An Active Early Warning System for Heavy Construction Vehicle Drivers based on Mixed Reality

Tingsong Chen, chen.tingsong@it.see.eng.osaka-u.ac.jp
Graduate School of Engineering, Osaka University, Japan

Nobuyoshi Yabuki, yabuki@see.eng.osaka-u.ac.jp
Graduate School of Engineering, Osaka University, Japan

Tomohiro Fukuda, fukuda@see.eng.osaka-u.ac.jp
Graduate School of Engineering, Osaka University, Japan

Abstract
Trucks, earth-moving equipment, and other heavy vehicles are essential on construction sites. Their existence has significantly improved the efficiency of modern construction sites and the ease of workers. However, due to the obvious defects of the construction vehicles and their drivers, these helpers have become one of the main causes of accidents for construction workers. Recently, mixed reality (MR) technology has emerged in the construction industry. Through efficient virtual and display technology, many functions such as remote collaboration and expected rendering realization can be applied. In this paper, an MR-based accident prevention and supervision method for large construction vehicles is proposed. A safety alerting method is proposed to remind the driver of abnormal site information, and to reduce the drivers' conflict with people or other vehicles.

Keywords: safety management, mixed reality, construction sites.

1 Introduction

In the construction field, the usage of heavy vehicles has made a lot of heavy work easier, meanwhile, the work pressure and fatigue of many workers are also reduced. However, heavy vehicles hold many objective shortcomings, which bring a lot of damage and danger to other workers. In many construction sites, due to the huge size of heavy vehicles, workers are forced to share working space with vehicles, which leads to a much higher chance of accidents. In many heavy vehicles related accidents, it is often the driver's mistakes or misoperations that cause the workers to suffer the most serious injuries or fatalities.

In the United States, more than 20,000 workers were injured directly due to traffic-related accidents in the construction activity area each year. In 2016 alone, more than 25,000 crashes occurred in the Texas workplace, resulting in 181 people died [1]. Distracted and inattentive drivers can easily run over or back over road construction workers or collide with other vehicles. Similarly, unsafe drivers on public roads pose threats while passing through the construction zone.

In Japan, the same situation also occurs in the construction field. According to the questionnaire results of more than one hundred construction companies, over half of the companies have experienced vehicle accidents during the construction process.

The main causes of serious fatal accidents are vehicle overpassing and retreating injuries, vehicle collisions, and worker deaths due to conflicts between construction equipment and vehicles, etc.

Due to the subjectivity of driving, 85% of the control of the vehicles depends on the driver [2]. Therefore, a monitoring system that concentrates on drivers themselves other than vehicles is necessary. Figure 1 shows an Overspeed truck trying to turn but failed (the picture is taken under the authorization of the copyright owner).

Figure 1. Overspeed accidents of heavy vehicles during turning (Simulated scene)

Speaking of mixed reality (MR), it is the merging of real and virtual worlds to produce new environments and visualizations, where physical and digital objects co-exist and interact in real-time. It allows people to have a more comprehensive holographic experience.

MR is known as a technology that combines virtual elements with the real world. Augmenting the real-world environment by superimposing virtual content has the potential to provide a rich, interactive, and fascinating experience. In many different fields such as medicine and healthcare, education, entertainment, industrial maintenance, etc., many interesting applications have been introduced in terms of proof-of-concept systems or commercial applications.

Due to the characteristics of MR technology, it can be perfectly integrated with the construction field. Several mainstream research directions have emerged. The first is the building information modeling (BIM) display and management of holograms. The second direction is remote monitoring to enhance the sense of presence. [3] used the holographic MR technology running on Microsoft HoloLens [4] to achieve visual interaction and remote collaboration of on-site risk discussion on the construction site.

In this study, an early warning system for heavy vehicle drivers based on MR will be proposed. The following sections are arranged like this: Section 2 introduces the related works of safety-related driving systems and MR researches, section 3 is the proposal of this study and details of the realization of the proposed method, section 4 mainly includes the experiment implementation, section 5 introduces the result of this experiment and conclusion.

