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The Use of Virtual Reality for Training in Securing the Functioning of Critical Infrastructure

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Abstract. Our national security, economic prosperity and national welfare depend on a set of highly interdependent elements of critical infrastructure. Examples of critical infrastructure facilities include the national electricity grid, oil and gas systems, telecommunication and information networks, transportation networks, water systems and banking and financial systems. Given their importance, it is crucial to maintain the reliability of critical infrastructure facilities, especially power plants, both in times of peace and also in times of crisis or under conditions of attack. For this purpose, on the one hand, it is possible to improve and create new technical solutions supporting the restoration of the proper functioning of critical infrastructure facilities, such as remotely controlled mobile robots for example. On the other hand, it is important to prepare employees to operate in unusual conditions by organising appropriate training. In both cases, it can be useful to apply virtual reality techniques.

Keywords: critical infrastructure, reliability, virtual reality, development of training applications

1. INTRODUCTION

The risk related to ensuring the proper functioning of the critical infrastructure constitutes a specific problem for the country. Businesses that own critical infrastructure facilities generally operate in a competitive and regulated environment and must balance risk, investment and cost for customers. Although responsibility for their customers and shareholders is extremely important for these companies, those involved in managing the functioning of critical infrastructure facilities realise that fully securing the infrastructure against all threats and failures is not practical (e.g. due to costs), or even possible (e.g. due to technological limitations or the possibility of planned attacks on a critical infrastructure facility). For the country, ensuring the continuity of the proper functioning of critical infrastructure facilities, in particular electricity supply, is of key importance, especially from the point of view of the need to achieve and maintain goals such as: stability and economic growth, national security, public safety and quality of life.

Increasing the resilience of critical infrastructure facilities to accidental failures and possible attacks requires its owners and operators to determine the system's ability to withstand specific threats, minimise or mitigate potential consequences and to return to normal operation if a failure or damage occurs. Thus, the methodology for assessing the resilience of such facilities requires a comprehensive assessment of systems and resources of critical infrastructure facilities – from the threat to the consequences that may occur, i.e. the effect of these threats. The methodology must support decision-making in the field of risk management, responding to failures, damage and disasters and in particular, support the implementation of tasks ensuring the continuity of operation of the critical infrastructure facility. In particular, rules, procedures and tools related to maintenance and removal of the effects of failures and damage should be taken into account. It is also extremely important to train people responsible for maintaining the continuity of the operation of the critical infrastructure facility, also in the case of unusual or unlikely events, so that employees are well prepared for the widest possible spectrum of possible events. Since training directly at the critical infrastructure facility may be associated with an increased risk associated with the need to ensure the proper functioning of the facility, it seems that various types of simulators and trainers based on virtual reality techniques may be an efficient and effective tool in this situation.

According to Art. 3 point 2 of the Act on Crisis Management, critical infrastructure consists of systems and their functionally interconnected facilities, including construction facilities, devices, installations, services critical for the security of the state and its citizens and for ensuring the efficient functioning of public administration bodies, as well as institutions and entrepreneurs.

The concept of Critical Infrastructure includes the following systems:

- supply of energy, energy resources and fuels,
- communication,
- tele-information networks,
- financial,
- water supply,
- food supply,
- healthcare,
- transport,
- rescue,
- ensuring continuity of public administration functioning,
- production, storage and use of chemical and radioactive substances, including hazardous substance pipelines.

2. APPLICATION OF REMOTE-CONTROLLED ROBOTS IN THE MAINTENANCE OF CRITICAL INFRASTRUCTURE

Remote control of robots and other machines (teleoperation) is a tool that is intensively developed, including due to the steady progress in the field of data transmission and the miniaturisation of electronic circuits. The use of the teleoperation concept makes it possible to avoid problems, risks and costs related to the possible exposure of an employee (e.g. an operator in a machine/vehicle cabin or using a manual machine) to various hazardous conditions. The implementation of the teleoperation method is of particular importance in military applications (e.g. for remote control of military vehicles), astronautics (e.g. for performing remote repairs and maintenance works in orbit), in underground mining plants, as well as in underwater works. Remotely controlled mobile robots replace humans in life threatening or health threatening situations. This technology can also be used in more common works and tasks, including among others in the case of transport equipment such as cranes, industrial cranes, port cranes and construction cranes. Another area in which the implementation of teleoperation principles may be particularly effective and efficient may be the remote control of inspection robots and robots for remote service works, intended for carrying out various works in hazardous areas, e.g. at risk of explosion, poisoning or burns (e.g. when operating a melting furnace).

Moving people away from danger zone and improving the work of the robot operator through the use of the telepresence concept enables the implementation of tasks that would otherwise be dangerous and/or time-consuming for humans (in the event of a critical infrastructure failure, short response time is extremely important). A mobile robot equipped with an arm ending with a gripper can carry out work related to decontamination and removal of other threats, including the removal of relatively heavy loads from a dangerous zone, e.g. chemically contaminated or at risk of explosion.

