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Development and Evaluation of Remote Multi-Player Connection Technology for Forklift Mixed Reality Training System

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***Abstract*— Traditional forklift certification training typically requires trainees to queue up and wait at the certification site. For the trainees, there is a lack of training opportunities. This project has developed a Mixed Reality (MR) simulation training system to address these needs. The system is capable of meeting the requirements of trainees and enables remote monitoring and training for instructors. This system offers an MR multiplayer online training mode that allows instructors to simultaneously monitor the training progress and content of trainees. The research methodology involves multiple rounds of expert testing and suggested revisions.**

In the case of the third station for forklift operators, instructors require additional viewing interfaces to ensure the smooth completion of the task involving moving cylinders. Furthermore, when combined with the developed multiplayer connectivity system, practical validation was carried out. The research findings indicate that the MR simulation system can resolve the issue of insufficient training for trainees and provide instructors with a rapid and effective training mode.

***Index Terms*—Mixed Reality training system, Forklift, Multi-player connection technology.**

I. INTRODUCTION

This study is based on the integration of Mixed Reality (MR) technology and Machine Learning (ML) with physical interaction devices. It utilizes MR technology to create training and testing scenarios for forklift driver training. Additionally, it employs MR connectivity technology to enable remote supervision of both instructors and trainees, while also incorporating physical simulation interaction devices for forklift operation. This paper defines MR as an interface designed for the physical control of forklifts, which combines a large-screen display with a head-mounted display presenting a 360-degree virtual environment. This setup allows trainees to control the forklift according to their preferences, enabling them to complete skill-based certification test items.

Prominent consulting firm Frog Design believes that the fusion of Artificial Intelligence (AI) and MR has already entered the mainstream. By utilizing algorithms and user data, it can create excellent user experiences [1]. This approach can facilitate visualized learning of safe driving knowledge, immersive learning of hazardous driving scenarios, real-time assessment of driving behavior, and synchronous communication between instructors and trainees. Furthermore, through the analysis of Big Data in the cloud, it can present more optimized, professional, and real-time customized visualized data on the backend, identifying key issues in forklift driver training and enhancing their skills. This project aims to address the following issues:

A. Lack of automatic scoring and recommendation mechanisms for exam training.

In order to understand the actual operation of the forklift training center, this project conducted observations and interviews with Industrial Safety and Health Association (ISHA), the instructor at the Taichung Vocational Training Center. Their training methods are similar to those of a driving school, with instructors verbally instructing and sometimes even shouting due to mistakes made by trainees. These errors can sometimes lead to dangerous and unexpected incidents. Therefore, there is an urgent need to transform and improve the overall forklift training mechanism, especially by using interactive technology to achieve automatic scoring in the digital exam training mode. Additionally, it should recommend training on areas where trainees are prone to making mistakes based on their individual progress, in order to achieve the desired skill certification goals.

B. Improving the existing training model

In terms of practical skills training, reliance on the vocational training center's actual driving facilities and instructor assistance is necessary to complete the training according to regulations before certification. Even though there are currently forklift simulator training options available, there is no VR training mode that allows multiple trainees to connect simultaneously. For novice trainees, once they use VR equipment, they need to individually explore and master the relevant skills for controlling the forklift. If there is timely guidance and assistance from connected instructors, trainees can complete the prescribed training tasks more efficiently, as instructors can assess the issues

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through a shared perspective. Through the connectivity mechanism, instructors can even provide remote teaching to trainees from all over Taiwan. As a result, when trainees arrive at the actual testing site, they can operate the forklift more proficiently for training or certification purposes.

C. Evaluating the realism of VR simulation training equipment

VR applications for occupational safety training have seen numerous cases, but there is a limited focus on the realism of VR training equipment concerning its influence on training content and scenario-based learning. Since the application of VR technology to forklift training is expected to be one of the pathways for future skill certification, consider vocations such as forklift or crane operation, which are not easily accessible and require specific locations for training. In regions with limited transportation access, remote islands, indigenous communities, and other inconvenient locations, there is a need for alternative simulation equipment for training. For this reason, it is necessary to develop and assess its training effectiveness.

II. RELATED WORK

Government and businesses increasingly prioritize worker safety through training. Yet, traditional training methods are inefficient and accident-prone. Virtual reality has proven to be a valuable tool in safety training scenarios, including dental surgery [2], construction safety [3], and fire safety [4, 5]. It has led to improved safety outcomes and reduced training costs.