2 Related works

This section mainly collects the research on construction site vehicle safety in recent years, as well as MR-based researches, construction field, and safety-related researches.

2.1 Vehicle safety-related research

In recent years, there have been many studies on the safety of construction vehicles, and most of which are classified as driving monitoring and assistance system (DMAS). Among them, three main types can be divided.

2.1.1 Driver focused studies and systems

Among vehicle accidents, driver distraction is one of the main reasons, 50% of driving accidents are related to it. Distraction mainly includes the following kinds: Cognitive distraction; olfactory distraction; biomechanical distraction; auditory distraction; gustatory distraction; and visual distraction.

Studies in [5], [6] showed that the analysis of gaze patterns can distinguish between focused driving a scattered driving and provide a relative degree of cognitive engagement. Studies have shown that cognitive workload, distraction, and eye movements (scanning, chasing, and staring) are interrelated [7]. Besides, with the increasing cognitive workload, so does the driver's head movement. It is reasonable to believe that the increased head movement is a compensatory action of the driver to obtain a larger field of view. According to [8], the driver's cognitive dispersion state can be appropriately detected by the standard deviation of head and eye movements. The research in the literature [9] shows that frequently looking at objects at a far distance will increase the dispersion of vision; blinking frequency increases with the dispersion of cognition, and the concentration of gaze and the reduction of the saccade are signs of the visual and cognitive distraction of the driver.

Some studies [2] have also shown that around 25% to 35% of driving accidents are related to fatigue. Driver fatigue is mainly divided into three types. The first type is sleepiness caused by mental and central nervous system fatigue. This is the most dangerous type. The second is general physical fatigue, such as the feeling after physical labor, and the third is local fatigue, such as skeletal muscle fatigue caused by prolonged sitting.

Fatigue has a great influence on driving performance, and some of which are intuitively reflected in the physical state of the driver, such as increased blinking frequency caused by yawning, burning eyes, difficulty keeping hands on the steering wheel, erratic eyes, slower response time, increased number of nodding, etc. [10], [11], [12].

2.1.2 Vehicle focused studies and systems

The vehicle-based safety system mainly considers the personalized customization of driving style. By considering the environmental factors (weather, light time, season, light conditions) and human factors (age, personality, behavior) to personalize system performance and enhance safety [13], [14].

2.1.3 Driving environment focused studies and systems

DMAS can also improve driver attention and avoid possible collisions by detecting surrounding vehicles and pedestrians. Using multiple kinds of sensors such as passive sensors (vision, sound) [15], [16] and active sensors (radar, Lidar) [17], [18] to understand the environment and vehicle condition.

2.2 Mixed reality-related researches in the construction field

Regarding the research of MR technology based on the construction industry, most of them are focused on education and skill training, on-site environment monitoring, and preconstruction planning.

2.2.1 Education and skill training

The skill training and education of students, employees, and managers are the most common purpose of MR applications. MR has the potential to offer training for works that are dangerous and allows user to simulate their work contents without the risk of real work. [19]. For instance, a multi-user training program is developed [20], in which users can use the Wii game controller to learn about the crane dismantling skills and practice in the virtual environment. An experiment between students who learned from the MR training program and skilled trainers is compared, and the result shows that training with an MR environment performs better.

2.2.2 On-site environment monitoring

The on-site monitoring connected MR systems with location trackers and shared valuable safety information in real-time. A system based on Google glass is proposed to track workers in real-time to expand their vision range [21]. When the user is near a labeled dangerous area or machine, he will be warned visually, at the same time, the operator of the dangerous machine will also be alerted that other people approach. [22] concentrated on using VR-based real-time tracking and efficient training. Dangerous areas are labeled, and radiofrequency identifiers (RFIDs) are used in the helmet of workers, whenever they enter a dangerous area or near heavy machinery, the helmet will provide an auditory warning as "Beep" to alert the user to step away. This method also presented a virtual environment of the site called "Virtual Construction Simulation System". which can be monitored by managers and safety professionals. The researcher mentioned that real-time visualization can only provide a limited level of realism, AR and MR is the future of construction monitoring.

