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A VR-Trainer for Forklift Operation Safety Skills

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Abstract: This research investigates how a Virtual Reality (VR)-based simulation could be used to train safe operation skills for forklift operators. Forklift operation is categorized as high-risk work by many occupational health and safety regulators and authorities due to high injury and fatality rates involved with forklifts. Therefore, many safety guidelines have been developed for forklift operators. Typically, forklift operation safety training is delivered based on instructional texts or videos, which have limitations in influencing people's safety behavior. Against this background, we propose a VR-based forklift simulator that can enable safe operation skills training through a feedback system. The training program consists of several modules to teach how to perform the basic tasks of forklift operation, such as driving, loading and unloading, following the safety guidelines. The system provides instantaneous instructions and feedback regarding safe operation. This training system is based on the model of "learning-by-doing". The user can repeat the training modules as many times as necessary before being able to perform the given task without violating any safety guidelines. The last training module tests the user's acquisition of all safety skills required. The user feedback from several demonstration sessions showed the potential usefulness of the proposed training system.

Key words: Virtual Reality (VR), training, forklift, safety

1. INTRODUCTION

Forklifts are used in various workplaces to transfer, lift and stack different types of loads. Despite their versatility and usefulness, forklifts are often involved with incidents, and the resulting human and financial cost of forklift-related incidents is substantial[1]. According to a research paper analyzing 14,625 occupational fatalities involving machinery from 1992 to 2010 in the US, 1,487 fatalities (10% of all fatalities investigated) were involved with forklifts for the period of time, making forklifts as the type of machine involved with the second largest number of deaths after tractors [7]. Due to such high injury and fatality rates involved with forklifts, forklift operation is categorized as high-risk work by many occupational health and safety regulators and authorities around the world.

Forklift operation requires the operator to have a high-level of safety skills. To increase forklift operators' safety skills and awareness, many safety guidelines and best practices have been developed and used for training purposes. Typically, these guidelines are communicated through verbal/visual instructions or in texts such as Code of Practice[2]. In this background, the use of Virtual Reality (VR) for forklift operation training has recently been proposed, and several prototypes have been developed

[1] https://www.safework.sa.gov.au/sites/default/files/forkliftsafety.pdf?v=1527223033
[2] https://www.safeworkaustralia.gov.au/system/files/documents/1703/industrial-lift-trucks-general-guide.pdf

[2][12][13]. However, these prior works were mostly focused on the visualization of potential dangers and safety risks, and they were limited in providing a learning environment in which the user can acquire transferrable, "hands-on" safe operation skills.

To address the issue, we propose a VR-based forklift simulator that can enable safe operation skills training through a feedback system. The system has its conceptual basis on the idea of "learning-by-doing". The training program consists of several modules, through which a user can learn how to safely perform the basic tasks in forklift operation, including basic driving, loading and unloading, while getting instantaneous instructions regarding safe operation and feedback on how they are performing. The rest of this paper provides the details of the concept and design of the prototype developed.

2. RELATED WORK

2.1. VR-based Training

Over the last two decades, VR systems have been increasingly accepted as a promising training platform for many industrial skills. The use of VR for training has been found to have a range of benefits when compared to traditional training approaches. A VR-based training environment can provide the user with a unique learning experience combined with multi-sensory inputs such as vision, sound, and haptics [4]. Also, a VR-based training system can enable "learning-by-doing" when such a form of learning is difficult to implement in the real environment due to the availability of equipment or facility, safety concerns, or cost constraints [4]. Due to these perceived benefits of VR-based training, several prototypes have been developed and tested for various applications, including surgical skill training [8], industrial assembly and maintenance skill training [3][4], and manufacturing system operation training [11], to name just a few. Most of these earlier works have demonstrated that a VR-based training system would be an effective alternative to traditional training methods such as instructional videos.

Gavish et al. [4] found that people trained in the VR platform outperformed the people trained based on an instructional video in terms of the error rate. Brough et al. [1] found similar results in the context of mechanical assembly operations. An extensive review found that there is clear evidence that the surgical skills (e.g., endoscopy and laparoscopy) acquired through a VR simulator-based training are transferred to actual operation room environments [8]. Additionally, Stefanidis et al. [9] found that trainees who received a proficiency-based laparoscopic training in a VR simulator retained the skills for the long term.

