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Immersive Virtual Reality Training for Inspecting Flagger Work zones

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***Abstract*— Construction and maintenance work on roads pose safety risks to both drivers and workers. The responsible agencies regularly inspect work zones for compliance with traffic control and signage standards. The current training practice is to review documents related to temporary traffic control and reports from previous inspections, typically Power Point files with pictures. It would be beneficial if a new mechanism for training could be developed that is as effective as field visits but without the amount of time and effort required to visit multiple field sites. This study developed an immersive training module for transportation agency staff that inspect flagger operations in road construction and maintenance work zones. Human flaggers are commonly used to control traffic at work zones on two lane highways (one lane in each direction). The main objective of the proposed training is to deliver a realistic experience to trainees in an immersive virtual environment using the current traffic control protocols and standards. The module creation consisted of three steps. First, the roadway geometrics, work zone signage, traffic control devices, and the natural environment was created. Second, motion capture technology was used to replicate the actual movement of a human flagger directing traffic in a work zone. The environment and flagger avatar created in the first two steps were integrated and implemented in a simulation in the third step. The module was demonstrated to inspection staff at one state department of transportation (DOT) and revised based on their feedback. The state DOT staff were highly receptive to the use of virtual reality for training and commented on the benefits of the immersive experience that is lacking in their current training practices.**

Keywords—Virtual Reality, Training, Work Zone, Transportation

I. INTRODUCTION

Roadway work zones pose a safety risk to drivers. In the United States, around 94,000 crashes occurred in work zones in 2017 – 710 were fatal, 37,000 involved injuries, and remaining 56,290 involved property damage [1]. These statistics do not capture the safety risk the workers experience.

From 2003 to 2015, 1,571 workers lost their lives in work zones, averaging 121 lives each year. Transportation agencies responsible for conducting road work seek innovative approaches to enhance safety. Intelligent transportation system technologies such as vehicle intrusion alert systems, sequential warning lights on tapers, and queue warning systems have been deployed in many states in the US. While innovation has occurred in systems alerting traffic and drivers of impending hazards, not much attention has been given to the training of staff involved with work zone setup, operation, management, and inspection.

In this paper, we present the results of a case study of using virtual reality to train transportation agency staff that inspect work zones for safety compliance. The presented work builds upon our recent work by developing training module for work zones that consist of human flaggers. Flaggers control traffic at work zones on two lane highways (one lane in each direction). In these instances, one of the two lanes is closed for road work, and traffic in both directions must take turns in using a single lane open to traffic. One flagger is located at the upstream work zone entry point in each direction and route traffic in a safe manner. Two lane roads are one of the most common type of roads in the US, particularly in rural areas. These roads also typically have high speeds, sharp curves, low sight distances, making it challenging for drivers to spot work zones and human flaggers.

Compliance with standard signage and traffic control devices is critical to safely routing traffic through the work zone. Transportation agency staff inspect work zones for compliance with the manual on uniform traffic control devices (MUTCD) and any state-specific standards. The inspection staff look for proper use of signage, channelizing devices, barriers, flaggers, etc. Any discrepancies from satisfactory performance are also recorded. A rating value is assigned for each factor based on discrepancies and deficiencies. Staff on the inspection team are trained in several areas. They need to be familiar with any inspection worksheet and associated evaluation categories. They also need to be familiar with the MUTCD typical applications (TA) for different facilities and work activities. TAs provide the standard layout and specifications for the placement of signage and temporary traffic control devices. The aforementioned knowledge attainment requires robust training of the personnel, which is difficult to accomplish without extensive field visits (i.e. prior experience).

The current state of practice is to review the documents related to temporary traffic control and reports from previous inspections, typically power point files with pictures. A new training approach based on virtual reality could offer a more realistic platform for staff to experience the conditions similar to those they will likely encounter in actual work zones.

II. RELATED WORK

A. Virtual Reality and Training

Several fields have used virtual reality for training. A review of literature found applications in education, medicine, media,

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mining, energy, and defense. One inherent advantage of the immersive environment is that it allows access to a wide range of scenarios that are difficult or infeasible to train in the real world [2]. McComas et al. [3] explored using VR to train children to safely cross an intersection. Training was tested at two school, one urban and one suburban, for crossing intersections. They found that students from the suburban school showed significant improvement after training and successfully transferred their skill to crossing at real-world intersections. Koskela et al. [4] used virtual learning in an occupational safety engineering course and compared it with a conventional lecture. The number of students reaching a set high score increased fourfold when virtual learning module was implemented.

Xie et al. [5] reported that a welding training module based on VR was able to achieve accuracies currently required in practice. Tanaka et al. [6] developed a virtual substation to train electricians for operating equipment and managing emergencies. They reported favorable performance and found VR to be a useful tool for training.