[23] also used MR device and having Skype talking while driving to test if MR device affects too much and lead misjudge to drivers. The experiment was set up in an isolated environment and was carried out under safety standards.

2.2.3 Preconstruction planning

Preconstruction safety planning plays an important role before the project begins. It can prevent potential dangers with some proper designs to assure the project goes well in the future. MR is a promising method in preconstruction. A VR-based 4D simulation system is proposed in [24] to support the analysis from designers and construction managers. In conclusion, virtual simulation of preconstruction can assure the safety and efficiency of real construction, meanwhile, the waste of cost (such as overturn and start over) can be prevented or well-controlled. In a word, it will become an important method in future construction.

3 Proposal

After synthesizing all relevant studies, it can be known that most of the driver-based safety monitoring and early warning method is partial biological index measurement, which has high requirements for daily use and re-implementation. At the same time, due to the complexity of the processing equipment, it is possible to implement the actual environment. The researches on safety monitoring of the construction environment based on MR technology are based on the macroscopic, and they focus more on training, danger prevention, and remote human monitoring.

In this study, a mixed-reality-based active monitoring system for drivers of heavy vehicles will be proposed, instead of concentrating on the entire environment of the construction site and biological methods, this method focuses on the dangerous behaviors that are not subject to the drivers' will, such as irregular driving due to distraction or fatigue, etc.

3.1 Method realization

This study is based on mixed reality technology, using MR equipment worn by heavy vehicle drivers, to analyze the data and achieve real-time warning.

One of the current mainstream MR headsets, HoloLens 2 [4] will serve as the hardware basis for this study. Because functions such as hand motion tracking, head gyroscope, and gaze tracking are available, active driver behavior monitoring can be achieved, multi-dimensional prediction of some abnormal and dangerous behaviors of drivers can be detected. During the monitoring process, for suspected dangerous driving behaviors, the MR device will give visual warnings (levels that won't affect normal driving), at the same time, it will also provide auxiliary reminders

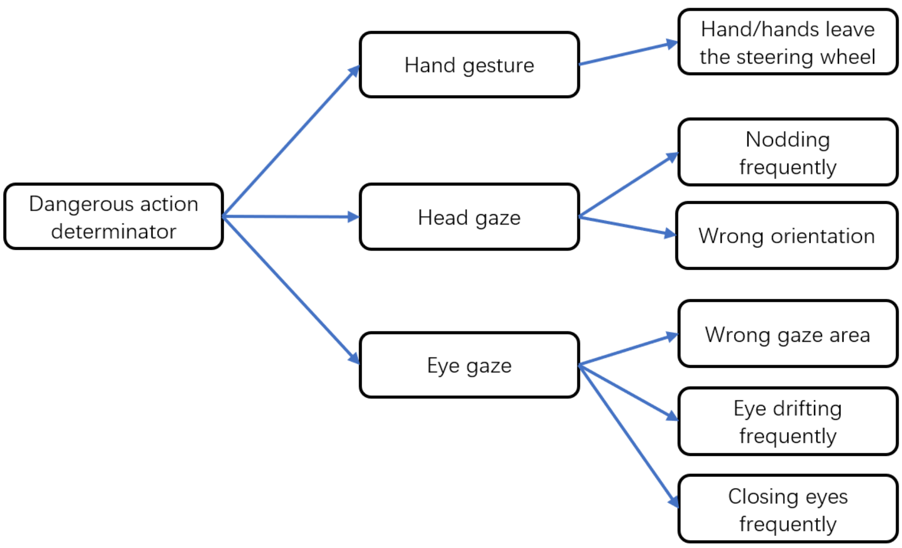

Figure 2. Introduction to dangerous actions based on three dimensions

in auditory and other aspects. This research is mainly aimed at the slow-moving heavy vehicles in the construction area. Within the scope permitted by law, the system can be extended to roads and other areas.

