Collaborative virtual reality environment for training load movement with Overhead Bridge Cranes

David Checa[a], Ines Miguel-Alonso[a], Henar Guillen-Sanz[a], Andres Bustillo[a]

[a] Departamento de Ingeniería Informática, Universidad de Burgos, Burgos, Spain
[a] {dcheca,imalonso,hguillen,abustillo}@ubu.es

Abstract. In the last decade, the rapid development and the price reduction of immersive Virtual Reality (iVR) devices allow its application to a wide range of applications. The sense of immersion and presence that these iVR devices produce surpasses any other display. These unique characteristic opens up new ways of training in Occupational Risk Prevention (ORP). iVR can create applications in collaborative training environments that mimic real situations and reinforce collaborative work and avoids unnecessary risks to the user in their training, as well as to other people or equipment that would exist if working with real equipment. Overhead cranes are one of the most interesting elements for the application of iVR training simulators. Firstly, because they are present throughout the production space and their movement involves the displacement of heavy loads that are not always well balanced. In addition, these movements occur in areas where other operators might be present and, in some cases, their collaboration is necessary during the movement stage. This research presents the design of a collaborative iVR application for training the movement of loads with overhead cranes. This developed application focuses on providing the user with the ability to proficiently operate an overhead crane. The usefulness of the iVR application was tested with 3 experienced overhead crane operators and 29 undergraduate students. These users reported that the experience was enjoyable and felt that the iVR environment was realistic and that the application would be useful to train how to handle an overhead bridge crane.

Keywords: Virtual Reality, Overhead Crane, Training, Collaborative environments.

1 Introduction

Virtual reality was described as early as 1965, as "a room in which a computer controls the existence of matter" [1]. This definition already foreshadowed the great potential of this technology, although the technological challenges it faced hindered it from becoming a reality for the general public for more than half a century. This slow maturation accelerated definitively in the second decade of this century, and Virtual Reality Head Mounted Displays (HMDs) have become available on the market in the last five years at an affordable price. These devices have been complemented by other technologies such as hyper-realistic video game engines that have been developed at

adfa, p. 1, 2011.

the same time. [2]. This fusion of technologies is what we currently define as Immersive Virtual Reality (iVR).
IVR outperforms other computer-generated image display systems in terms of the sense of immersion and presence it produces in the user. After a few minutes of immersion in the virtual environment, it becomes practically indistinguishable from the real one. These characteristics make it a particularly suitable technology for training. Firstly, it allows a first-person experience with a very high degree of interaction in real time and a sense of presence in the environment impossible to achieve with other technologies; these characteristics increase motivation and therefore the effectiveness of training in end users [3]. In addition, it allows the user to work autonomously and receive immediate feedback on their performance [4].

These unique features of immersive Virtual Reality open a new way of understanding Occupational Risk Prevention (ORP) training. iVR avoids unnecessary risks to the user in their training, as well as to other people or equipment, that would exist if working with real devices. Even high-risk situations can be simulated with great realism that are too difficult to achieve with desktop applications and impossible to do with real equipment. In addition, this type of training requires regular updating, making the use of iVR simulators an easy, flexible and dynamic solution compared to traditional training [7]. Within the multifaceted scope of the ORP, the machinery responsible for moving loads, such as bridge cranes, is one of the most interesting elements for the application of Immersive Virtual Reality. Firstly, because they are always present throughout the production space and their movement involves the displacement of heavy loads that are not always well balanced. Moreover, this movement takes place in areas where other operators are present.

Early applications of Virtual Reality in training were not focused on ORP. These first academic works, more than a decade old, were oriented towards describing the potential advantages of these VR technologies [5]. In 2015, iVR experiences began experimenting and demonstrating the improvement of learning and training [6, 7]. Although the technological problem remains unresolved because the devices were still relatively expensive and produced with some regularity dizziness in long experiences. With the emergence of low-cost HMDs, iVR applications are beginning to be applied in industries. The general purpose of these applications is to provide practical utility regarding a suitable work-force training for certifying new operators to work under dangerous and complex environments [8, 9].

