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DEVELOPMENT OF TOOLS FOR EXPANDING THE USE OF VIRTUAL REALITY (VR) TECHNOLOGY IN THE FIELD OF CONSTRUCTION SITE FALL PROTECTION

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Abstract

In the construction industry, the occurrence of work accidents is considered to be a critical issue. With advancements in technology, various innovative tools and methodologies have emerged that may provide solutions to mitigate this risk. One of these technologies could be virtual reality that has the potential to enhance worker safety by providing a controlled environment for practicing relevant safety tasks during safety training. The objective of the research and development was to create a system that links fall protection equipment in the physical environment with the virtual space. This study presents a comprehensive examination of the methodology, outcomes of the tool development, and the evaluation of this system.

Keywords: *health and safety, fall protection, virtual reality, AEC industry.*

1. Introduction

The risk of accidents at work in the construction industry is particularly high. It has been presented in research that between 2001 and 2020, 5% of all accidents at work in Hungary occurred in the construction industry, and in a narrower 5-year period between 2014 and 2018, 17% of accidents were caused by workers falling to a lower-level **[1]**. This ratio shows that it is of paramount importance to investigate how to prevent accidents at work caused by falls from a height. With the development of technology, several innovations are emerging that could provide solutions to the above-mentioned problem. One of these is virtual reality (VR) technology. Researchers have explored the various possibilities for the use of VR in the construction industry, with a large number of studies focusing on architectural design support, architectural visualisation, building information modelling (BIM), quality control, and education **[2]**. In recent years, there have been tool developments **[3]** and publications that focus on the use of VR technology for fall protection **[4]**. This paper presents details of a research and tool development project that investigates the feasibility of combining virtual space with real fall protection tools, thereby expanding the application of VR technology for fall protection.

2. Introduction of research and tool development

2.1. Choosing the right VR and fall protection equipment

The first step of the research was to identify the VR and fall protection tools that could be used to achieve the development objectives. Professional VR devices can typically be divided into two main categories, standalone VR solutions and PC VR solutions. A major advantage of standalone VR solutions is that the applications are run on the device and therefore do not require a computer connection. This solution gives users much more freedom of movement and freedom of action compared to wired PC VR glasses. There are two possible ways to manage the running applications, one is to use controllers and the other is hand tracking. For the hand tracking, devices typically use an infrared camera to determine the position of the hand. From the point of view of the device, this solution has the disadvantage that it is difficult or impossible to apply it to other object tracking in addition to hand tracking.

In the case of PC VR solutions, the VR goggles are connected to a computer by a wire or, in some devices wirelessly, and the application is running on the computer. The VR application is typically handled by controllers as well, but there are some manufacturers that provide various developer solutions for custom accessories. Taking this into account, the Vive PRO VR set from HTC was selected for this research and device development, and a wireless adapter was added to improve its mobility. The product can be extended with a sensor called VIVE Tracker 3.0, which can be used to integrate fall protection devices into virtual space.

One of the most used fall protection devices is a lanyard with a shock absorber, which is easy to learn and requires no prior training. A lanyard with a shock absorber has one end attached to a body or waist strap on the user and the other end attached to a mooring point. Anchoring to the mooring point shall be a twist lock carabiner or screw gate carabiner or scaffold hook carabiner. Looking at the possible devices, it can be concluded that twist lock or screw gate carabiners vary in size between 10 and 15 cm, which is not sufficient to secure the HTC Vive Tracker 3.0, which measures approximately 8 cm. It could not work without affecting the functional operation of the carabiner. Scaffold hook carabiners are significantly larger, averaging 21-35 cm in length, which may be suitable for mounting the sensor. Considering the above parameters, the Portwest FP51 type Y strap equipped with FP 35 type scaffold hook carabiners were selected for the research.

The tools used in this research are shown in Figure 1.