A remotely controlled robot can be used for ad hoc maintenance by experts not located in the critical infrastructure. Therefore, the robot should be able to move freely around the critical infrastructure and have a wide range of arm movement. For this reason, it is advisable to equip the robot with Mecanum wheels that allow movement in any direction on the floor and to use an arm structure that takes into account additional degrees of freedom, which are not necessary when carrying simple loads, but which may be useful when carrying out maintenance works (e.g. turning the gripper around its own axis).

Another potential application of the discussed system is the semi-automatic operation of robots, which could autonomously perform most, especially simple, tasks (e.g. movement from point A to point B). Then, one teleoperator could supervise the entire group of robots, taking control of the selected robot in unusual, demanding and emergency situations, or if the artificial intelligence software did not provide a sufficient level of autonomy of the robot's work and a human decision was needed. In the case of critical infrastructure, this solution has the added benefit associated with the size of multiple critical infrastructure installations. Relatively simple, remote-controlled robots could be stationed in many locations being particularly sensitive or potentially requiring intervention (maintenance, adjustment, etc.). As a result, the reaction time to a failure or other critical situation would be significantly reduced. The robot could be used for emergency operations almost immediately, much faster than if the repair team had to travel a relatively long distance. This would significantly reduce the response time to the occurrence of a failure and increase the chances of maintaining the continuity of the functioning of the critical infrastructure (e.g. inhibition of the cascade propagation of defects and failures thanks to the reaction in a very early, initial stage of the development of a dangerous situation).

3. VIRTUAL REALITY TRAINING APPLICATION FOR TELE--OPERATORS

The use of remotely controlled robots is only the first step towards increasing the operational reliability of the critical infrastructure. It is also very important to prepare the potential operators of these robots so that they can carry out maintenance and intervention work as soon as possible. Virtual reality techniques turn out to be particularly useful for this purpose, because within the virtual training environment it is possible to simulate any dangerous event, including various types of failures of critical infrastructure elements.

A properly designed training scenario will make it easier for teleoperators to make decisions during real events, especially when disruption of critical infrastructure important from the point of view of training (e.g. a disruption of a power plant – Fig. 1) are recreated in a virtual environment, so that the spatial relations between various elements are identical to the real ones. An example of such a training application is presented in Fig. 2.

The effectiveness of using training simulations in virtual reality can be increased by applying the concept of gamification. Gamification is related to the application of assumptions typical of computer games in order to facilitate and accelerate the process of modifying human behaviour in tasks that are not related to the world of electronic gameplay. The results of the research conducted indicate that the implementation of certain concepts typical of games in the training environment improves the assessment of the usefulness of the training tool and increases the participants' involvement in the training process [1].

Technology related to computer games (e.g. game controllers and other hardware dedicated to computer gamers) as well as computer games are increasingly being used for non-entertainment applications. This is clearly indicated by the increasing number of scientific publications and ready-made products available on the market regarding serious games applications, i.e. software similar to a computer game but used for research or training purposes. Scientific research shows that there is a link between playing computer games, or using training software modelled on a computer game and improved cognitive functioning (e.g. increase in attention span). According to the research conducted, the use of games of skill of the First Person Shooter (FPS) type [2] and real-time strategy games of the RTS (Real Time Strategy) [3] type may noticeably improve the results obtained in tests of visual attention. As the possibility of supporting the process of acquiring new knowledge and consolidation of skills has also been demonstrated, gamification becomes a method facilitating the building of an engaging training environment, the additional advantages of which are natural and easier cooperation with other users [4, 5].

The results of many scientific publications indicate that people with experience in FPS and RTS games achieve better results in tests concerning certain cognitive functions [2,6-7]. This is especially true of visual attention or the ability to switch between tasks (which is particularly interesting in the case of training operators who would be responsible for managing the work of multiple remote-controlled robots). The experimental studies conducted on the impact of training based on FPS and RTS games indicate that it is possible to notice better results in functioning tests (e.g. in terms of attention) even after relatively short training.

Moreover, the observed improvement in cognitive functioning lasts for weeks and in some cases even for months, after the completion of stimulation training [8]. The influence of interactive simulation modelled on computer games has a wide range of positive effects on the functioning of people using this type of tool [9-12].