3.2 Method details

As shown in Figure 2, most of the conditions that may happen with the heavy vehicle drivers (fatigue, distraction, etc.) can be distinguished based on the state of their hand gesture, head gaze, and eye gaze. Based on the above dangers and abnormal behaviors, the monitoring focus can be divided into the following points:

3.2.1 Hand monitoring

According to the function introduction of the Mixed Reality Toolkit (MRTK) [25], HoloLens 2 can recognize 25 nodes of a single hand (as shown in Figure 3). As one of the main input methods, the hand has many gesture operations including instinct interaction [26]. Gestures such as grabbing, clicking, air tapping, and long-distance cursor pointing, etc. are also the gesture operations that can be implemented in HoloLens 2.

According to our study, when the driver is suspected of being distracted or fatigued, his hand may move abnormally, such as leaving the steering wheel [11] (when trying to operate the center control panel, or when the hands cannot remain in the steering wheel position, etc.). Reference to

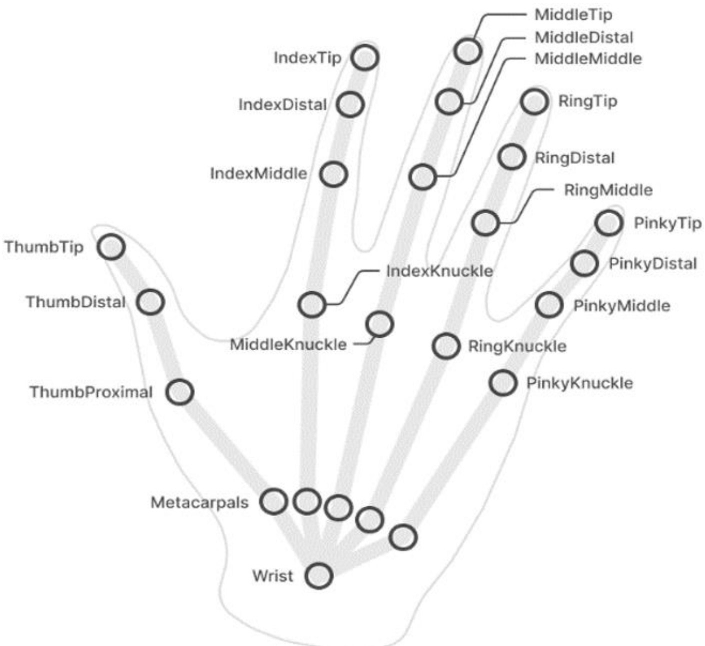

Figure 3. 25 nodes that HoloLens 2 can recognize in one hand

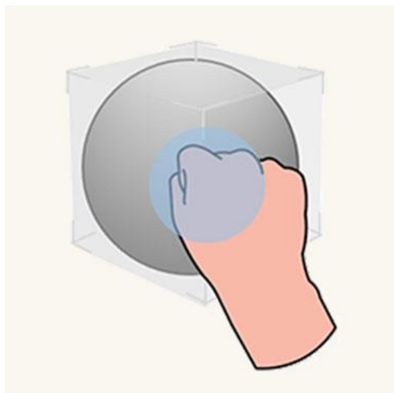

Figure 4. Description of grab motion in mixed reality environment

MRTK, we decided to use the grasping action to simulate the state of holding the steering wheel. By identifying the grasping state of the hands-on steering wheel, we can analyze the current state of the driver in one dimension, as shown in Figure 4.

3.2.2 Head gaze monitoring

When hands are occupied, many gestures cannot be complete, so MRTK also provides the function of head gaze and stay, to helps the wearer to perform convenient operations by pointing the head to the mark.