Figure 1. *Tools used in the research: (1) HTC Vive PRO VR glasses, (2) VIVE Wireless Adapter, (3) SteamVR Base Station 2.0, (4) Portwest FP51 Y sling, (5) Portwest FP35 hook carabiner, (6) CADO AT 150 fixed mooring point, (7) CADO AT 150 fixed mooring point.*

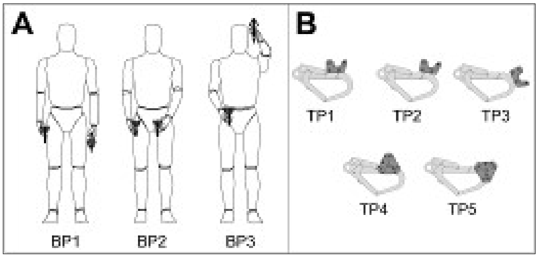

Figure 2. *Examined (A) body and (B) sensor positions.*

2.2. Examining possible solutions through 3D analysis

HTC Vive Pro uses the SteamVR Base Station 2.0 to track the spatial movement of the user and determine the position and movement in the virtual space. For this it is using signals reflected from sensors on the VR glasses, controllers and the Vive Tracker 3.0 sensor. The aim of the test was to determine the correct position of the base stations, including the position of the sensor on the carabiner.

The base station can detect in the vertical direction 110° in the horizontal direction 150° at a range of 7m [5]. The size of the "playing field" using two base stations is 5 m^2, which can be extended to 10 m^2 -re using 4 base stations [6].

A three-dimensional analysis of the possible configurations was carried out using ArchiCAD 25 design software, in which the spatial configurations were modelled (Figure 3.), considering the body positions and sensor positions (Figure 2.).

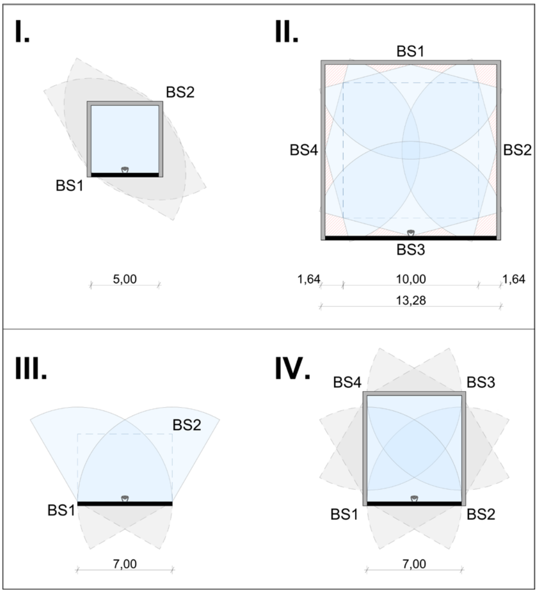

Figure 3. *Possible configurations for base stations.*

The "camera" tool in the software provides the possibility to set the real position and the exact field of view for the base stations. In addition to the position of the base stations, the analysis also included the visibility of the sensor (**Figure 2.** B) mounted on the carabiner in the different possible positions of the three body positions (**Figure 2.** A) that occur during use. For reliable operation, at least three sensors from at least two base stations must be visible on the sensor at the same time. The study recorded the number of sensor visibility from each base station on the left and right hand carabiners for different base station configurations (**Figure 3.**), in different body and sensor positions (**Figure 2.**), As a first step in the analysis, the proposed base station positions in the manufacturer's instructions were examined (**Figure 3.** I., II.). The proposed position of the base stations is defined so that the user should stand in the center of the space, if possible. It is not feasible for this situation as the mooring points have to be fixed to some vertical surface, e.g. a wall. In the case of the four base station set up (**Figure 3.** II.), there are many areas next to the wall surfaces that are outside of the proposed detection range of the base stations. For the two-base station configuration (**Figure 3.** I.), it was found that in the examined three body positions, the carabiner, and the sensor on the hand (BS2) are not visible, so there is a risk that the position of the carabiner in virtual space may be inaccurate during its use. Based on the experience of the preliminary study, two configurations (**Figure 3.** III., IV.) were defined to ensure that the base stations have a proper view of the sensors.

It was found that for configuration III, enough sensors are visible from all three body positions and for different sensor positions (**Figure 2.** TP1 and TP2). In the other cases, the number of sensors visible was less than three. For configuration IV, all sensor configurations in all body positions ensured that at least three sensors were visible from at least two base stations. Furthermore, by examining the possible positions of the sensors, it was also found that sensors placed on the upper plane of the carabiner (TP1, TP2, TP3) are less likely to be obscured. Looking at the sensor positions TP1, TP2, and TP3, there is no significant difference between them.