The logical evolution is to turn these applications into collaborative training and learning environments that mimic real-life situations. These environments are intended to reinforce collaborative work. iVR environments reinforce collaborative work, and the sense of immersion can be enhanced when users are also present in a shared physical space [15]. Therefore, this research is based on the development of a collaborative immersive virtual reality application for training the movement of loads with overhead cranes. The structure of this paper will be organized as follows: in Section 2, the development of the collaborative VR environment will be described. In Section 3, the usability evaluation will be analyzed with its procedure and results. Finally, the main conclusions and future lines will be exposed in Section 4.

2 Development

This iVR application is intended to instruct in the prevention of occupational hazards in the interaction with overhead bridge cranes. Overhead cranes are the most widespread method of transporting loads in industrial environments. This heavy machinery is operated with remote controls, so the training can be simulated in iVR with a high degree of fidelity to the real training. Furthermore, in this case, the iVR allows us to face dangerous situations such as unbalanced loads, operators passing under the load or transit through poorly lit areas. This type of training is rarely carried out in real environments because of its high level of risk. Therefore, this training solution prepares the user to deal with such dangerous situations.

For the development of this application a framework of key aspects of iVR experience design and optimization for the prevention of occupational hazards has been followed [10]. This strategy is divided into 4 levels: 1) instruction, 2) interface, 3) simulation and 4) evaluation. Figure 1 shows the proposed strategy for the design of a collaborative iVR application for training the movement of loads with overhead cranes.

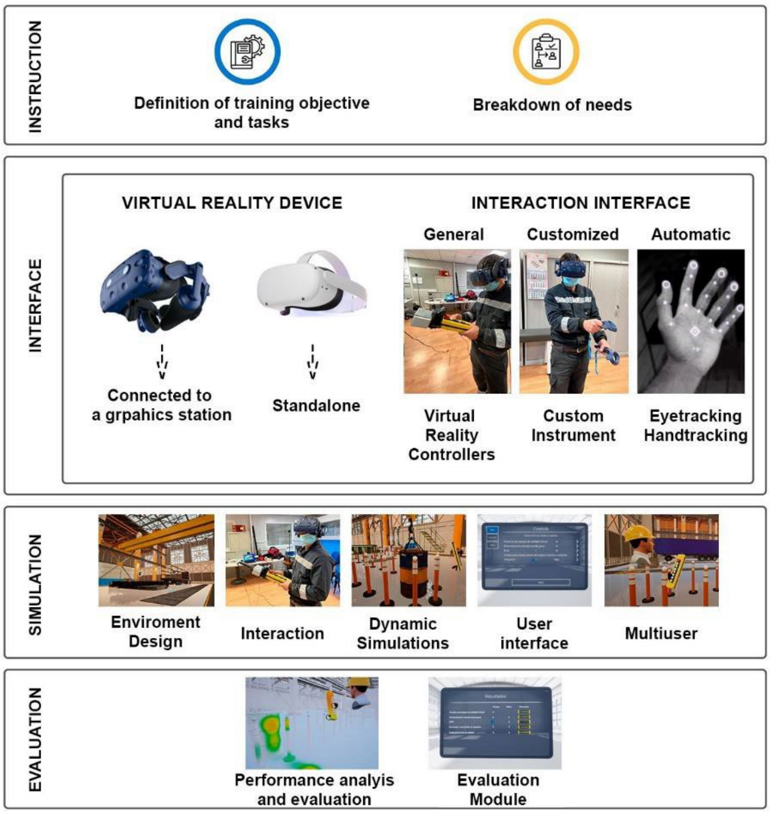

Fig. 1. Proposed strategy for the design of a collaborative immersive virtual reality application for training the movement of loads with overhead cranes.

In the first level of instruction, the definition of the tasks to be performed by the users in the iVR environment is carried out. In order to achieve this objective, operations and risks present in the handling of overhead cranes were defined. It has been taken into account that they can be trained autonomously or with the help of another user in a collaborative environment. Among the most common risks detected are the following:

- Risk of overturning and falling objects or equipment.
- Poor handling of equipment due to lack of operator training.
- Risk of entrapment caused by equipment transported on the traffic lanes.
- Risk of entrapment or dragging due to incorrect handling and / or load conduction.
- Collisions with other work equipment due to: Simultaneous and uncoordinated work of several pieces of work equipment in close proximity to each other or because a lack of signaling.