An analysis of occupational hazards in forklift operation has shown that many accidents result from operator mistakes during the operation [6]. These errors can be attributed to inattention, misunderstandings, or poor judgment [7, 8]. When operating a forklift, it frequently navigates narrow and confined pathways. If the route isn't adequately planned, it may come into close proximity with people, materials, and equipment.

Currently, forklift training is limited in duration, allowing only one person to train with a vehicle at a time, leading to wait times for others. This project aims to address the issue by developing a comprehensive Mixed Reality-based forklift training system to improve learning outcomes.

Novice forklift trainees face risks in operating forklifts, and it can be challenging to find a suitable practice field. Chen [9] proposes integrating training courses through computer simulations of common accidents and collapses to boost trainee engagement and safety awareness. Mogessie et al. [10] showcased an innovative training system for managing metal additive manufacturing machines (EOSM290) in a virtual, immersive learning environment. The system includes a virtual instructor to address any doubts or fears during operation.

III. DEVELOPMENT OF MR SYSTEM

This project is a second-year grant funded by the National Science and Technology Council. The research results from the first year have already been presented at international academic conferences. This paper is a continuation of the first-year project, aiming to design and develop a Mixed-Reality training system suitable for both trainees and instructors in the forklift certification field. However, the prototype system from the first year still requires ongoing optimization to meet the expectations of instructors and trainees (Fig. 1).

Fig. 1 3D simulation of the forklift at the certification field.

Table 1 indicates that there are still some challenges to overcome in the third-station warehousing loading and unloading tests. The VR and PC versions presented in Table 1 represent experiential devices that integrate different equipment. The PC version indicates that trainees do not need to wear a head-mounted display, but they only need to observe the large screen in front of them. In contrast, the VR version requires the use of HTC's Vive Pro equipment. Both versions require the control devices necessary for forklift operation, including a steering wheel, handbrake lever, lift lever, tilt lever, inching pedal, brakes, and throttle, among other functions.

The reason for having these two types is that this project collaborates with the ISHA. After experiencing the systems, ISHA provided feedback and strongly recommended having two versions to choose from. This is particularly important because some individuals may experience dizziness or discomfort when using VR devices, and it is not feasible to compel trainees to use VR for forklift simulation training.

Table1 List of unresolved issues for the PC and VR version.

Items	Details	PC	VR
wooden pallet	• Incorrect Wooden Pallet Lifting Position: The fork is not positioned correctly at the hole. • Incorrect Insertion into the Hole: There should be an audible alert (e.g., sound notification) when the fork is	V	V

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	not inserted correctly, either not fully or less than 10 cm deep into the hole.		
forklift	• Distance Warning for Forklift from Front Rack: Implement an audible warning when the forklift is approaching too close to the front rack. • Reverse Radar for Forklift: Install a reverse radar system to assist in judging the distance when the forklift is moving in reverse. • Fork Elevation Height Prompt: Provide a height prompt to indicate when the fork is raised to a suitable height for depositing cargo. • Adjustment of Lift Speed: Modify the lifting and lowering speed of the forklift's lift lever for improved control and safety.	V	V
position	When re-experiencing a level, it should not require repositioning, and there should be an optimization of the positioning method for a smoother and more user-friendly experience.		V
sight	Adding buttons for four-directional viewpoints or a top-down view would be beneficial, as it would allow users to see the overall position of the forklift from different angles. This can greatly enhance the user's situational awareness and improve the training experience.	V	
interface	Displaying the left and right hands as well as the right foot with VR trackers is a valuable addition to the VR training system.		V

The aforementioned issues require continuous efforts from the team members, involving adjustments and refinements to the prototype. During this process, consultation with technical personnel from ISHA is also necessary. There are three main issues still present in the overall third-station test:

(1) Trainees' difficulty in judging obstacles such as fork blades and wooden pallets (including proper insertion, assessing the distance to the rack, and height determination).

(2) Unrealistic perception of objects in the trainee's field of view.

(3) Problems with the wooden pallet and fork model (trainees may think the fork is inserted into the wooden pallet hole when it is actually inserted below the wooden pallet).

