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Utilisation of Games and Virtual Reality to Train Competences Relating to Industry 4.0

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Abstract. Implementation of concepts of Industry 4.0 and cyber-physical production systems (CPPS) requires changes to be introduced to production processes and leads to the fact that employees are expected to acquire new competences and skills pertaining to their work tasks in the production industry. It is assumed that employees of factories of the future will have to execute more complicated tasks, such as the monitoring and adjustment of highly automated and complex processes, and supervision and efficient use of machinery, more frequently. Another issue is the utilisation of augmented reality (AR) systems to provide an employee with additional information. This is why the need arises to develop skills covering the management of high volumes of data and machine interaction, as they will be the basic abilities of persons working in the factories of the future. To master new skills and competences, VR training games can be used.
Keywords: Industry 4.0, production process management, virtual and augmented reality, training games

1. INTRODUCTION

Changing market requirements and new technologies result in a series of changes in the industry work systems. Due to the increasing demand for non-standard and specialised products and shorter batches of the manufactured products, automated mass production has ceased to be the best choice in economic terms. Flexibility, speed and performance of the production system are considered the most important factors with regard to competition on markets characterised by decreasing stability and increasing global character since small batches and manually assembled products are regaining their significance [1, 2, 3]. With the increase in the number of product options, production complexity also increases. To deal with this complexity, new methods and technologies, such as support systems and IT and communication technologies (ITCT) become increasingly important.

The introduction of the concept of Industry 4.0 and cyber-physical production systems has triggered serious changes in production processes, and as a consequence in work tasks in the production industry. This in turn influences the scope of skills and competences that employees should have. The trend to make easy and monotonous tasks, such as loading or unloading of goods, automatic, will continue. Employees will have to more frequently execute more complex and indirect tasks, such as cooperation with machines [4]. Their main task will be to monitor and adjust highly automated and complex processes, and supervise and efficiently use machines [1, 5]. Therefore, dealing with information and high data volumes and machine interaction will be the fundamentals of future tasks of employees of factories of the future [6]. Along with the change in operating means and work tasks, the required employee skills and competences will also change [7]. The scope of skills essential to perform work will include skills to solve complex problems, social skills, process analysis skills, and in particular cognitive abilities. On the other hand, physical skills will constitute a basic requirement in a decreasing number of workplaces [7, 8, 9]. IT-related skills, processing of information and data, and understanding of organisation and processes, as well as human and machine interaction capacities are perceived as crucial for employees of modern production systems. What is more the importance of the willingness and ability to learn throughout one’s life, and multi-disciplinary thinking and acting will increase [6, 10]. In general, it means that it is expected that industrial employees will become employees who use their knowledge to a greater extent in the sense that a considerable portion of their work will require actions involving cognitive abilities, such as application of (complex) knowledge, seeking information, creating new knowledge, or sharing (transferring) new knowledge [11].

2. REQUIREMENTS FOR EMPLOYEES IN INDUSTRY 4.0

The implementation of new concepts of Industry 4.0 introduces significant changes in production processes. New production systems will become more complex, without limitation in the following aspects [12, 13]: work content (diversity), work organisation (team work planning), work management (communication and problem solving), and work safety.

New production systems that will learn and make decisions can restrict the role of humans in the industrial environment to some extent [14]. This does not mean, however, that all humans will be replaced by robots in all parts of production processes. Industrial transformation will enable industrial robots to go beyond their existing tasks – they will not be limited to handling objects and executing very simple, repetitive tasks, but they will be able to merge their capacity with human skills [15]. Instead of competing on who will be replaced, the integration of robots cooperating with the industrial environment should be regarded as a partnership. It seems inevitable that Industry 4.0 employees will spend most of their time on cooperating with machines on complex tasks [16].

The majority of tests carried out in terms of Industry 4.0 concern the application and implementation of these new technologies in industrial systems. In spite of the fact, however, that man is regarded a vital part of the system, few tests seem to include human factors and ergonomics [17]. The lack of consideration of human factors may result in unsuccessful implementation of this new paradigm since humans may feel frustrated, neglected and overwhelmed by robots [17]. In an environment abundant in connected intelligent machines, in which humans still play an important role, it is essential to fully understand how they can act on each other, so that the workflow be as smooth as possible [18]. These complex human-robot systems have to be based on human factors and ergonomics to ensure the safety of both humans and machines [19].

In the next part of this article, two training games are presented. They are aimed at developing skills and cognitive resources concerning the new requirements of Industry 4.0: production process management and utilisation of additional information provided via augmented reality.

