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Verification of Overhead Crane Simulator in a Training Centre

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Abstract. This article presents the results from a practical test of a portable overhead crane simulator. The test was carried out to determine the usability of the simulator in the training being conducted. The simulator is developed using virtual reality (VR). With this solution, the user can be immersed in a virtual work environment.
Keywords: portable overhead crane simulator, virtual reality, training material, training sessions

1. INTRODUCTION

The portable overhead crane simulator discussed in this article is intended for interactive simulation of use of a virtual overhead crane. The simulator is developed using virtual reality which allows the user (trainee) to become immersed in a virtual environment of a production and storage hall. Having entered this environment, the user becomes the operator of a virtual overhead crane controlled from the cab.

This simulator can be used to train overhead crane operators while discussing subjects relating to the occurrence of accidents during overhead crane use (according to item 16 of a draft programme prepared by the Office of Technical Inspection [1]). It can also be used as a supporting tool during hands-on activities carried out on an actual overhead crane. The use of this simulation during hands-on activities will obviously not be equal to the use of a real overhead crane, but the trainee will be able to familiarise himself/herself with the functioning of the overhead crane (i.e. lifting, transporting and handling loads in a work environment) and to gain confidence in its use. What is more, the introduction of dangerous dynamic phenomena, such as loss of load, or hitting other environment objects or users with load, in the simulation process will allow the user to become acquainted with circumstances leading to accidents that may occur during overhead crane use and that cannot be arranged in real conditions purposefully for safety purposes.

Research carried out in the field of utilisation of VR in training of future operators of various machines point out that they not only make the training process more entertaining [1], but they also facilitate development of the users' skills and knowledge in safety of machine use [2]. Moreover, VR technology accelerates the training process and reduces training costs [3, 4] in terms of consumption of office materials and consumables, utilities, machines used, etc. Furthermore, the research presented in references [5, 6] indicate that the utilisation of VR in the training of future operators of various machines is very effective. Additionally, the use of stereoscopic images displayed in VR goggles allows the user to participate in the simulation process and perceive events initiated in a virtual environment in an intuitive and real manner.

2. PORTABLE OVERHEAD CRANE SIMULATOR

The portable overhead crane simulator presented in this article was developed on the basis of the existing laboratory overhead crane simulator [7, 8]. A view of the laboratory version of the simulator prior to modification is presented in Fig. 1.

Fig. 1 View of laboratory overhead crane simulator:
1. simulator seat, 2. real panels to control a virtual overhead crane,
3. VR goggles, 4. user movement tracking system markers

The simulator was modified based on an analysis of training programmes used by training centres and based on verification tests concerning the possibilities to support training of overhead crane operators. The verification covered the simulator software and hardware, i.e. the real control panel consisting of 2 individual panels, VR instrumentation, including VR goggles to display the image of the virtual environment. Additionally, during verification activities, discussions on the simulation functionalities with test users (overhead crane operators, training instructors, OHS service personnel) were held. The users provided a handful of hints as to its proper functioning. They assisted in determining the scope of works to be executed to modify the simulator. The verification also helped in introducing significant changes to the software [9] in terms of the virtual environment, fulfilment of the training programme with the use of simulated overhead crane operation, and initiating dangerous situations leading to accidents.

Modified portable overhead crane simulator (Fig. 2 and 3) is developed in virtual reality which allows the user to become immersed in a virtual production and storage hall environment. Having entered this environment, the user becomes the operator of a virtual overhead crane controlled from the cab. User immersion is possible by using external instrumentation in the form of VR goggles (Fig. 2, item 2) and a user movement tracking system (basic stations – Fig. 2, item 3).

The simulator also consists of a seat with a structure supporting the control panel (Fig. 2, item 1), a LeapMotion camera (Fig. 3) mounted on the VR goggles to present the user hands in the virtual environment, and software to run the simulation and display the virtual production and storage hall environment on a screen or in the VR goggles.