2.2. VR-based Training for Safety Skills

Many researchers suggested that VR-based training can be particularly useful for safety skills training for high-risk industrial activities, such as construction or mining [14], incident response [10], and industrial facility maintenance and operation [3][6]. This is because a VR-based approach can be an effective way to create a hazardous situation without posing a real safety risk to the trainee and train a person regarding how to behave and respond to the hazards in the situation through simulation. Most of the earlier developments of VR-based training system focused on the visualization of the hazardous situation and training skills related to what to do in response to the hazards. Specifically, skills related to risk identification, risk evaluation, and risk response planning were focused in the earlier works [5]. VR-based safety training has been found to have benefits in improving worker safety performance and also in terms of training cost [3]. However, it has been suggested that more future works are required to develop a VR-based safety training program that can cover all the risk management phases (i.e., risk recognition, risk evaluation, risk response planning, and risk controlling and monitoring) [5]. Several researchers have particularly emphasized the importance of realistic scenarios [5] and the facilitation of interactive learning [10][14] in VR-based safety skills training.

Several VR-based forklift simulators have also been developed for operator safety skills training purposes. The prototype developed by Yuen et al. [12], for example, included a few case scenarios of 'virtual accidents', but it was not designed to provide any instantaneous feedback to the user regarding their detailed actions. Similarly, the prototype developed by de Villiers and Blignaut [2] included a few scenarios simulating dangerous situations. In their simulator, the user can see his/her safety performance after the simulation is finished. A review of previous examples of VR-based forklift operation simulators revealed that prior works mostly focused on the visualization of hazards and training how to respond to the hazards in the given situation, but they have weakness in the aspect of interactive learning within the VR environment.

3. DESIGN OF VR FORKLIFT TRAINING SIMULATOR

In this section, we describe the design of a VR forklift training simulator developed in this research as a prototype. We note that the project focused on creating a VR-based simulation environment in which safety guidelines can be trained through interactive, reinforced learning based on feedback. The training content is scoped to only the essential forklift controls, including driving forwards/backwards, turning, changing gears, sounding the horn, controlling the forklift mast (up/down, left/right, tilt).

3.1. Training contents-‘Scenarios’

In the training simulator, the user is shown a list of training Scenarios from which they can choose (Figure 1). Table 1 shows the list of Scenarios and the tasks included in each Scenario. The training program is designed so that the user can learn the most basic forklift operation skills progressively as they go through the Scenarios in sequence. Users are required to complete all tasks to complete a Scenario. Upon successful completion of a Scenario, the user is taken back to the main menu and can start any other Scenarios. The user can pause the training at any time and return to the main menu or restart the current task/Scenario at any point in the simulation.

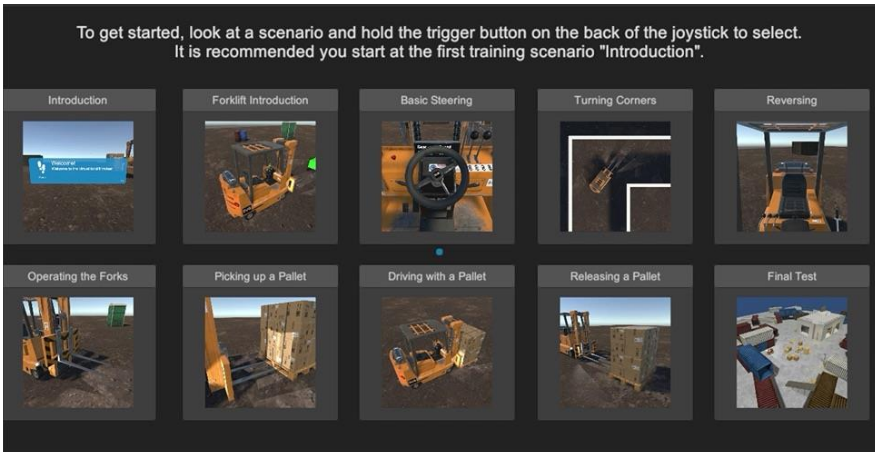

Figure 1. The Scenarios displayed in the main menu

Table 1. Training Scenarios

Scenario	Tasks included
Forklift Introduction Scenario	Changing forklift gears Driving forward Reversing
Basic Steering Scenario	Forward steering Backward steering
Turning Corners Scenario	Turning Corners Passing Intersections
Forklift Driving Test Scenario	Driving Turning Passing Intersection
Forks Introduction Scenario	Raising the forks Tilting the forks Shifting the forks Driving after moving the forks
Picking up a Pallet Scenario	Approaching a pallet Lifting the pallet
Driving with a Pallet Scenario	Driving with a pallet loaded Driving reverse with a pallet loaded
Releasing a Pallet Scenario	Releasing a pallet Backing away
Final Test Scenario	Comprehensive tasks combining all previous tasks

3.2. Feedback system

In each Scenario, except the Final Test, the user follows the instructions on how to operate a forklift safely and receives feedback messages on how they are performing. The system will constantly check the user's actions to ensure that they are complying with all safety guidelines embedded in the training program. If the system finds the user taking an unsafe action, an instantaneous warning or violation message is triggered, as shown in Figure 2. Specifically, thirteen different types of safety requirements were included in the design of the training program. These requirements were designed based on the safety guideline and requirements developed by SafeWork South Australia[3] and US Occupational Safety and Health Administration[4]. Below is the description of how the safety requirements work in the simulation.