3. EXAMPLE GAME – PRODUCTION PROCESS MANAGEMENT

Management of a production process in a factory. Control of numerous pieces of information from different machines, including mobile and autonomous robots. This game is based on a concept of modular, mostly automated, and reconfigured factories of the future. This concept is developed and promoted, among others, by Bosch.

The player sees in front of him/her a mock-up of a factory hall connected to a warehouse, in which 3 types of materials (metal, glass and plastic) are stored, and to a hall where the finished product is submitted. Goods are picked up from the warehouse by partially autonomous robots that should be provided with indications of a raw material pick-up point (one of the three available types) and a production centre where the raw material should be handled. Then the semi-finished products are taken from the centre by robots of the same type (acting according to the instructions sent by the player) to the destination point in the hall. For every produced and delivered product, the player gets virtual currency that can be used to purchase: raw materials, robots handling raw materials and products, subsequent production centres, and upgrades to the existing centres. The player starts the game with three raw material pick-up points, three robots handling raw materials, one production centre (located in the first row on the warehouse side), one robot handling the product, and one product destination point.

Production centres: to operate, each centre creates a product at *n* advancement level. Product prices are selected so that it will be most profitable to manufacture products with the highest degree of processing, just as in the real world. To prepare a product, a centre at *n* level requires: a randomly selected raw material, a product at *n*-1 processing level, and a product at a randomly selected level within the scope <1; *n*-1>. For n lower than or equal to zero, a semi-finished product is replaced with a randomly selected raw material. Random selection of semi-finished products ensures a diverse and unpredictable gaming experience. Production centres can be positioned at points intended for this purpose, except for robot corridors.

The player is responsible for: quality control, inspection and maintenance of machines, repair of damaged machines, adding new production centres and mobile robots, modifying locations of production centres to optimise the production process.

Quality control: it may happen that in some of the centres it will be impossible to manufacture the product, and raw materials and semi-finished products will be wasted (this fact is indicated in a visual and audible manner, which means that the player has to continuously monitor the functioning of the factory). This state indicates that the quality of one of the semi-finished products is too low. The player has to identify the source of the problem by inspecting and maintaining the machines manufacturing the semi-finished product for this centre.

Inspection and maintenance of machines: if a production centre is clicked and an appropriate option is selected, the player is taken from the mock-up monitoring level to the factory working level where he/she stands directly at the machine. The machine has to be switched off, its cover has to be removed, the diagnostic system should be activated, and the player should respond to its result appropriately.

If the player selected by mistake a machine that does not require maintenance, a diagnostic indicator lamp turns green and a key to return to the strategic part of the game is displayed. If a machine requires maintenance, one of the several available logical mini-games that develop cognitive resources is enabled. If an attempt to maintain the machine fails (no success in the mini-game), the player has to purchase parts with virtual currency and repeat the maintenance.

Repair of damaged machines: any failure state is indicated. Failure repair is similar to the maintenance procedure, but it does not include diagnostics. The player immediately goes to the mini-game, but this mini-game has a higher level of difficulty than in the case of maintenance. If an attempt to maintain the machine fails (no success in the mini-game), the player has to purchase parts with virtual currency and repeat the repair.

Adding a new production centre: the player can spend a portion of his/her cash to purchase a new production centre. The player can select the level of the production centre, but it cannot be higher than n+1, where n is the highest level of the currently owned centre. The player has to indicate the place where a new production centre is to be installed.

Adding a new robot: the player can spend a portion of his/her cash to purchase a new robot handling raw materials or (semi-finished) products. If a robot is purchased, it has to be configured by providing the points between which it is going to handle the goods.

Changing production centre: the player may grab a machine and move it to another place. Removing a production centre: the player can grab a centre and throw it in the bin. A portion of the resources is recovered; ¼ of the price if a centre is operational, and 1/8 of the price if a centre is non-operational. Removing a robot: the player can grab a robot and throw it to the bin next to the mock-up. A portion of the resources is recovered.

The goal of the player is to grow the factory and earn virtual currency. The game's difficulty level can be adjusted by changing: probability of failure, probability of insufficient quality of workmanship, mini-game degree of complexity.

The game also has an arcade part. The player can at any time go to the factory's work floor and facilitate work by: handling raw materials, semi-finished products or products; manual manufacturing of the products in the workshop (on a special table located in the corner of the production hall).

Mini-games: they require different types of cognitive resources, such as working memory (as in memo-type games), multi-tasking, selective attention, switching between tasks, holding reactions, planning. The final version of the mini-games will be provided after testing in a virtual environment scheduled as part of stage 2. Example mini-game: the machine has a faulty pipe coolant transfer subsystem.