The following operations were also identified as particularly useful for simulation and training in individual or collaborative iVR environments:

- Transporting loads without visibility aided by another user or with lighting conditions affecting visibility (low luminosity, zenithal lights...)
- Hearing impairment (high ambient noise, communication problems between different users, etc.)
- Technical complications (carrying loads with a mass greater than that allowed by the crane or tooling, transporting unbalanced loads, balancing loads in motion)

In this way, as well as how to operate the overhead crane proficiently, the user will learn to detect occupational hazards, especially those associated with crushing accidents, as part of a work team, coordinating with co-workers and dealing with problems arising from working in a team and with complex machinery.

To maximize the naturalness of the interaction with the iVR environment, several approaches have been developed to allow the user a natural and trustworthy interaction with the environment. First, an ad-hoc custom controller interface was developed for this simulator: a real bridge crane pushbutton controller that is connected to the simulator. Likewise, and with the objective that the simulator can be used in any context and not only with specialized equipment, other available interfaces were also integrated, such as the Oculus Touch and HTC Vive controllers. As well as the integration of the user's hand tracking through the front cameras of the HTC Vive and Oculus Quest. This is necessary for some collaborative tasks such as communicating by signals with your co-worker.

In the next stage, the requirements to create the simulation are detailed. This phase included the tasks of creating the virtual environments, programming the interactions with this environment, with the objects and with the interfaces to be used by the user. Regarding the creation of the environment, generic factories were created. These factories had to meet the requirement of being modular in order to be able to adapt to the widest range of possible situations that can arise in the handling of overhead cranes in different industries. Figure 2 shows the modularity of these environments. In addition, it was also necessary to model the overhead cranes, controls, slinging and lifting accessories, as well as connection elements between accessories or load grips with high detail and fidelity.

Fig. 2. Example of the modular factory, recreating a single building on the left and a double building on the right.

For the development, Unreal Engine was used in conjunction with a previously created framework [12] that, by means of predesigned tools, simplifies the development of the iVR application. In particular, this framework includes tools for creating interactions with the scenario and objects. It also facilitates the creation of tasks and their objectives. Finally, it also facilitates the extraction of data and user performance indicators.

The multi-user support has been realized with the help of Epic Online Services which provides the online infrastructure for the multiplayer integration. A basic lobby was created to set up multiplayer and the replication, since all actors whose position or other properties are relevant in multiplayer must replicate to ensure synchronization between all the clients. At the same time the system supports the presence of viewers, used by managers or technicians to evaluate in real time the user's performance. These can be visible or invisible to the user depending on the desired effect.

3 Usability

The usability of the iVR application was tested on 3 experienced overhead bridge crane operators. The equipment used in these tests is made up of a workstation equipped with Intel Core i7-10710U, 32GB RAM, with NVIDIA GTX 2080 graphics card connected to the HTC Vive Pro Eye HMD. This is an HMD that includes a high-quality display, 6DOF controllers, eye tracking and sensors to calculate the user's position in the virtual environment. Thanks to its integrated eye-tracking system, it allows real-time analysis of the user's performance, as well as detecting improper behavior, for example, if the user is not monitoring the load being carried continuously. The experience was executed in one session. First a brief explanation of the iVR system and HMD was given as introduction. Then, participants began the iVR experience with a tutorial on how to use the virtual environment and interaction de-vices before moving on to a test in which they had to complete a circuit by handling a load. Subsequently, users were faced with different tasks that varied according to the slinging accessory chosen, the type of load and the movement conditions, among others, sequentially increasing the difficulty throughout the different levels. These experienced crane operators used both types of interaction devices as shown in Figure 3.

Fig. 3. Crane operator testing the different methods of interaction. A: real bridge crane controller. B: general virtual reality controllers.