In our study, we aim at the driver's status to identify if he is driving dangerously. When the driver is distracted for a long time, the head will point to the non-frontal area [9] (such as the roadside, the rearview mirror, the center control panel, etc.). At the same time, when the driver is in a fatigue condition, there will be a state of excessive nodding [12]. Based on these, we can rely on the MRTK's head gaze and stay function to analyze the driver's head pointing, and provide early warning for the driver's suspected distraction and fatigue, so as to avoid accidents.

3.2.3 Eye gaze monitoring

Eye-tracking is one of the new features of HoloLens 2. With this feature, head shaking can be avoided while selecting different objects in the same area of view. Through its combination with gesture functions, selection, movement, and manipulation of objects can be realized more conveniently.

According to our study, when a driver is distracted and fatigued, the state of his eyes changes the most. Under normal driving conditions, the driver's eyes are mainly focused on the road conditions ahead, and occasionally there will be some drifts (such as checking the rearview mirror and vehicle instrument information, etc.), but they will quickly return to the state of focusing on the road conditions ahead. When the driver is driving distracted, his eyes will focus on abnormal directions or objects [5]. Prolonged distracted gaze can lead to serious consequences. For example, the steering wheel will unconsciously fine-tune the gaze direction, and when driving on the road, it will lead to the result of rushing into the opposite lane or the area off the road. When driving with fatigue, the eyes of drivers cannot concentrate and blink more frequently due to heavy eyelids, which lead to a slower refocusing time after each blink [10], and will lead to an untimely analysis of the road conditions and cause serious accidents or other consequences.

Based on the above situations, we can monitor the driver's eyes in real-time through the eye-tracking function in MRTK. By setting up the sensing function in the abnormal gaze area, the driver who gazes too much can be warned visually and audibly, to achieve timely warning and to alert the driver in time, and provide sufficient preparation time for subsequent measures (retarding, etc.).

4 Implementation

For this experiment, on the hardware side, HoloLens 2 from Microsoft was prepared, on the software side, Unity 3d (version 2019.4.21f1) and MRTK 2.6.0 were prepared. For the scene construction, Euro Truck Simulator 2 [27] was prepared as the main tool to test the degree of realization of the functions.

4.1 HoloLens 2

HoloLens 2 as shown on the left side of Figure 5 is the second-generation MR device released by Microsoft in 2019. After the improvement from the previous version, the viewing range becomes 2 times wider, the holographic resolution is up to 2K, makes it a clearer projection of virtual objects, and be able to show more internal details. In terms of hardware, HoloLens 2 owns four visible light cameras for head tracking, two infrared (IR) cameras for eye tracking, a 1 MegaPixel (MP) time-of-flight depth sensor to detect depth information, and an initial measurement unit (IMU), as well as a camera which provides with 8-MP photo capturing and 1080p 30fps video recording.

In terms of human-computer interaction, HoloLens 2 can realize full-joint model recognition of both hands and direct operation with bare hands. It also supports real-time eye tracking.

Figure 5. HoloLens 2 used in this experiment and MRTK Examples holographic view

4.2 Unity 3d and MRTK

The Unity 3d version used in this simulation experiment is 2019.4.21f1, and MRTK 2.6.0 is used for mixed reality development.

MRTK for unity is an open-source, cross-platform development kit for mixed reality applications. It provides a cross-platform input system, basic components, and general building blocks for spatial interaction, including but not limited to camera modules, coordinate system, head gaze, text, hand and eye tracking, voice input, spatial mapping, and spatial sound effects, etc. The right side of Figure 5 shows some example functions that MRTK is able to achieve.

4.3 Simulation setup

This simulation was initially constructed on Unity 3d, and it will be installed in the HoloLens 2 for actual MR experience feedback. By creating a virtual scene in Unity, an actual truck driver's view including position and the distance information of the surrounding environment is simulated, the overall framework of the early warning system is constructed as well. As shown in Figure 6 in this experiment, a visual model of a right-hand drive truck is used. According to driving behavior habits and the distribution of various parts in the vehicle, we divide the driving visual range of truck drivers into the following parts: gaze danger zone; gaze attention zone; gaze safe zone; hand operation zone. When the driver behaves differently than normal driving status, such as looking at the wrong zone for a long time or loosen their hand on the steering wheel, they will be assumed as distracted or fatigued, the corresponding alarm measures will be activated.