As a result, the development team is making further adjustments and system optimizations within the Unity program. They are also working on refining the Arduino programming within the Mixed-Reality equipment and ensuring the durability of the hardware. This will facilitate the smooth achievement of the expected goals during subsequent real-world testing. Figure 2 illustrates the code content of the core programming language.

```
//實插
//_mastTilt = logtichControl.MastTiltForwards ? 1 : logtichControl.MastTiltBackwards ? -1 : 0;
//_forksVertical = logtichControl.ForkUp ? 1 : logtichControl.ForkDown ? -1 : 0;

//Pot 2
if (GetAllJoysEvent.DegreeBar_Rz_傾斜 < 0.0f) _mastTilt = 1;
if (GetAllJoysEvent.DegreeBar_Rz_傾斜 < 0.135f && GetAllJoysEvent.DegreeBar_Rz_傾斜 > 0.0f) _mastTilt = 0;
if (GetAllJoysEvent.DegreeBar_Rz_傾斜 > 0.135f) _mastTilt = -1;
//Pot 1
if (GetAllJoysEvent.UpDownBar_Ry_升降 < 0.18f) _forksVertical = -1;
if (GetAllJoysEvent.UpDownBar_Ry_升降 < 0.35f && GetAllJoysEvent.UpDownBar_Ry_升降 > 0.18f) _forksVertical = 0;
if (GetAllJoysEvent.UpDownBar_Ry_升降 > 0.35f) _forksVertical = 1;
```

Fig. 2 Unity code of forklift simulation

Figure 3 displays the control situation of the forklift in Unity editor mode. This requires the use of buttons on the Logitech steering wheel to control functions such as switching the viewpoint, adjusting height, and moving the coordinates left and right. These buttons also enable trainees to quickly grasp the relevant positions of the forklift, facilitating the execution of the third-station warehousing loading and unloading tasks.

Fig. 3 3D Forklift simulation and other hardware

IV. MULTIPLAYER VR CONNECTION

While Photon is a popular choice, the suitability of any networking solution can also depend on the specific requirements and constraints of your VR project. It's essential to evaluate different options, consider factors like the size of your user base, the complexity of your VR application, and your budget, and choose the networking solution that best aligns with your project's needs and goals. Photon PUN (Photon Unity Networking) is a multiplayer networking solution built in C++, designed specifically for Unity engine developers to enable multiplayer interactions within the same game scene (Fig. 4).

(1) Multiplayer Networking: Photon PUN facilitates the implementation of multiplayer networking, allowing multiple players to interact within the same game. It handles various aspects such as connection, synchronization, and communication (Fig. 5).

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(2) Room and Lobby System: Photon PUN provides a room and lobby system where players can create or join different game rooms and discover other players through lobbies.
(3) Custom Synchronization: With Photon PUN, you can customize the synchronization of in-game objects to ensure consistency in what all players see in the game. This includes player positions, animations, object states, and more (Fig. 6).
(4) RPC (Remote Procedure Call): Photon PUN enables remote procedure calls between players, facilitating communication among players.
(5) Automatic Server Distribution: Photon PUN supports automatic server distribution and has wide platform compatibility, including PC, mobile devices, and consoles. This allows you to create cross-platform multiplayer games.

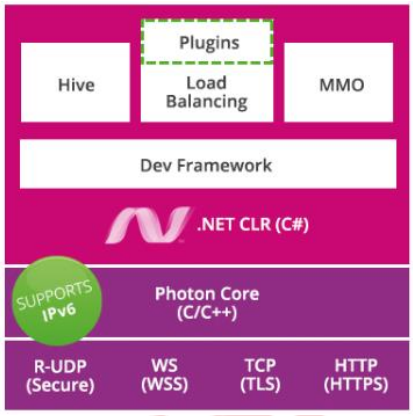

Fig. 4 Photon High-Level Architecture (Source: photon website).

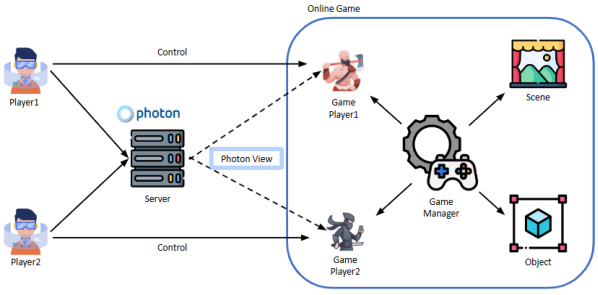

Fig. 5 Overall Photon architecture in game

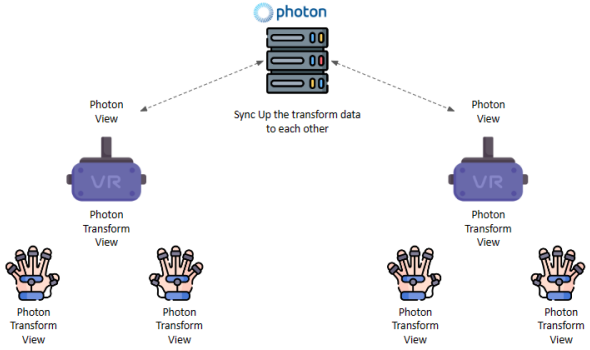

Fig. 6 Photon PUN Configuration

The MR prototype developed in this project requires the assistance of forklift instractors throughout the development process. They are responsible for actual operations and a detailed examination of the skill-based certification tasks for the third station. During this expert validation phase, feedback on areas for improvement in the simulation system and constructive suggestions can be provided, as shown in Figure 7.