In relation to the validation experience, the survey is comprised of 11 questions to measure cybersickness, satisfaction and usability. Eight multiple choice questions (MCQs) were used, rating each aspect with 1 to 5 points on a Likert scale, where 1 means not at all and 5 means very much. In the survey, there are included additionally three open questions for giving the positive and negative aspects and suggestions of the iVR experience. The 8 MCQ were divided into categories to evaluate 5 different aspects of the iVR experience. These aspects are satisfaction, usefulness perception, usability, presence, and immersion, using a validating and unified questionnaire on user experience in immersive virtual environment (IVEQ) [13]. None of these users had used an iVR device before, and they did not report any dizziness. Satisfaction with the application was very high, as well as the usefulness perceived by the user, because of their good opinions that the simulator would help in learning how to operate a bridge crane. Regarding realism, users gave an average of 7.5 out of 10 to the recreation of the factory and 8.5 to the level of presence experienced. Reported usability was much higher with the customized device (9.1) than with the general controllers (7.9), although in both cases reasonably high. In addition, after completing the survey, these crane operators were given a personal interview while using the simulator again to receive more direct feedback. Possible improvements to the simulator were also addressed at this time. Small bugs were corrected, such as the correct crane speed when using two-speed push buttons or the increased braking distance when moving large loads.

The usability was also tested on 29 undergraduate students. This sample group is balanced in terms of gender. Its average age is 22.86 years. The experience was run in 3 sessions. In the first one, a brief explanation of the iVR system and HMD was given.

Then, participants began the iVR experience with a tutorial on how to use the virtual environment and the interaction devices, before moving on to a test in which they had to complete a circuit by handling a load, as shown in Figure 4.

Fig. 4. Example of skill test that students used in the usability test.

After this first session, the users used the simulator two more times in the following weeks. In these sessions the participants performed the same circuit, but with different complications while the difficulty was being increased. At the end of it, participants were asked to complete the usability and satisfaction survey. Cybersickness was only reported by 4 of the 29 participants. One of the participants considered his cybersickness event as "moderate". The other 3 participants rated their cybersickness as "low level". As it can be seen in the Table 1, the participants' satisfaction was high (4.55) as well as the presence (4.43). In the contrary, their usefulness perception, usability and immersion have the lowest rates (3.84 in usefulness perception, 3.90 in usability and 3.83 in immersion). This difference between the classification of the questions means that the experience was enjoyable, and they felt that the iVR environment was real, but the handling of the bridge crane was difficult and make them get distracted from their tasks during the iVR experience.

Table 1. Mean and Standard Deviation (SD) of satisfaction and usability surveys.

	M	SD
Satisfaction	4.55	0.63
Usefulness perception	3.84	0.94
Usability	3.90	1.26
Presence	4.43	0.84
Immersion	3.83	1.14

Moreover, the open questions demonstrate the results of the 8 MCQ. Participants commented as positive aspects that the application was useful to train how to handle a bridge crane and the iVR environment was realistic. However, as negative aspects, they considered that the use of the virtual control of the bridge crane was not intuitive, and they had little precision when pressing the virtual buttons. In addition, some participants asked for more obstacles and variety of circuits. These negative aspects and your suggestions will be taken into account for future improvements of this application as well as in research.

4 Conclusions and future research lines

This paper proposed an immersive and collaborative virtual reality application for training the movement of loads with overhead cranes. This application focuses on providing the user with the ability to proficiently operate an overhead crane. In addition, the user will learn to detect occupational hazards, to be part of a work team, to coordinate with colleagues and to deal with problems arising from working in a team and with complex machinery. The usefulness of the iVR application was tested with 3 experienced overhead crane operators and 29 undergraduate students. The experience was enjoyable, and they felt that the iVR environment was real.

Future works will be focused in expanding the scope of applicability of this application, as well as integrating intelligent systems in its evaluation. Occupational Risk Prevention training can be much more effective if immersive Virtual Reality devices become serious games with artificial intelligence. In this case, training can be adapted to the skills, habits and knowledge of each user, and training gaps or improvements can be identified semi-automatically. Virtual Reality 3D visualization equipment is particularly suitable for incorporating artificial intelligence, given that it always reflects the way the user interacts with the virtual environment, by means of haptic or manual interfaces, and what is being visualized at any given moment, given the tendency of human beings to focus on the fovea on what they are focusing their attention.