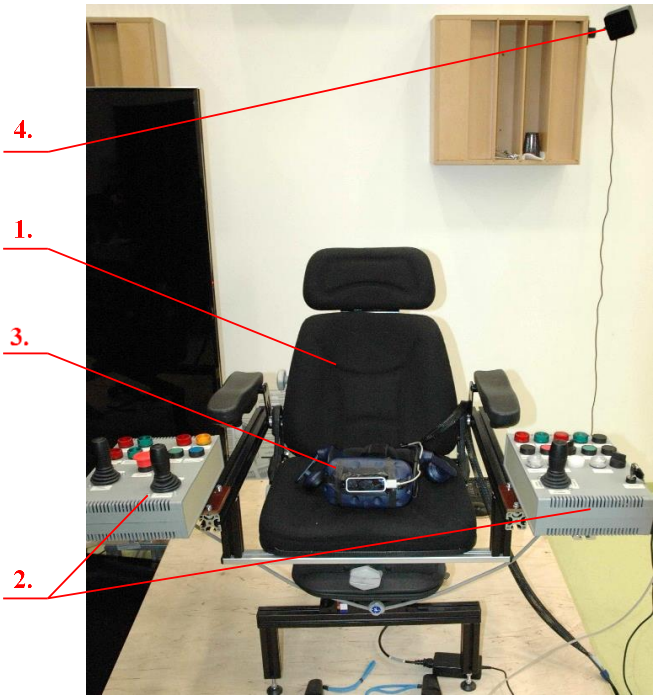

Fig. 2. View of portable overhead crane simulator:
1. Seat, 2. Overhead crane simulator control panel including left panel and right panel, 3. VR goggles – HTC VIVE PRO,
4. Stands with basic stations of the simulator user movement tracking system

To begin using the simulator, select appropriate information from the menu displayed on the screen. Selection is made with regard to the type of overhead crane used in a given task, type and number of transported loads, and task supporting elements, i.e. counting errors made by the user, indicators facilitating the precision of load lifting and positioning. What is more, it is possible to enable displaying of messages concerning errors made by the user during simulation. They can be disabled from the menu.

Fig. 3. View of portable simulator in use

If the type of overhead crane is selected, appropriate loads to be transported are displayed in the menu. An overhead crane with a hook is used to transport cages (with/without load), and an overhead crane with an electromagnet is used to transport metal loads (long/short or single/bundled pipes, beams, bars). The number of loads to be transported to complete a task can also be selected from the menu. On selection, press the "START" key and go to the simulation. To start the simulation, turn the key in the switch on the right control panel (Fig. 2, item 2).

To control the overhead crane, use the real controls installed on two control panels (Fig. 2, item 2) mounted on both sides of the operator's seat (Fig. 2, item 1). The use of real panels in the simulator provides the user with a realistic experience in controlling a virtual overhead crane since he/she physically senses these elements by touching them.

Using the controls, the user can execute typical tasks involving transportation of various loads with a virtual overhead crane. Load or cage selection determines the tasks to be executed by the simulation user. They include delivering a load, lifting and positioning a load, selecting a transport route, experiencing dangerous situations occurring on a load transport route, etc.

Simulations on this simulator may include typical dangerous situations relating to lifting, transporting and positioning a load in a real work environment. These situations are initiated when the user makes an error, triggered by the instructor, or initiated when several causes leading to an accident overlap.

The following situations may be initiated in the simulator: hitting an employee working in his/her workplace or moving across the virtual environment with the transported load, crushing an employee with the transported load, hitting a hooker presenting hand signals with the lifted load, hitting fixed objects of the environment with the transported load, etc.

3. SIMULATOR PRACTICAL TEST

The portable simulator was verified in practice. The verification was carried out in a training centre outside the Institute. 5 training instructors and 7 overhead crane operators participated in the tests. Each participant started training using the simulator according to the following schedule:

- Provision of information on the simulator and on the test – approx. 10÷15 minutes.
  - As part of this activity, the participants were provided with information on the scope and aim of the test. They were also presented with information on voluntary participation and the possibility to withdraw from the test at any stage, and signed a form stating that they participated in the test with conscious consent. They were familiarised with ailments that could occur while using the simulator (motion sickness, bad disposition, headaches, etc.) and with methods to mitigate these problems.
  - The participants were also provided with information on the functioning of the overhead crane simulator, including the simulator's components and their functions. The method of adjustment of the VR goggles (i.e. taking them on and off) was also described.
- Simulator operation training – approx. 10 minutes,
  - The participant was familiarised with the method of operation of the simulator by observing actions taken by the instructor during execution of a specific control task.
  - The participant individually carried out a preliminary interactive overhead crane simulation to become familiar with the method of operating the simulator and its controls. Free simulation – no task assigned.
- General tests – total time: approx. 20÷40 minutes.
  - The participant was to complete 2 control tasks. Before and after the tasks, he/she filled in a psychological test to determine his/her level of fatigue and a simulator usability evaluation questionnaire according to the SUS method [10 and 11].
- Break between test tasks – approx. 5÷10 minutes.
  - If the test involved two participants, the sessions were carried out alternately by the users (one participant performed a simulation, and the other had a rest).

3.1. Tasks executed during the test

The participants executed two control tasks during the test. The first control task involved transporting three long metal elements using an overhead crane equipped with a sling with an electromagnet. The load was to be transported from a lay-down area in the storage hall to a truck located in the parking area, and positioned on the truck's drop side body. The second control task involved transporting two loading cages from the lay-down area in the storage hall to an employee station in the production hall.

In this task, an overhead crane with a sling with a hook was used. Lay-down areas, long loads, and cages were selected every time by the inspector supervising the test and the simulation process.