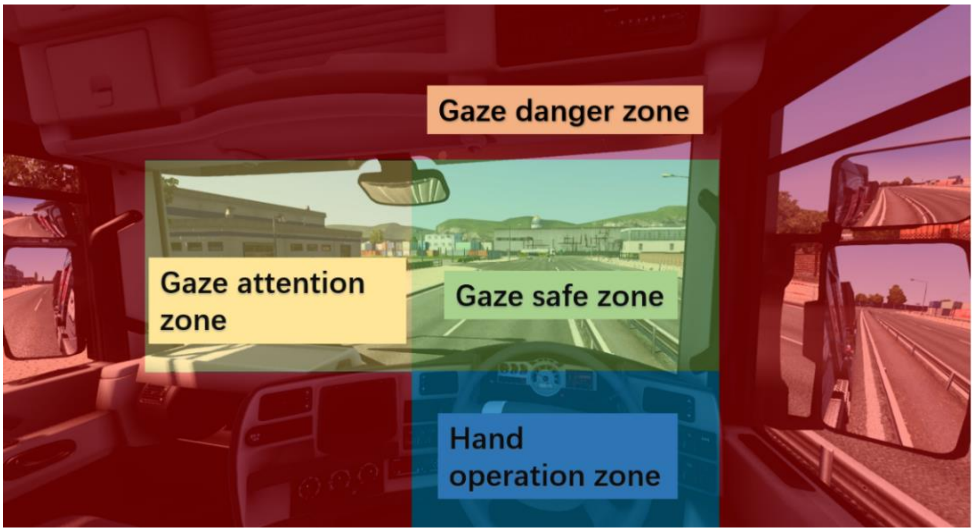

Figure 6. Introduction of division on driver's visual area

In this experiment, feedback from 2 dimensions is added to the early warning system, so that drivers in dangerous situations can respond quickly to avoid accidents. In the part of hand monitoring, the components such as *NearInteractionGrabbable*, *ManipulationHandler*, etc. are used to realize the driver's grasping feedback on the steering wheel. When the driver's hand or hands leave the sensing area or loses the grasping action, the sensing object will become opaque to provide a warning. The sensing objects are set about 0.35 to 0.4 m away from the driver to ensure that the driver can grasp the steering wheel in the most natural way. At the same time, a new script named *HandDetector* has also been written and added, which can detect the three-dimensional coordinates of both wrists in real-time to assist in early warning.

In head/eye gaze monitoring, components such as *EyeTrackingTarget*, *GazeProvider*, and *Gaze* are used, and the areas of each level are divided by different kinds of colors (safe zone and hand operation zone are set without color), while the eyes or head of the driver is pointed to the designated area, and pauses for more than 0.8 seconds, the pointed area will turn red/yellow to provide a visual alert, a short "Beep" will provide auditory alert as well. In the gaze danger zone, the "Beep" comes along with the color change, to alert the driver in different dimensions as soon as possible. Meanwhile, in the gaze attention zone, the "Beep" will come slightly later than the visual alert, since the danger level is not as high as in the danger zone.

5 Result and conclusion

5.1 Result

Since the eye direction point should not be shown during the HoloLens 2 real machine test (to prevent interference with the driver), the results of this experiment are presented from two forms. The head monitoring and hand monitoring are fed back through the frame captured during the real machine test; the eye gaze monitoring is performed by Unity 3D's simulation result.