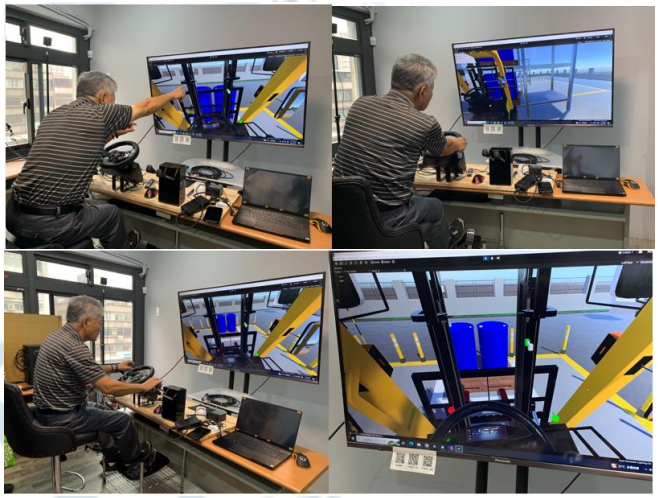

Fig. 7 The actual operations and improvement suggestions from the forklift instructor.

V. OPTIMIZING MR SYSTEM

After expert testing, it was found that there are still some issues that need further optimization in this MR training system. Figure 8 shows the overhead position of the forklift at the third station and the correct method is to rotate in place with the intersection of the red lines as the center when a rotation direction change is needed (Fig. 8).

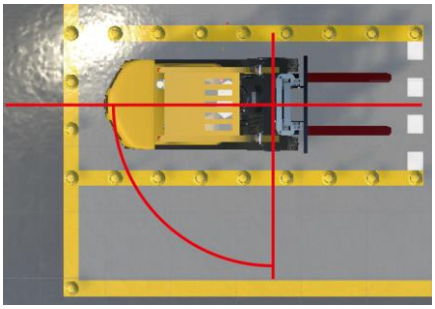

Fig. 8 Overhead view of parking position and reference position during rotation

In order to allow users to complete the steps easily by following a mnemonic while experiencing it, the steering wheel angle, rear wheel rotation angle, and body rotation angle of the simulated forklift have been adjusted to match those of a real forklift. To make the simulated controls more closely resemble the operation of a real forklift, the steering wheel angle after being turned to the extreme and the rotation angle of the forklift's rear wheels have been adjusted to match those of a real forklift (Fig. 9).

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Fig. 9 Body rotation angle of the simulated forklift

When users are experiencing the third station, where they need to place the pallet behind the shelves, it is important to provide feedback to let them know if it's in the correct position. Therefore, incorporating audio cues, text messages and pop-up window can ensure that users are aware of whether they have placed the pallet within an acceptable range during the experience (Fig. 10).

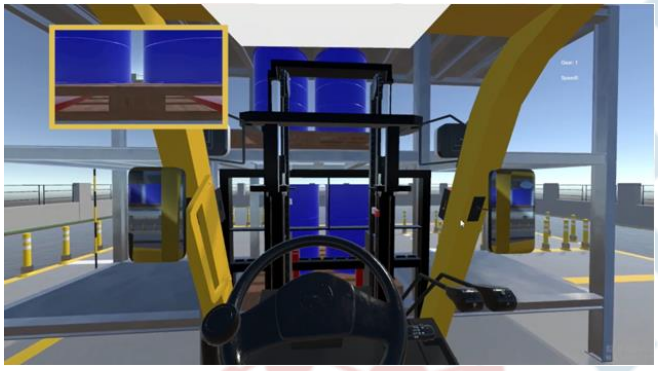

Fig. 10 Pop-up window of pallet details

In PC mode, to allow users to stay focused on the experience without being distracted by using the mouse, many camera angle functions can be called using the buttons on the Logitech G927 steering wheel (Fig. 11), as configured.