In medicine, Ahlberg et al. [7] reported that a VR-based training of surgery residents resulted in significantly fewer errors. Yang et al. [8] tested a VR-based training module for people recovering from a stroke. The performance of study participants improved after they were trained by the VR module. Improvements were noticed in walking speeds, community walking time and walking ability. Using VR to enhance the communication skills of medical students was studied by Johnsen et al. [9]. They found VR to be a useful training tool to improve communication between patients and doctors including correctly greeting patients and effective questioning for diagnosis. VR use for training emergency personnel such as firefighters has also been explored. Tate et al. [10] reported that a VR-based training of shipboard firefighters improved their skills and performance and that the performance translated well into the real world.

Despite the wealth of literature on using VR for training professionals in various disciplines, not much work has been done in using VR for training staff that inspect roadway work zones. Details of one study that reported using VR for training work zone inspectors is presented in the next section.

B. *Virtual Reality Training in Work Zone*

In this section, the study by Edara et al. [11] on the use of virtual reality for designing training modules for work zone inspection is presented. This is the only study in the literature specifically focused on training staff that inspect work zones for compliance. A training platform was developed using virtual reality technology and illustrated using Missouri Department of Transportation (MoDOT) data. The platform consists of two steps. The first step is a *learning* module which is founded on the historical knowledge gained by DOT staff from inspections dating back at least five years. The second step is an *immersive* module that places trainees in virtual work zones where their inspection performance will be observed and assessed. The developed training platform was assessed by 34 participants from MoDOT. The participants' background knowledge of work zones ranged from expert to novice.

The learning module quiz was developed to measure participants' performance. The quiz included questions from MoDOT inspection worksheet and the trainees rated the quality of temporary traffic control and signage. Figure 1 shows examples of defective signage that were included in the quiz. The quiz results revealed that the average score for participants was 44%. These scores validated the need for proper training of staff that inspect and rate work zones. The recommended rating for each question was based on the consensus of work zone experts from MoDOT.

Fig. 1. Example of deficient signage in work zone [11].

In the second part of the study, two scenarios of immersive virtual work zone were developed – a practice scenario and a test scenario. The work zone involved closure of a single lane in one direction of a four-lane interstate highway (with two lanes in each direction).

During the test, the participants called out any deficiencies in temporary traffic control and signage. The test results indicated that the average score for the participants was 79%, while 88% of the participants earned a score over 70%. It was recommended that MoDOT establish a minimum passing score (e.g. 70%). An overwhelming majority (97%) agreed that virtual reality offered a realistic and effective way to train inspectors. They also indicated that the virtual environment allowed trainees to explore various temporary traffic control features inside a work zone.

III. FLAGGER IMMERSIVE MODULE

In this section, the development of a scenario for flagging operations on a two-lane one-way work zone is presented. The objective of this module is to create a scenario with a human flagger directing traffic through a work zone. The scenario was created using field video of flagger operations on a two-lane highway in rural Missouri. The scenario creation process consisted of three stages. In the first stage, the field video was analyzed to determine the exact location of the work zone. After determining the location, the geometric design for the entire stretch of the work zone (from the advance warning signage to the end of work zone) was obtained. In the second stage, motion capture technology was used to replicate the behavior of a human flagger. The third stage of the process involved the integration of the environment, roadway section, flagger, and simulation of the movement of the inspection vehicle.

A. State Guidance on Flagger Operations

Missouri Department of Transportation's Engineering Policy Guide (EPG) provides guidance on flagging procedures in work zones [12]. The guidance pertaining to flagging procedure in long, intermediate and short-term stationary operations consists of four steps as explained in Figure 2.

Step	Procedures
 Step 1	• Setup cones as shown and return to shoulder • Remain facing traffic, with STOP paddle visible • Keep visual contact with drivers of stopping vehicles • Keep left hand raised with palm facing driver, signaling to stop
 Step 2	• Once traffic has stopped, move out towards the center of the lane • Keep Stop/Slow paddle in your right hand and position it out towards the center line, be sure not to cross the line with the Stop/Slow paddle • Keep visual contact with drivers of stopped vehicles • Keep left hand raised with palm facing driver, signaling to stop, until traffic has completely stopped
 Step 3	• Once you have confirmed opposing traffic is clear, pick up the middle cone and make your way back to the shoulder taking the cone with you • Be sure to keep Stop paddle visible to stopped traffic
 Step 4	• Once on the shoulder, rotate the Stop/Slow Paddle to Slow and release traffic • Direct traffic by signaling with your arm and waving vehicles through

Fig. 2. Missouri DOT Practice for Flagger Operations.