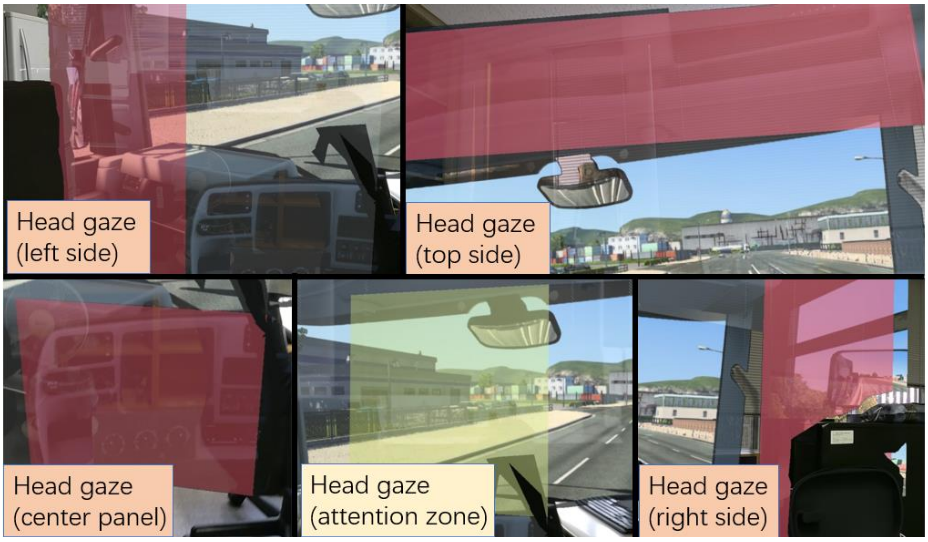

Figure 7. Alert feedback of head gazing areas

Firstly, the head monitoring result is shown in Figure 7. In a simulated truck cockpit environment, the experimenter's head is pointed at each area, and the function is confirmed by getting feedback from alerts. As shown in Figure 7, in the simulated cockpit environment, the tester aims his head at zones as the left rearview mirror, the top rearview mirror, and top cockpit area, the center control panel, the right rearview mirror, and the front windshield of the co-pilot side to get gaze warning and feedbacks.

The second is hand monitoring. As shown in Figure 8, in a simulated truck cockpit environment, the tester's hands are used to grab the simulated steering wheel area, two sensing objects (currently are shown as red balls) will be placed in the hand operation zone, when the tester grab the right position, the sensing objects will feedback with a transparent effect. Then once the hand or both hands cancel the gasping action, the sensing object will immediately give an alert through color changes and auditory feedback to remind the driver to restore the correct driving posture. The position of the head sensing object is not fixed, but it is limited inside the

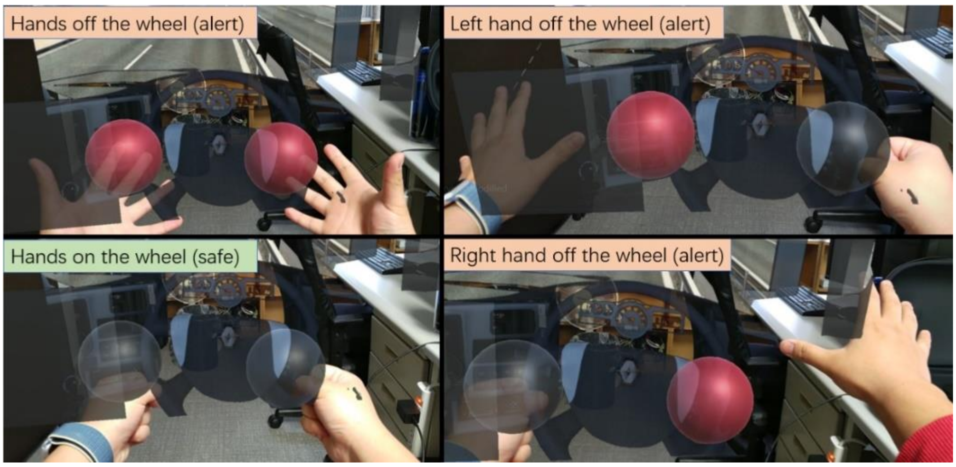

Figure 8. Grabbing motion sensing of the hand/hands in hand operation zone

hand operation zone. It also has a reset function, when the position of the sensing object drifts too much, the tester can reset the object to the origin position.