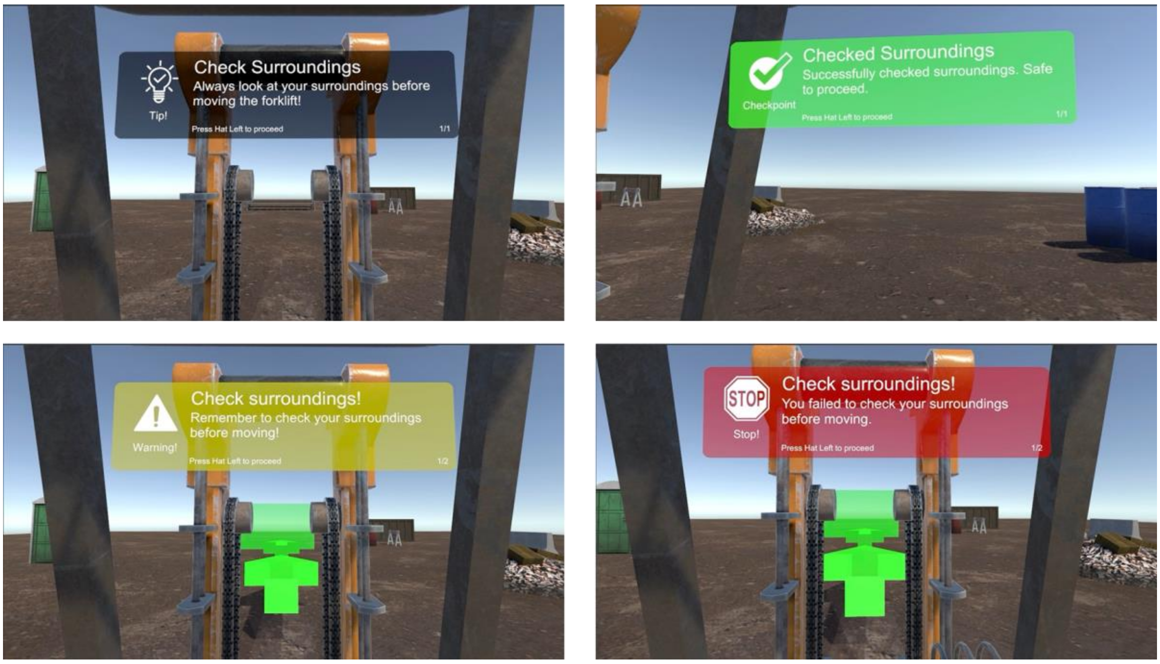

Figure 2. Various instruction and feedback messages generated in the simulator for interactive learning

Check Surroundings Before Driving. The system checks if the user checks the surroundings (by looking left and right) before driving the forklift. If the user stops driving for more than 10 seconds, they will need to check the surroundings again. The system warns the user if they start driving and have not checked their surroundings, and a violation is raised when the user continues to drive even after receiving the warning.

Drive Slowly. The system checks if the user is driving at a slow, safe speed. It warns the user if they are travelling at an unsafe speed (e.g., over 5 km/h). A violation is raised when the user exceeds the speed limit, which is set at 8 km/h.

Drive Smoothly. The system checks if the user is pressing down too fast or strongly on the accelerate or brake pedals. It warns the user if they have pressed a pedal too strongly over a set threshold.

Look in the Direction of Travel. The system checks if the user is looking in the direction of travel while the forklift is moving. It warns the user if they are not looking in the direction of travel while moving. A violation is raised if the user continues to look away from the direction of travel after warning.

Turn Wide. The system monitors if the user has performed a dangerously sharp turn. It warns the user if their turning angle is greater than the turning angle considered to be safe.

Sound Horn at Intersections. The system checks if the user has sounded the horn when approaching an intersection. It warns the user if they have forgotten to sound the horn. A violation is raised if the user ignores the warning and continues through the intersection.