2.3. Analysis of possible solutions through physical testing

After the analysis in virtual space, the devices were physically tested. The main objective was to determine how the sensor could be attached to the carabiner in a way that would not interfere with the operation of the carabiner, would not prevent the carabiner from being hooked into the mooring point, and would not risk damaging the sensor. During the tests, the attachment of the carabiner to two different mooring points was examined to determine which one might be suitable for future VR development. The first was a CADO AT 180 fix anchor made of a single-point steel plate and the second was a CADO AT 150 fix attachment point with two fixing points. To avoid damage to the Vive Tracker 3.0, a 3D-printed replica of the device was attached to the carabiner for testing (**Figure 4.**). The physical tests were based on the sensor positions shown in **Figure 2.**

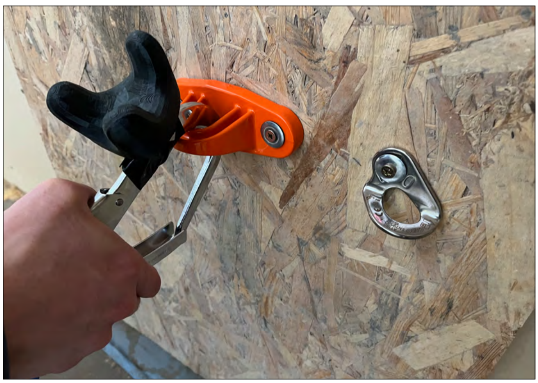

Figure 4. *Physical testing.*

The testing identified the following statements:

- in the case of TP1, the sensor is highly interfering with the release of the carabiner locking mechanism, but it does not affect the hooking of the carabiner in the anchorage point;
- -n the case of TP2, the sensor slightly interferes with the opening of the karabiner, it does not affect the hooking of the karabiner in the anchorage point;
- in the case of TP3, the sensor does not affect the opening of the karabiner, but the sensor may be damaged when the karabiner is hooked;
- in the case of TP4, the sensor is highly interfering with the release of the carabiner locking mechanism, it does not affect the hooking of the carabiner to the anchorage point;
- in the case of TP5, the sensor does not affect the opening of the karabiner, but the sensor may be damaged when the karabiner is hooked;
- for all the attachment methods examined, there is a risk of damage to the sensor due to the rotation of the karabiner after hooking;
- it was also found that the hole in the CADO AT 150 steel plate mooring point was of a size suitable for hooking the carabiner, but too small to allow accurate hooking while wearing VR goggles.

2.4. Description of the tool development

Based on the results of the three-dimensional and physical space tests, an accessory was designed in Shapr3D software to mount the sensor on a carabiner (**Figure 5.**). A key design consideration was that the accessory should reduce the risk of damage to the sensor and provide adequate space to operate the carabiner's locking mechanism. In addition, in accordance with the manufacturer's instructions **[7]**, it was necessary to ensure that the carabiner should be at least 30 mm from the lower plane of the sensor. The integration of the carabiner in virtual space was done in the Unity development environment using an accurate 3D model of the hook carabiner of the HTC Vive Tracker 3.0 and the attachment accessory.

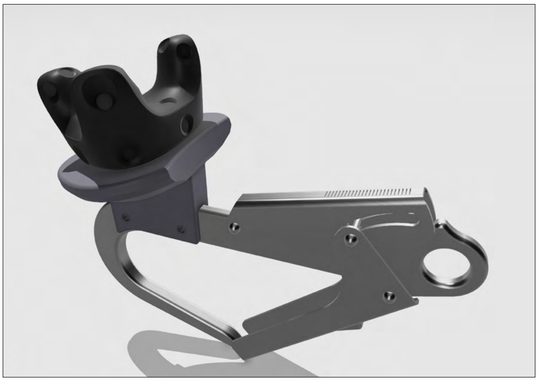

Figure 5. *3D model of the designed device.*

2.5. Testing the prototype of the device

As part of a non-representative evaluation, 5 people tried the first version of the tool. The feedback from users was consistent: the tool was sufficiently accurate and suitable for integrating the hook carabiner in the virtual space and could be used for future developments.

4. Further objectives of the research

The objectives include the further development of the tool and the solution of the opening mechanism in the virtual space. In addition, the aim is to create simulation courses that combine physical and virtual space for learning and practicing different tasks related to fall protection. Future plans include a detailed study of the potential educational uses of simulation and their validation using scientific methods.

Figure 6. *The developed device in operation.*

5. Conclusions

The study describes the development of tools to link fall protection devices with VR technology. The three-dimensional analyses and physical tests that formed the basis of the development were presented. Based on these results, the development of tools was presented, and further research directions were outlined. As a result of the research, it can be concluded that it is possible to combine VR technology and fall protection devices by using appropriate VR solutions.

Acknowledgements

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