3.2. Results of practical test

The questionnaire handed over to the participants included 10 statements. They are provided in Table 1. They indicate positive and negative aspects relating to the use of the tested simulator. Each answer provided to an individual statement was assessed on a 7-point Likert-type scale [12]. The scale included seven assessment values: totally disagree (1), disagree (2), rather disagree (3), no opinion (4), rather agree (5), agree (6), totally agree (7).

Table 1. Percentage distribution of answers provided to individual statements

#	Statement	1	2	3	4	5	6	7
1	If I had the possibility, I would use the tested simulator.	–	–	–	8%	25%	33%	33%
2	The simulator is unnecessarily complicated.	33%	50%	17%	–	–	–	–
3	The simulator is user-friendly.	–	–	–	8%	33%	25%	33%
4	I will need technical support to use the simulator.	25%	25%	42%	8%	–	–	–
5	The simulator functions used during the test are easily accessible.	–	–	17%	17%	50%	17%	17%
6	There are many inconsistencies in the simulator.	8%	42%	42%	8%	0%	0%	0%
7	Most people will be able to use the simulator efficiently at a glance.	–	–	–	8%	33%	42%	17%
8	The simulator is troublesome.	17%	50%	25%	8%	–	–	–
9	I feel very confident when using the simulator.	–	–	–	–	8%	42%	50%
10	I had to learn many things before using the simulator.	8%	42%	42%	8%	–	–	–

Data analysis was initiated by assigning numerical values from 1 to 7 to the corresponding statements. Then the answers provided were estimated on the basis of a percentage fraction for statements with reference to the total value (Table 1).

It can be seen on the graph (Fig. 4) that the practical test participants in most cases agreed with the statements associating the simulation's usability with positive or negative aspects of its use. The participants jointly claimed that the simulator is user-friendly (Fig. 4, no. 3) and felt quite confident during its use (Fig. 4, no. 9), that the simulator's operator is simple (Fig. 4, no. 2), that technical support is not required (Fig. 4, no. 4), or that the simulator is not troublesome (Fig. 4, no. 8).

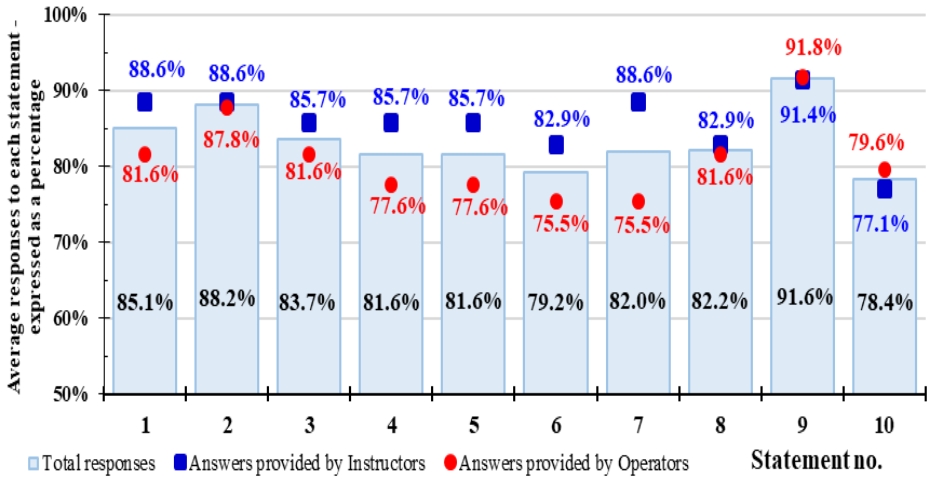

Fig. 4. Graph presenting the percentage distribution of answers provided by the practical test participants

Determination of statistical significance showed that the differences between the mean results from both groups are statistically insignificant ($p > 0.05$ and $F < 1$). There is no basis to reject the adopted hypothesis: "*Do the mean values of answers provided by the respondents from both groups do not influence on the results of the test"*. Based on the results, it can also be concluded that the assessment of usability of the overhead crane simulator was higher among the respondents from the first group ($M = 7.7$, $SD = 0.46$) than from the second group ($M = 7.2$, $SD = 0.66$).

Upon determining statistical significance, the mean value for the overhead crane simulator usability coefficient was calculated using the SUS method. The analysis showed that the simulator usability coefficient was 75 ($M = 7.5$, $SD = 0.52$).

Table 2. Statistical significance of answers provided by the respondents from the first group and the second group

Group	**Mean** ***M***	***t***	**d*f***	***p***	**Standard deviation** ***S***	**Standard deviation variance** ***S*²**	**Levene's test** ***F***
Instructors	83.33	1.3881	10	0.19693	2.04124	4.1667	0.6714
Operators	77.85				8.53719	72.8836	

This coefficient should be within the range from 0 to 100, where if the value is higher than 68, the result should be interpreted as good. Therefore, the portable overhead crane cab-controlled simulator can be considered a useful tool to support overhead crane operator training.