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[3] https://www.safework.sa.gov.au/sites/default/files/forkliftsafety.pdf?v=1527223033
[4] https://www.youtube.com/watch?v=VR2j3hIGs_o

No Operation of Forks while Moving. The system checks if the user is operating the forks while the forklift is moving. Operating the forks may be either raising, lowering, tilting, or shifting. It warns the user if they operate the forks while moving.

Load Pallet Correctly. The system checks that the pallet is correctly loaded onto the forks when the user attempts to lift a pallet. It warns the user if the pallet is not correctly loaded.

No Collision. The system checks if the forklift collides with any objects in the surrounding, e.g. walls or objects. A violation is raised if the forklift collides with anything in the environment.

Approach Pallet Safely. The system checks if the forklift has approached the pallet at a safe speed. A violation is raised if the forklift collides with the pallet at high speed.

Check Surroundings at Corner. When turning a corner, the user will be required to check both left and right. A violation is raised if the user drives passed a corner and has not checked both their left and right surroundings.

Check Pallet Secured. The system checks if the pallet is safely secured on the forklift. Fully secured means the forks are completely tilted back. It warns the user if they attempt to drive with a pallet when it is not fully secured

Travel with Forks at Lowest Safe Height. The system checks if the user is driving with the forks at a safe height. Warns the user if they are driving and the forks are at an unsafe height.

4. IMPLEMENTATION

Based on the design described in the previous section, we implemented a prototype VR-based forklift simulator using commercial VR gaming devices. The prototype system used a desktop PC (CPU: Intel Core i7-7700k 4.20 GHz, RAM: 16GB, GPU: nVidia GTX 1070) running Windows 10 operating system for driving the VR simulation software and hardware. We used a Samsung Odyssey[5] VR head-mounted display (1440x1600 resolution at 90Hz refresh rate and 110 degrees field of view) which provided immersive visualization and also tracked the user's head motion. A Logitech G920 Driving Force[6] racing wheel and pedals were used as input devices for steering, accelerating, and braking the virtual forklift. The steering wheel also included buttons for sounding horn and changing gears. The system also used a Logitech Extreme 3D Pro[7] joystick to mimic the levers to operate the forks (e.g., raise, lower, tilt, and shift) while a set of buttons on the joystick can also be used for responding to feedback messages (e.g., show next or previous message) or navigating in the system menu. Figure 3 shows the prototype system in use.

The training simulation software was developed using a Unity 2018.3.12f1[8] 3D game engine and was organized into several modules. The Input module captures user input from the steering wheel, pedals, and the joystick, and feeds the input to the other modules, such as the Forklift module which simulates the movement and operation of a virtual forklift. The Scenario module defines and manages training scenarios. A Scenario consists of a list of training goals, tasks, safety rules, and messages which is progressed through as the user completes each task in the Scenario. While a Scenario is run, the Safety module checks if the user is following a certain safety practice required in the Scenario, and triggers feedback to the user as managed by the Feedback module.

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[5] https://www.samsung.com/us/computing/hmd/windows-mixed-reality/hmd-odyssey-windows-mixed-reality-headset-xe800zba-hc1us/
[6] https://www.logitechg.com/en-us/products/driving/driving-force-racing-wheel.html
[7] https://www.logitechg.com/en-us/products/gamepads/extreme-3d-pro-joystick.html
[8] http://unity.com

Figure 3. VR Forklift Simulator prototype system setup. A user wears a VR head-mounted display while interacting with the simulation using a steering wheel, pedals, and a joystick

5. USER FEEDBACK

We collected user feedback through various demonstration events. The participants included both novice users and those with previous forklift operation experience. Several participants provided qualitative feedback after trialing one or two Scenarios. Most users found the simulator is easy to follow, and the driving wheel and pedal settings are intuitive. However, some users were shown to experience some difficulties with using the joystick controller to change gears, maneuver the forks or move in or out of the menus. We postulate that it is a limitation with using a single joystick to control various features, but not an issue with the design of training content or feedback system. In the user trials, it was observed that many users were initially not familiar with the safety requirement to check the surroundings prior to moving the forklift, but after some playtime, they automatically checked their surroundings before moving the forklift. This observation provided anecdotal evidence that the training system can quickly influence the user’s safety behavior. Generally, the participants reported that they can clearly see the potential usefulness of the training approach, ‘learning-by-doing’ in the VR environment, especially for safe operation skills, because industrial safety has very much to do with how deeply internalized the safety guidelines are in one’s habitual behavior.