5 Acknowledgments

This work was partially supported by the ACIS project (Reference Number INVESTUN/21/BU/0002) of the Consejeria de Empleo e Industria of the Junta de Castilla y León (Spain) and the Erasmus+ RISKREAL Project (Reference Number 2020-1-ES01-KA204-081847) of the European Commission. This work has been made possible thanks to the support received from Nicolas Correa S.A. where the validation tests with final users were performed.

6 References

1. Sutherland, I.E.: The ultimate display. Proceedings of the Congress of the Internation Federation of Information Processing (IFIP). (1965). https://doi.org/10.1109/MC.2005.274.

2. Das, S., Maiti, J., Krishna, O.B.: Assessing mental workload in virtual reality based EOT crane operations: A multi-measure approach. International Journal of Industrial Ergonomics. 80, (2020). https://doi.org/10.1016/j.ergon.2020.103017.

3. Bustillo, A., Alaguero, M., Miguel, I., Saiz, J.M., Iglesias, L.S.: A flexible platform for the creation of 3D semi-immersive environments to teach Cultural Heritage. Digital Applications in Archaeology and Cultural Heritage. 2, 248–259 (2015). https://doi.org/10.1016/j.daach.2015.11.002.

4. Checa, D., Bustillo, A.: A review of immersive virtual reality serious games to enhance learning and training. Multimedia Tools and Applications. 79, 5501–5527 (2020). https://doi.org/10.1007/s11042-019-08348-9.

5. Dong, H., Xu, G.: An expert system for bridge crane training system based on virtual reality. In: Proceedings - International Conference on Artificial Intelligence and Computational Intelligence, AICI 2010 (2010). https://doi.org/10.1109/AICI.2010.247.

6. George, A.K., McLain, M.L., Bijlani, K., Jayakrishnan, R., Bhavani, R.R.: A Novel Approach for Training Crane Operators: Serious Game on Crane Simulator. In: Proceedings - IEEE 8th International Conference on Technology for Education, T4E 2016 (2017). https://doi.org/10.1109/T4E.2016.030.

7. Moreland, J., Zaraliakos, J., Wang, J., Zhou, M., Zhou, C.: Interactive Training for Fall Protection and Crane Safety.

8. Müller, D., Ferreira, J.M.M.: MARVEL: A mixed reality learning environment for vocational training in mechatronics. In: T.E.L. '03 Proceedings: International Conference on Technology-enhanced Learning (2004).

9. Travassos Valdez, M., Machado Ferreira, C., Martins, M.J.M., Maciel Barbosa, F.P.: Virtual labs in electrical engineering education-The VEMA environment. In: ITHET 2014 - 13th International Conference on Information Technology Based Higher Education and Training (2014). https://doi.org/10.1109/ITHET.2014.7155714.

10. Checa, D., Martínez, K., Osornio-Ríos, R., Bustillo, A.: Virtual Reality opportunities in the reduction of occupational hazards in industry 4.0. DYNA. 96, 620–626 (2021). https://doi.org/10.6036/10241.

11. Beck, S., Kunert, A., Kulik, A., Froehlich, B.: Immersive Group-to-Group Telepresence. IEEE Transactions on Visualization and Computer Graphics. 19, 616–625 (2013). https://doi.org/10.1109/TVCG.2013.33.

12. Checa, D., Gatto, C., Cisternino, D., de Paolis, L.T., Bustillo, A.: A Framework for Educational and Training Immersive Virtual Reality Experiences. In: de Paolis, L.T. and Bourdot, P. (eds.) Augmented Reality, Virtual Reality, and Computer Graphics. pp. 220–228. Springer International Publishing, Cham (2020).

13. Tcha-Tokey, K., Christmann, O., Loup-Escande, E., Richir, S.: Proposition and Validation of a Questionnaire to Measure the User Experience in Immersive Virtual Environments. International Journal of Virtual Reality. 16, (2016). https://doi.org/10.20870/ijvr.2016.16.1.2880.