4. CONCLUSIONS

Using the simulator during training not only enhances the training process, but can also provide it with new possibilities. If this tool is used in the training, the trainee can personally participate in an interactive process of simulation of the use of an overhead crane. It also allows the users to become familiarised with the causes and circumstances of accidents during execution of a given process of operation of a given machine. As a result, they can raise their awareness and improve their skills, in particular in situations that may lead to an accident or in terms of machine operation precision.

The practical test showed that the portable simulator is a good tool to support training of future overhead crane operators and to increase the above-mentioned awareness. This statement was confirmed by the test participants when they provided positive opinions on this form of training. During the tests, the participants also provided positive and negative opinions with regard to simulator-based training. The submitted opinions were largely valuable in terms of improvement of the functioning of the simulator and its adaptation to training needs.

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REFERENCES

[1] Program ramowy nr 2/2007/OUTB opracowany przez UDT w aspekcie *Minimalne wymagania dotyczące programów szkoleń dla osób ubiegających się o uzyskanie zaświadczenia kwalifikacyjnego do obsługi urządzeń transportu bliskiego* (UTB).

[2] Prudenzi, Arianna, Brendan Rooney, Giovambattista Presti, Marco Lombardo, Daniele Lombardo, Concetta Messina, Louise McHugh. 2018 "Testing the effectiveness of virtual reality as a defusion technique for coping with unwanted thoughts". *Virtual Reality* 23 : 179-185.

[3] Lozia, Zbigniew. 2005. Driving Simulators as a Tool for Road Traffic Safety Research. W *Materiały konferencyjne konferencji VIRTSAFE*. Warszawa: CIOP-PIB.

[4] "Virtual Reality Goes to School". 2012. *New York Times*, http://www.nytimes.com/2012/05/20/automobiles/virtual-reality-goes-to-school.html?_r=1.

[5] Shu, Yu, Yen-Zhang Huang, Shu-Hsuan Chang, Mu-Yen Chen. 2018. "Do virtual reality head-mounted displays make a difference? A comparison of presence and self-efficacy between head-mounted displays and desktop computer-facilitated virtual environments". *Virtual Reality* 23 : 437-446.

[6] Kalwasiński, Dariusz. 2014. "Praktyczny test symulatora suwnicy w aspekcie symulacji wrażenia dotyku". *Mechanik* 7 : 285÷294.

[7] Kalwasiński, Dariusz. 2012. "Opracowanie komputerowego narzędzia do interaktywnego odwzorowania zdarzeń wypadkowych podczas użytkowania suwnic (Development of computer tool for interactive simulation of accident situations occurring during overhead crane operation)". *Mechanik* 7 : 317÷324.

[8] Kalwasiński, Dariusz. 2018. „Przenośny symulator suwnicy do wspomagania szkolenia operatorów suwnic – koncepcja (Mobile symulator of the crane to suport trainings of crane operators – a concept)". *Mechanik* 7 : 609-611.

[9] Kalwasiński, Dariusz. 2019. „Oprogramowanie do symulatora wirtualnej suwnicy (Computer software of virtual overhead crane simulator)". *Mechanik*, 7 : 442-444.

[10] Hartson, H. Rex, Terence S. Andre, Robert C. Williges. 2001. "Criteria For Evaluating Usability Evaluation Methods". *International Journal of Human-Computer Interaction*, 13 (4) : 373-410.

[11] Brooke, John. 1996. SUS-A Quick and Dirty Usability Scale. In *Usability Evaluation in Industry* (Eds. Patrick W. Jordan, B. Thomas, Bernard Weerdmeester, Ian Lyall McClelland). CRC Press.

[12] Jezior, Jagoda. 2013. „Metodologiczne problemy zastosowania skali Likerta w badaniach postaw wobec bezrobocia (Methodological problems of application of likert scale)". *Przegląd Socjologiczny* 62 (1) : 117-138.

Weryfikacja symulatora suwnicy w ośrodku szkoleniowym

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Streszczenie. W artykule przedstawiono wyniki z przeprowadzonego testu praktycznego wykonanego symulatora suwnicy w wersji przenośnej. Test miał na celu określenie użyteczności symulatora w prowadzonym szkoleniu. Symulator wykonano w technice rzeczywistości wirtualnej (VR). Rozwiązanie to umożliwia zanurzenie użytkownika symulatora w wirtualnym środowisku pracy.
Słowa kluczowe: symulator suwnicy w wersji przenośnej, technika rzeczywistości wirtualnej, materiał szkoleniowy, szkolenia

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