B. Geometric Design of Road Segment

MoDOT's work zone staff provided two drive-through videos of work zones in Missouri. Exact location and the boundary of the work zone was determined using online maps and video footage. The work zone was located at 38°44'38.4"N, 91°42'40.3"W on Rte. D in Callaway County in central Missouri. Next, the topology and landscape of the roadway segment was created using a Height. A Height Map is a raster image containing surface elevation data that can be displayed in 3D. Temporary traffic control devices were added to the segment.

C. Flagger Modeling

In this step, a model of a human flagger was created using motion capture technology. The movement of the flagger was collected from the field video. The Motive software was used to motion capture a 3D model from the video that is compatible with Unity. Figure 3 shows a researcher wearing sensors to emulate the flagger movement. The cameras mounted on the tall tripods shown in Figure 3 captured the researcher's movements.

Fig. 3. Capturing motion data using Motive.

D. Simulation

In this step, we synthesized all objects from the previous step, including the car model (in which the work zone inspector is seated), the flagger, and the roadway geometrics. The car is an auto-pilot mode, meaning it drives itself through the work zone. The inspector experiences the environment from the passenger seat of the vehicle. The VR scenarios were created using field video footage of a work zone as a reference. One flagger was located at each end of the actual work area (plus buffer space) inside the work zone. Figure 4 shows a screenshot of the flagger holding the STOP sign paddle standing on the shoulder next to the open lane. On the other end, the second flagger stands in the closed lane in front of a work truck. The flagger checks (via radio or cellular) with the other flagger if they have stopped traffic, then performs a visual check of the open lane (for any vehicles still using the open lane in the opposite direction), and then directs traffic to proceed slowly by turning the paddle to display SLOW sign.

Fig. 4. Flagger located in the open lane.

Figure 5 shows a user wearing the Oculus Rift head mounted device to experience the flagger scenarios. The completed training module was demonstrated to inspection staff at MoDOT. The MoDOT staff were highly receptive to the use of virtual reality for training inspectors on the proper flagger practices and commented on the benefits of the immersive experience that is lacking in their current training practices. The staff feedback included suggestions on improving roadway geometrics, adding missing signage, modifiying flagger actions (improving eye contact with the driver of an approaching vehicle, movement towards traffic, etc). The training module was revised based on their feedback.

Fig. 5. Participant wearing a HMD to experience the VR-based flagger training module (closed lane)

E. Testing Approach for the Immersive Module

The flagger scenarios can be incorporated into the inspector training module presented in Section II B. A short survey consisting of four questions is suggested to test the performance. These questions correspond to each step in the EPG flagger procedure. In Figure 6, the four rows correspond to the four steps shown in Figure 2. The first column describes the step, the second column provides a picture of the guidance, the third column provides a screenshot from the scenario that the participant experienced in the VR environment, and the fourth column poses the question. The answer key is shown in the fourth column for evaluation purposes, but will not be shown to the participant. Two approaches are feasible to conduct this survey. One approach is to ask the participant to call out any deficiencies while they are immersed in the virtual reality scenario. The other approach is to conduct the survey upon completion of the immersive scenarios.

Step	MoDOT EPG	Post-VR test	Question
Step1 :Stopping traffic			• Q: Is the flagger accurately positioned? • A: No. The flagger needs to face the driver of an approaching vehicle with the hand raised to indicate the driver to stop the vehicle.
Step2 :Traffic has stopped			• Q :Is the flagger correctly approaching the cones? • A: No. The flagger needs to move toward the centerline with the hand raised.
Step3 :Preparing to release traffic			• Q: Is the flagger correctly approaching the cone? • A: No. The flagger needs to approach the cone and face the driver.
Step4 :Releasing traffic			• Q: Is the flagger releasing the traffic correctly? • A: No. The flagger needs to point the direction of travel to the driver.

Fig. 6. Test questions for the flagger scenarios.

IV. CONCLUSION

Work zone training has not taken advantage of new technologies that could improve training effectiveness, immersion, cost, availability, and flexibility. Outdated training practices are not sufficiently engaging for the future generation workforce consisting of Millennials, Gen X and Z generations. In this paper, we extended the recently created VR-based inspection training module for work zones. Flagging operations are critical components of work zones on rural highways in many states. The immersive scenarios of flagger operations created in this paper are expected to complement the other work zone training scenarios and help offer a complete training package for transportation agency staff. In future research, the set of training scenarios can be expanded. Of particular interest are work zone scenarios for urban and rural areas, night-time and day-time conditions, different roadway types (freeway, arterial, two lane highways), and new interchange designs such as the diverging diamond interchange. In addition to creating new scenarios, the fidelity of the scenarios can also be improved to enhance realism and interactive features added to facilitate rating the traffic control elements of a work zone.

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