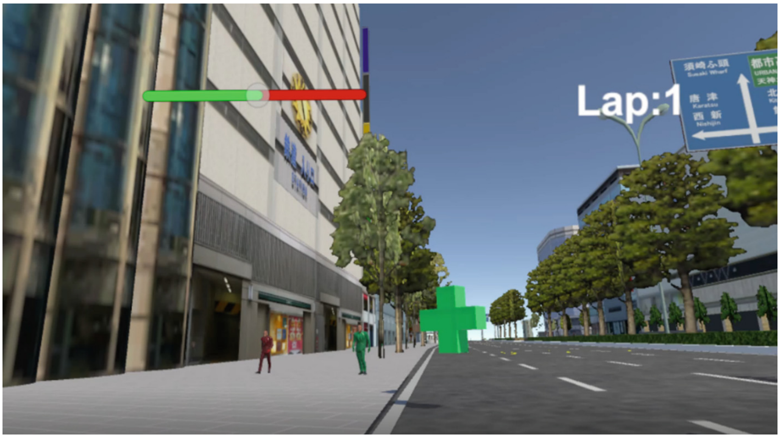


**Fig. 5.** An item that gains the score (Color figure online)

***Potential Pitfall of Gamification***
There is a potential pitfall to use gamification that a user cannot correctly distinguish whether the action induced by the gamification is the actual safe bicycle riding and the correct bicycle riding manners or whether a user just follows a rule defined by the gamification mechanisms in the training system for increasing his/her scores. Due to this pitfall, there is a danger that training by the system has its effect only when there is a scoring system, and it will not be effective for actual riding in the real world. To solve this problem, we use the feedback system introduced in Sect. 3.3. By using the feedback system, a user can accurately grasp what was dangerous to his/her bicycle riding, so the user can understand the actual rules without, and he or she wants to follow the rules without the scoring system.

## 4 Implementation

Our training system consists of the following five components: a head mounted display (HTC Vive[2]), an HTC Vive Controller (a device that can be tracked the position), a simple exercise bicycle as shown in the left photo of Fig. 6, an acceleration sensor, and training system software. A user wears a head mounted display and is trained bicycle riding in a virtual city by pedaling and operating the handle of a simple exercise bicycle as shown in the right photo of Fig. 6.

Figure 7 shows the relationship of our system components. In our system, a user rides on a simple exercise bicycle and wears a head mounted display as described above. The HTC Vive Controller and the acceleration sensor are attached to a simple

[2] https://www.vive.com/.


**Fig. 6.** A simple exercise bicycle in the training system

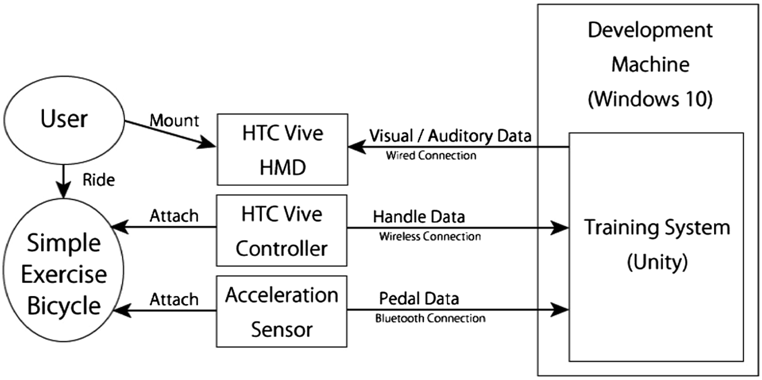


**Fig. 7.** System components

exercise bicycle and send the bicycle handle bars' inclination and pedal acceleration data to the bicycle training system software. The training system displays a virtual city to a user based on the information.

The speed of the bicycle in a virtual space is determined from the rotational speed of a simple exercise bicycle pedal. The speed of the rotation of the pedals of a simple exercise bike is retrieved from the acceleration sensor contained in Nexus 6 (Android device), where the Nexus 6 is attached to the pedals.