The last part is eye monitoring, as shown in Figure 9, in the simulated truck cockpit environment, set the head movement of the tester fixed, only the tester's eyes can look around the environment, stare and stay for a while in different zones. During the process of looking around, feedback from different zones is used to confirm whether the eye gaze warning function is available. The white points (marked with blue circles) in Figure 9 are where the eyes are pointed at.

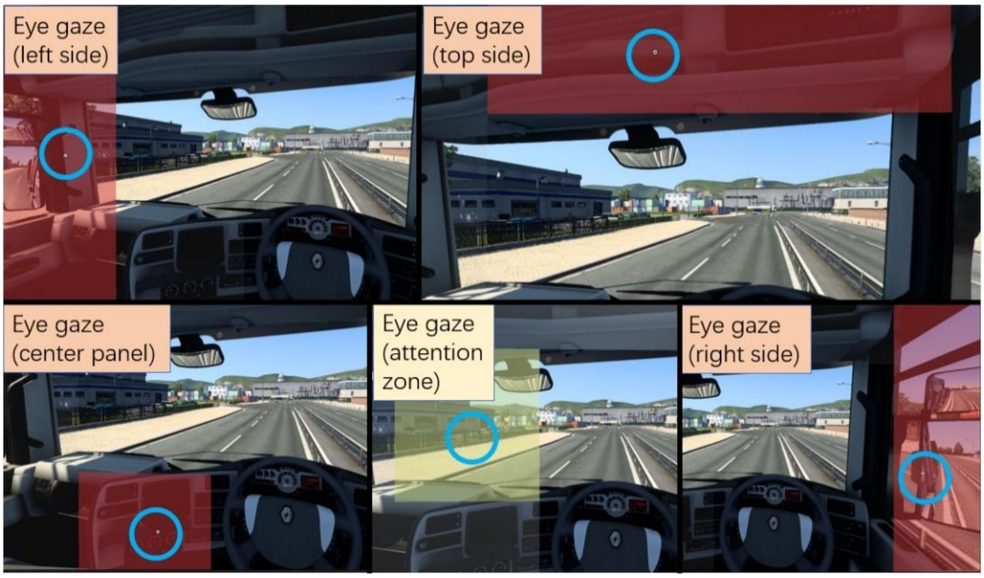

Figure 9. Alert feedback of eye gazing areas

5.2 Conclusion

In this study, an MR-based active monitoring system for drivers of heavy vehicles is proposed. This study focuses on active early warning, through real-time monitoring of the driver's status using HoloLens 2, to confirm whether the driver is in a state of distraction or excessive fatigue. This study is based on three body parts that used frequently while driving: head, eyes, and hands, to further determine the current state of the driver. A series of abnormal states based on these body parts are discussed. According to the combination of some components in MRTK and some origin components, information of hands, head orientation, eye pointing direction are collected and analyzed, and multi-dimensional feedback is added to monitor abnormal movements and states of designated body parts in real-time, to discover and prevent potential dangers.

According to this experiment, the feasibility of an active heavy vehicle driver monitoring system can be determined. The real-time hazard warning feedback works well, during our tests, there is no unrecognizable state. However, we collected the feedback from our testers, the most mentioned points are: UI interface is simple, the design can be improved; richer feedback such as voice prompts can be added. Due to hardware limitations, although the function is already real-time, the realization of user-friendly products still needs further improvement. At the same time, due to the restrictions of laws and regulations in different regions, some social studies, such as "discussion of carrying MR equipment during high-concentration operations", "the reliability and safety of actual use of MR equipment", etc., also need to be further studied from the perspective of ethics and safety.

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