Fig. 1. Virtual environment presenting an emergency situation (explosion and fire) in a critical infrastructure facility such as a power plant

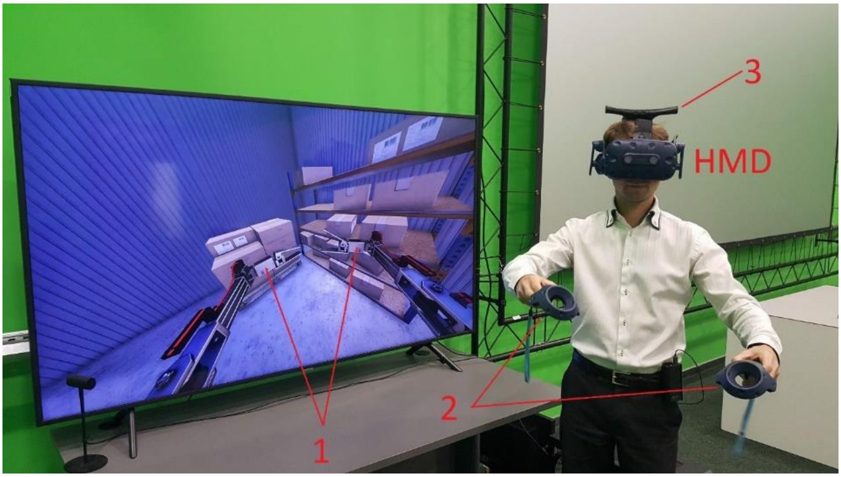

Fig. 2. The image of the virtual environment can be presented in many ways, e.g. on a computer screen or in HMD (*Head Mounted Display*) virtual reality goggles. The illustration shows a training application for operators of a remotely controlled mobile robot with two arms: 1 – operator-controlled virtual robot arms, 2 – controllers used to determine the position and orientation of arms in three-dimensional space, 3 – antenna of the wireless image transmission system to HMD.

4. CONCLUSIONS

This paper presents issues related to the use of ICT systems for broadly understood support to maintain the continuity of operation of critical infrastructure facilities using an example of a power plant. On the one hand, a solution is presented which consists in physically removing the consequences of a failure using remotely controlled robots equipped with arms ending with grippers. On the other hand, a training application using virtual reality techniques to prepare operators working in critical infrastructure facilities to deal with unusual, rare failures and scenarios involving damage is presented.

Training in a virtual environment does not have to be limited to training operators of machines (in particular robots). In the future, it is planned to extend the scope of virtual training in order to increase the competences of managers of companies, especially those belonging to the category of critical infrastructure, in the field of emergency and crisis management, with particular emphasis on cybersecurity because such threats are relatively new and poorly known. Due to the common occurrence and key importance for the functioning of all industries and the entire State, training scenarios will be related mainly to the operation of energy sector plants with the possibility of adaptation and use in other sectors, such as water supply, transport or other branches of the fuel and energy industry.

Such training will develop skills related to the management of unusual situations, with particular emphasis on, inter alia, the following aspects:

- increasing cognitive resources (easier dealing with large amounts of information, easier switching between different tasks),
- increasing awareness (controlling excess information, prior knowledge of actual events, better situational awareness),
- acceleration of the reaction time (saving time when reacting to an event and reporting it, preventing escalation of events, reducing operating costs),
- more efficient use of resources (the ability to divide tasks, effective cooperation and communication, better use of existing systems),
- reduction of false alarms (focusing only on real events, saving the cost of unnecessary actions),
- ensuring business continuity (standardisation of reaction methods and behaviour in the event of various events, better compliance of actual activities with the expected method of responding to a threat).

It is assumed that the use of realistic simulations based on virtual reality techniques will increase the efficiency and effectiveness of this type of training, which is now carried out mainly by traditional forms of training and simple, schematic computer games or RPGs (Role Playing Games) without the use of computers.

It is assumed that simulation games would be based on virtual reality (Head Mounted Display – HMD) techniques and augmented reality (based on techniques such as Microsoft HoloLens).

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Zastosowanie rzeczywistości wirtualnej do szkoleń w zakresie zabezpieczenia funkcjonowania infrastruktury krytycznej

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Streszczenie. Nasze bezpieczeństwo narodowe, dobrobyt gospodarczy i dobrobyt narodowy zależą od zestawu wysoce zależnych od siebie infrastruktur krytycznych. Przykładem obiektów infrastruktury krytycznej jest krajowa sieć elektryczną, systemy naftowe i gazowe, sieci telekomunikacyjne i informacyjne, sieci transportowe, systemy wodne oraz systemy bankowe i finansowe. Biorąc pod uwagę ich znaczenie kluczowe jest zachowanie niezawodności obiektów infrastruktury krytycznej, zwłaszcza elektrowni, również w warunkach kryzysowych lub ataku. W tym celu z jednej strony mogą być udoskonalane i tworzone nowe rozwiązania techniczne wspomagające przywrócenie prawidłowego funkcjonowania obiektów infrastruktury krytycznej, takie jak np. zdalnie sterowane roboty mobilne. Z drugiej ważne jest aby przygotować pracowników do działania w nietypowych warunkach organizując odpowiednie szkolenia. W obu przypadkach przydatne może okazać się zastosowanie technik rzeczywistości wirtualnej.

Słowa kluczowe: infrastruktura krytyczna, niezawodność, rzeczywistość wirtualna, projektowanie aplikacji szkoleniowych