The direction of the bicycle in the training system is determined from the inclination of the handle bars of simple exercise bicycle. The inclination is retrieved from the relative position information of the HTC Vive controller attached to the handle through its built-in sensors. The training system software has been developed on Unity (Version 2017.1.1), which is a cross-platform game engine primarily used to develop both three-dimensional and two-dimensional video games and simulations.

## 5 Demonstrating the Initial Prototype System in a University Event

In this section, we show some observations of the initial prototype system that have been developed before designing the current prototype system. The initial prototype has been developed for investigating potential pitfalls before developing the prototype systems described in the previous section, and make us extract the design issues described in Sect. 3. In an event held in our university where junior high school students and high school students participated as shown in Fig. 8, 170 users have experienced the initial prototype system. They could experience with virtual traffic accidents when traveling into an intersection of a road at the speed above a certain level.

**Fig. 8.** An event held in our university

Participants joined to the event gave us the following comments. A participant said "*I really feel like I'm riding on a bicycle*". Some participants claimed "*Since a driving school like a car is not required for bicycle training, I feel that the training system is useful.*", "*The reality offered by the training system is incomplete. For example, the shadow of a building in the virtual space is looked unnatural.*", *and* "*It is hard to understand that I have met with an accident*". Also, a participant told us "*I feel the drunkenness while using the initial prototype system.*"

## 6 Evaluating Learning Effects of the Prototype System

We conducted the experiment of the bicycle riding training for 10 participants, where 7 have the car driver's license, and 3 do not have it. All 10 participants were in early twenties. In this experiment, we investigated how a participant's riding behavior, skills and attitudes were changed through using the training system before and after the training. Specifically, we examined whether the speed is not too fast, the distance to the surrounding cars and others is appropriate, the signals are followed, or whether a participant passes the correct spot on the road as an indicator. In addition to these points, we conducted a questionnaire survey and an examination on each participant's awareness of safe bicycle riding and understanding of traffic laws.

## 6.1 Research Method

We conducted the experiment by the following steps.

**Step1:** Preliminary questionnaire
**Step2:** Training explanation
**Step3:** Actual training
**Step4:** Post questionnaire

In the bicycle riding training, each participant measured the lap to ride in the course as described before, and then watched the replay of his/her riding. After that, the participant rides the bicycle in the same course again one more time. If an accident occurs, the participant restarted from the place where the accident occurred and watches the replay of his/her riding later.

## 6.2 Result

***Reality of the Training System***

In the post questionnaire after the training, we investigated how participants felt the system's reality with the 5-level Likert scale.
The results are shown in Fig. 9.

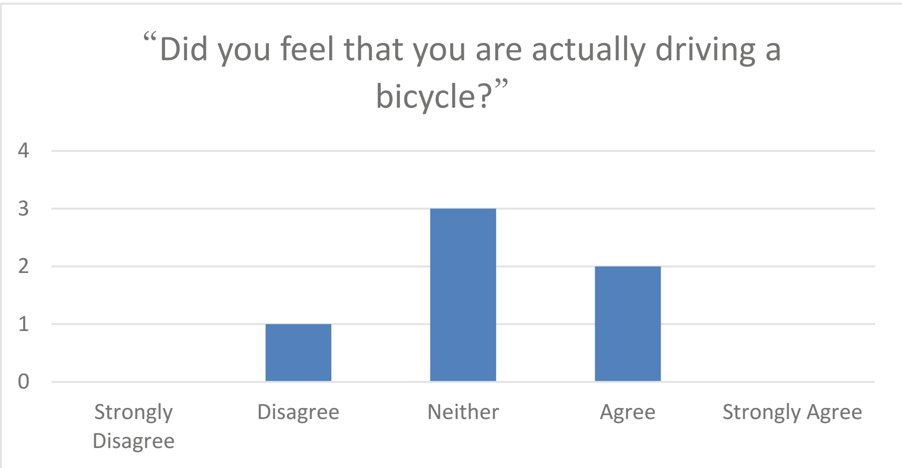


**Fig. 9.** Questionnaire on the reality of the training system

When asking what a reason that each participant felt the reality was low, he or she claimed that the problems are caused by the precision of the handle bar and the narrowness of the field of his/her view of the current prototype riding system. These problems are due to the current implementation' constraints not the concept's inherent limitation. Thus, we believe that these problems will be solved by the future system's improvements.