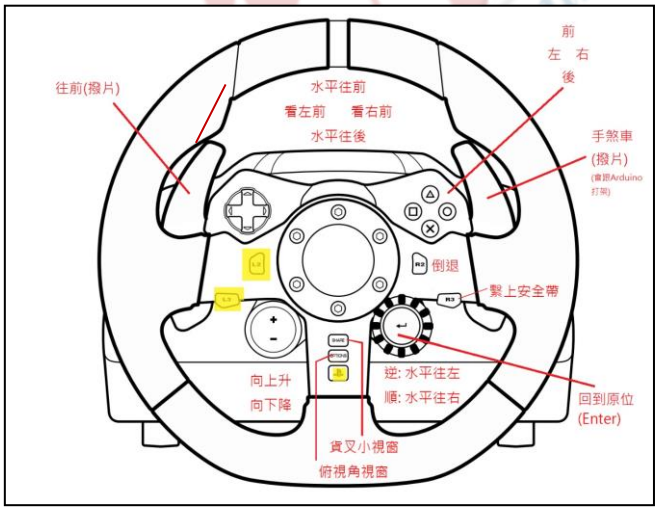

Fig. 11 Logitech G927 Explanation of Steering Wheel Button Function

VI. RESULT AND DISCUSSION

It is important to bridge the gap between developer intentions and user perceptions in the MR training system to ensure a safer and more effective learning experience. Here is how to address these concerns:

(1) User Experience vs. Developer Intentions: Developers may not always account for the user's perspective and sensory experience within the virtual space. To mitigate potential safety issues, consider incorporating realistic collision effects that are more tangible for trainees. This can help users better perceive interactions in the virtual environment, reducing the risk of workplace safety incidents.

(2) Enhancing Forklift and Pallet Handling Skills: In the third station, where precise judgment regarding forklift fork insertion into wooden pallets is crucial, the simulation system should include collision sounds and visual indicators. These features can reinforce the trainees' control skills and help them understand the successful execution of this task through auditory and visual cues.

(3) Forklift Steering System: Since the forklift's steering system is different from standard automobiles (rear-wheel steering), trainees should be informed about the specific steering behavior. Visual cues and guidance can be added to the simulation to help trainees understand when to turn the rear wheels to 85-90 degrees. Emphasizing the importance of minimizing the turning radius can reduce the risk of collisions with racks in the training scenario.

By addressing these issues and integrating feedback from both developers and users, the MR training system can provide a more realistic and effective learning environment for forklift operation skills.

The MR forklift training system aims to provide analog training environments for forklift operators, allowing them to practice and enhance their skills without the risks associated with real forklift operations. The content of assessments and evaluation criteria play a crucial role in ensuring the effectiveness and safety of the training program. This MR forklift system developed in this study requires testing through remote connections between trainees and instructors. The evaluation questionnaire consists of six assessment dimensions, as follows:

(1) Time Efficiency: The system can measure how quickly and efficiently the operator completes tasks while maintaining accuracy and safety.

(2) Load Handling Accuracy: Assessing the operator's ability to position loads accurately and without causing any damage during lifting and lowering.

(3) Safety Compliance: Evaluating how well the operator follows safety guidelines and procedures during the simulation.

(4) Avoidance of Collisions: Measuring the number of collisions or near-miss incidents to determine the operator's awareness and responsiveness.

(5) Corrective Actions: Providing feedback and points based

on the operator's ability to recognize and correct errors during the simulation [11].

(6) Knowledge Retention: Assessing the operator's ability to apply lessons learned in subsequent simulations, indicating knowledge retention and skill improvement.

The above assessment criteria will be measured on a Likert Scale ranging from 1 to 5, with at least 30 participants conducting usability evaluations immediately after the experiment to confirm their user experience feedback.

VII. CONCLUSION

The integrated virtual and real forklift system developed in this study requires continuous optimization and refinement, particularly regarding the integration of software and hardware components. Often, solving one issue can lead to the emergence of another. In such cases, the research and development team must demonstrate patience and resilience to overcome these challenges.

Another significant contribution of this research is the multiplayer online distance training system. Preliminary connectivity tests have been successfully completed. The IISHA recognizes the value of this system. It allows trainers in Taipei to provide timely guidance and corrections to trainees located in certification centers in other areas, such as Pingzhen (Taoyuan city) and Wuri (Taichung city) Training Centers. This ensures that trainees can receive instruction as smoothly as they would in an on-site training class.

Subsequent experiments will be conducted in remote training mode, connecting instructors and trainees at both ends to assess the effectiveness of trainees. The entire process will be recorded, and post-training evaluations and analysis will be carried out based on the recorded sessions.

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