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Development of Laborer Digital Twin Generation and Visualization Function for Hazard Prediction in Off-Site Training

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Abstract: We developed an MR-based system to enhance safety education for hazard prediction in off-site training by generating and visualizing digital twins of laborers. This system focuses on digitizing full-body movements, particularly foot movements and postures, to identify unsafe behaviors during training. Through trials with Vietnamese technical intern trainees, the system effectively identified these issues, highlighting its potential to improve safety training by providing detailed feedback on unsafe behaviors.

Keywords: Construction industry, safety education, MR, digital twin, unsafe behavior

1. Introduction

The number of fatalities due to occupational accidents in Japan has been decreasing, yet about 800 people die each year (Ministry of Health, Labour and Welfare, 2022). Among these fatal accidents, the construction industry accounts for the highest percentage, highlighting the importance of safety education for laborers at construction sites. Off-site training, while having challenges in practical exercises, offers advantages in terms of ease of scheduling.

Since 2018, the use of VR (Virtual Reality) for safety training has been widely studied in the construction industry and fire safety training, with evidence showing that VR is more effective than traditional training methods (D. Scorgie et al., 2024). Muguruma et al. (2024) developed a system providing a function to construct a digital twin of the laborer's head and hand movements during training, reproducing the laborer's behaviors in a VR environment. This system demonstrated the potential to trigger awareness of unsafe behaviors during reflections by laborers and safety managers.

In the construction industry, missing steps or uneven surfaces can lead to serious accidents, such as slips, trips, and falls. Therefore, foot movements are important. This study aims to develop a MR (Mixed Reality) training system that enables monitoring foot movements and posture by using a full-body digital twin to improve the training process.

2. Method

2.1 Requirements specification

The system utilizes a full-body avatar in an MR environment to achieve two key objectives: (1) To facilitate laborers' understanding of procedures and actions, allowing them to easily comprehend the correct steps and behaviors through a work model created by the safety manager, and (2) To promote reflection on training and the correction of unsafe behaviors between laborers and safety managers. Laborers can review their actions from a third-person perspective, making it easier to identify unsafe behaviors, while safety managers can better understand issues from the laborers' viewpoint. Additionally, the interaction between laborers and safety managers enables them to specifically point out overlooked aspects.

2.2 System development

Based on the requirements, we developed a training system using MR technology. We used the HoloLens 2 (Microsoft, 2024) as the MR headset. For the full-body sensing device, we employed the mocopi, developed and manufactured by SONY (SONY, 2024). The laborer digital twin generation feature captures motion data obtained through mocopi and integrates it into a full-body avatar. This allows the player's actions within the MR virtual space to be saved as a work model.

The laborer digital twin visualization feature visualizes the work model saved in the MR space by the laborer digital twin generation function. This feature allows the user to control the avatar through buttons, providing four functions: start, pause, toggle avatar visibility on/off, and reset the avatar's position.

The multiplayer feature enables multiple users to participate in the same virtual space. Through MR/PC applications, several users can synchronously join the system, allowing all participants to observe and review each other's work procedures and reflections.

2.3 Practice Method

The procedure consists of four steps: (1) the laborer checks the training task using the work behavior model (digital twin) pre-registered by the safety manager, (2) the construction practice is carried out with the laborer wearing an MR headset and sensors, and (3) the laborer and the safety manager together review the laborer's digital twin to check for unsafe behaviors, (4) an interview is conducted to discuss the advantages and areas for improvement of the system. No materials other than this system are provided. During step (2), the safety manager observes the laborer's viewpoint displayed on the PC screen. During step (3), both the laborer and the safety manager wear MR headsets to review the laborer digital twin and work behavior model. The laborer reflects on their behaviors and identifies any unsafe behaviors. Afterward, the safety manager provides guidance to the laborer while viewing the laborer digital twin.

Figure 1 illustrates the workflow of the laborer's movements during the step(2). The training process involves moving and installing gypsum boards, a key task in interior finishing work in the construction industry. This practice was conducted at a warehouse of Shin Nihon Kenko Corporation in Japan, targeting one Vietnamese technical intern trainee.

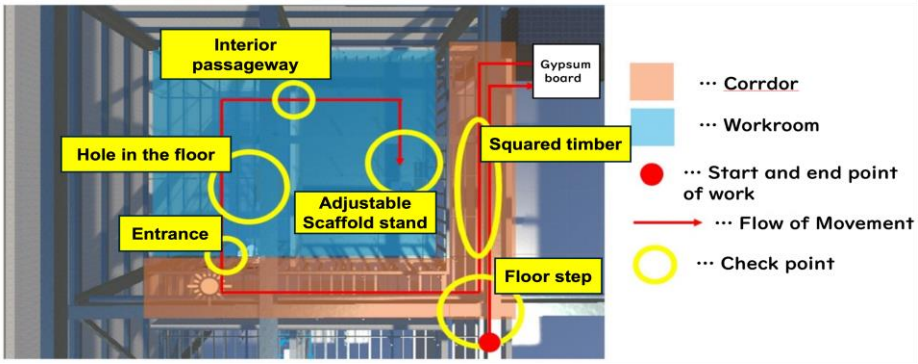

Figure1. Workflow diagram for training implementation

3. Result

In the interview conducted after the practice, the laborer expressed that it was easy to understand their own movements and that reflecting on these movements helped them better understand their actions and learn from them. Additionally, the safety manager noted that being able to review the training while observing the laborer's actual movements made it easier to identify and point out unsafe behaviors.

Figure 2 compares the laborer’s actions in both real and virtual environments during the practice, with the left side showing the laborer in the real world and the right side showing the

laborer as seen from the PC screen. Scene 1 depicts the laborer lifting a gypsum board, while Scene 2 shows the laborer carefully moving near a hole in the floor. In Scene 2, it can be observed that the avatar's head movements are linked to the laborer's line of sight.

The practice highlighted an instance of unsafe behavior determined by overlooking a step difference. Figure 3 shows the laborer's digital twin on the left and the work behavior model on the right. A comparison of the feet shows that the laborer's avatar is passing over the step without lifting his right foot. Actually, the laborer missed the step. Noticing errors in foot movements like this can raise awareness and help prevent accidents.

Figure2. Comparison image between Real and Virtual

Figure 3. Comparison of foot movements on a step

4. Discussion

According to interviews, reflecting on their actions using a full-body avatar helped participants understand how they were moving and proved to be an educational experience. Furthermore, comparing their movements with those of the construction sample avatar led to reflections that helped them recognize their unsafe behaviors. For example, in the early stage of the training, there was a noticeable difference in the foot movements between the sample construction avatar and the actual construction practice avatar regarding a step that was the focus. This revealed that the laborer had not noticed the step, leading to the identification of a potentially dangerous behavior. The contribution of this study is that it revealed a system that triggers awareness of potential unsafe behaviors related to laborers' feet and posture.The use of a full-body avatar enabled the identification of unsafe behaviors related to the laborer's foot movements, which is a key feature of this system.

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