***Bicycle Riding Behavior***

In the experiment, we collected the information about the average speed, a number of signals ignored, a number of pedestrians approached, a number of collisions with pedestrians or cars, and a number of times a participant passed the places where he or she should not go through. We measured the differences between the data obtained in the first run and in the second run (after receiving some feedbacks to understand safe bicycle riding from the riding training system). During the replay of the participant's riding and the second run, the bicycle riding speed of his/her bicycle was indicated in the field of his/her view. At this time, the speed faster than the desirable speed was displayed for the purpose of preventing the participant's speeding out too much.

Unfortunately, no meaningful differences were found in the experiment. This may be caused by the short training time for avoiding VR sickness. Also most participants are aware of because they consider that they know that the purpose of the experiment is the training, For example, most participants ignored the signal only zero or one time in the first training, but some other participants decreased the number of signal ignoring in the second training.

***Safety Awareness***

We also conducted questionnaires on the participant's safety awareness before and after his/her bicycle training. In both questionnaires, we asked the following questions.

**SQ1:** What is necessary as a safety equipment (like a helmet)?
**SQ2:** What do you pay an attention to when riding a bicycle?

In the questionnaire before the bicycle riding training, we also asked the following questions.

**EQ1:** How do you recognize the danger of a bicycle?
**EQ2:** Do you forget to take care of the safety when riding a bicycle?

Then, after the bicycle riding training, we asked the following question.

**EQ3:** Do you think that your bicycle riding was safe so far?

Comparing before and after the experiment, SQ2 shows the difference. Many participants increased their attention during bicycle riding after training. Especially, a participant who answered "*Not at all*" or "*Almost never forget*" in EQ2 tends to pay more attentions.

***Effect of Gamification***

We confirmed to make a participant to recognize the correct traffic rules when using gamification. We chose a minor traffic rule (a bicycle must run on a bus lane in the road [8].) and designed the bicycle riding training system to give him/her a penalty if he/she does not keep the rule. We have checked the knowledge gain about the rules through questionnaires before and after the bicycle riding training.

In this experiment, we were able to find participants who were able to learn rules as intended. However, some participants misunderstood the rules. There is a difference between the understanding of the rules and their actual actions in such participants. So such participants' actual actions follow the rules.

# 7 Conclusion and Future Work

In this paper, we presented a bicycling riding training systems using virtual reality technologies. The system, in particular, took into account the following four issues. The first issue is improving the effectiveness of bicycle riding training by improving the reality of a training system. The second issue is the improvement of the awareness of bicycle riding safety by experiencing virtual accidents in a virtual space. The third issue is to introduce a proper feedback system. The fourth issue is to introduce gamification in the training system. We presented some results showing the effectiveness of the proposed approach from the user studies, and investigated its feasibility and some potential pitfalls of the current prototype system.

## 7.1 Future Work

***Improving VR Device's Constraints***
In this study, we developed a training system using general purpose commercial devices like an HMD and VR controllers. However, due to the limitations of the VR devices, some users have experienced VR sickness during their training, and felt the inconvenience in narrowing their views. We consider that these problems will be solved by using more sophisticated VR devices in the future.

***Using Augmented Reality***
In the future, some training functions developed in this study may be useful in actual bicycle riding in the real world. In particular, showing feedback information on the current riding is effective to understand the current riding manners. For example, displaying the speed faster than actual and showing warnings when pedestrians approach by using augmented reality technologies are useful for increasing safety of most bicycle riders when riding in the real world. Also, a scoring system showing scores by using augmented reality technologies in the real world is useful for bicycle riders for encouraging their safety manners through gamification.

***Children's Training***
Although we believe that this training system is the most effective for children who are weakly conscious about the safety and did not use a bicycle, it is pointed out that making children wear HMDs may have an adverse effect due to such as strabismus. So, we did not conduct an experiment with children in this study. However, if an HMD that can be used safely for children is developed, the training system proposed in this study will examine the effectiveness for the children.

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