6. CONCLUSIONS AND FUTURE WORK

We developed a prototype of VR-based forklift simulator that can enable safe operation skills training through an interactive feedback system. The training program consists of several modules to teach how to safely perform the basic tasks of forklift operation, such as driving, loading and unloading, following the safety guidelines. The system provides instantaneous instructions and feedback regarding safe operation. This training system is based on the model of “learning-by-doing”. The user can repeat the training modules as many times as necessary before being able to perform the given task without violating any safety guidelines. A usability study conducted with a few forklift operators and several novice users provided preliminary evidence that the VR-based training system will be a useful and valid method for training basic safe operation skills, especially for inexperienced operators. For future work, we plan to conduct a formal user experiment to evaluate the prototype system, and we also plan to investigate further and extend the theme of VR-based safety training for other types of industrial skills.

REFERENCES

[1] John E Brough, Maxim Schwartz, Satyandra K Gupta, Davinder K Anand, Robert Kavetsky, and Ralph Pettersen. 2007. Towards the development of a virtual environment-based training system for mechanical assembly operations. Virtual Real. 11, 4 (2007), 189–206.

[2] Pieter Theunis de Villiers and A Seugnet Blignaut. 2016. Design evaluation of a forklift serious game. International Journal of Social Sciences and Humanity Studies 8, 1–17.

[3] Andrés Ayala García, Israel Galván Bobadilla, Gustavo Arroyo Figueroa, Miguel Pérez Ramírez, and Javier Muñoz Román. 2016. Virtual reality training system for maintenance and operation of high-voltage overhead power lines. Virtual Real. 20, 1 (2016), 27–40.

[4] Nirit Gavish, Teresa Gutiérrez, Sabine Webel, Jorge Rodríguez, Matteo Peveri, Uli Bockholt, and Franco Tecchia. 2015. Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. Interact. Learn. Environ. 23, 6 (2015), 778–798.

[5] Mohamad Kassem, Leila Benomran, and Jochen Teizer. 2017. Virtual environments for safety learning in construction and engineering: seeking evidence and identifying gaps for future research. Vis. Eng. 5, 1 (2017), 16.

[6] Jason Lucas, Walid Thabet, and Poonam Worlikar. 2008. A VR-based training program for conveyor belt safety. J. Inf. Technol. Constr. 13, 25 (2008), 381–407.

[7] Suzanne M Marsh and David E Fosbroke. 2015. Trends of occupational fatalities involving machines, United States, 1992–2010. Am. J. Ind. Med. 58, 11 (2015), 1160–1173. DOI:https://doi.org/10.1002/ajim.22532

[8] Neal E Seymour. 2008. VR to OR: a review of the evidence that virtual reality simulation improves operating room performance. World J. Surg. 32, 2 (2008), 182–188.

[9] Dimitrios Stefanidis, James R Korndorffer Jr, Rafael Sierra, Cheri Touchard, J Bruce Dunne, and Daniel J Scott. 2005. Skill retention following proficiency-based laparoscopic simulator training. Surgery 138, 2 (2005), 165–170.

[10] S Tretsiakova-McNally, E Maranne, F Verbecke, and V Molkov. 2017. Mixed e-learning and virtual reality pedagogical approach for innovative hydrogen safety training of first responders. Int. J. Hydrogen Energy 42, 11 (2017), 7504–7512. DOI:https://doi.org/https://doi.org/10.1016/j.ijhydene.2016.03.175

[11] Alberto Vergnano, Giovanni Berselli, and Marcello Pellicciari. 2017. Interactive simulation-based-training tools for manufacturing systems operators: an industrial case study. Int. J. Interact. Des. Manuf. 11, 4 (2017), 785–797.

[12] K K Yuen, S H Choi, and X B Yang. 2010. A Full-immersive CAVE-based VR Simulation System of Forklift Truck Operations for Safety Training. Comput. Aided. Des. Appl. 7, 2 (2010), 235–245. DOI:https://doi.org/10.3722/cadaps.2010.235-245

[13] Przemysław Zawadzki, Buń Paweł, and Filip Górski. 2019. Virtual Reality Training of Practical Skills in Industry on Example of Forklift Operation. In: Machado J., Soares F., Veiga G. (eds) Innovation, Engineering and Entrepreneurship. HELIX 2018. Lecture Notes in Electrical Engineering, vol 505. Springer, Cham. DOI: https://doi.org/10.1007/978-3-319-91334-6_7

[14] Dong Zhao and Jason Lucas. 2015. Virtual reality simulation for construction safety promotion. Int. J. Inj. Contr. Saf. Promot. 22, 1 (2015), 57–67. DOI:https://doi.org/10.1080/17457300.2013.861853