It should be arranged again from the available components. The first several components (pipes) have already been arranged. The player begins at a moment when the coolant starts to flow from the tank located at the top. He/she has to quickly plan the arrangement and lay the pipes, so that the coolant does not leak from the pipes. The tank must be connected to the destination point in a sufficiently short time. If the player fails to complete the task, the machine will overheat and be irreparably damaged.

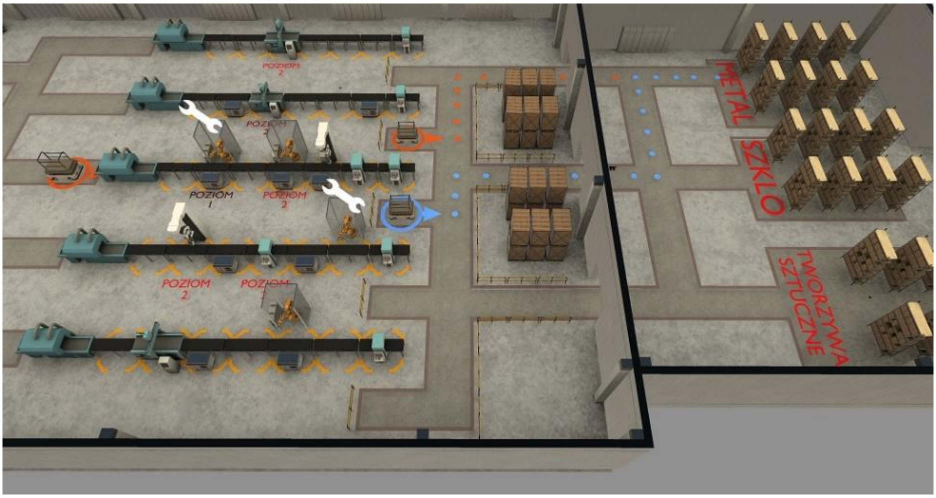

Fig. 1. Virtual environment of an example game relating
to the management of operation of an Industry 4.0 factory

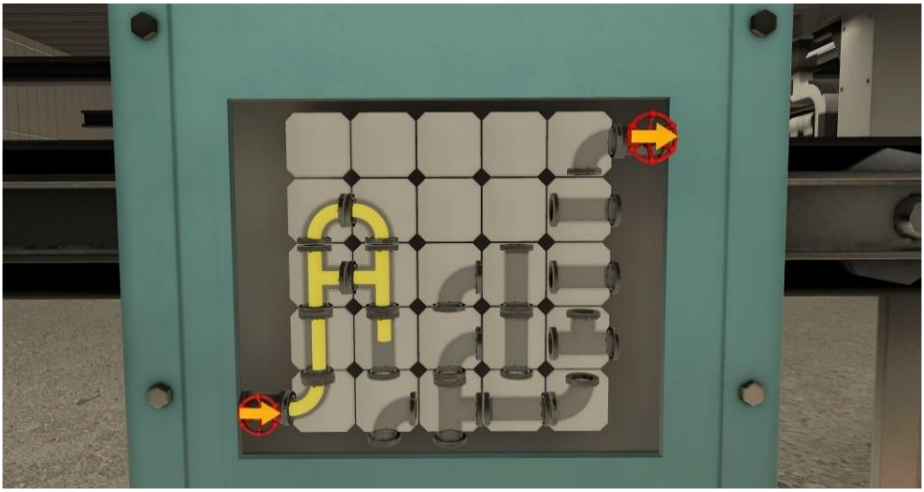

Fig. 2. Example logical mini-game.

4. EXAMPLE GAME – UTILISATION OF AUGMENTED REALITY (AR)

Utilisation of augmented reality systems, for instance in the factory's maintenance. Practical training in dealing with additional source of data displayed as an image superimposed on the real-world image. The game is associated with examples of AR utilisation in Industry 4.0 presented in scientific publications to support machine maintenance and to display production data.

The game's environment is an almost fully automated factory of the future provided with, but not limited to, mobile robots handling (semi-finished) products. An additional image simulating the operation of the factory may be imposed on an image of the factory's virtual environment seen from the working level. The player may call up a map indicating, among others, his/her location, positions of mobile robots and the general condition of the production centres. On the map view, the player may notice that maintenance may be required for some elements of the production process. In the event of failure of an element (e.g. a mobile robot), a formal message with information about the failed element on the map is displayed on a simulated image in AR goggles. The player's goal is to analyse the production data and maintain production continuity by performing maintenance and current repairs. Standing directly at the machine, the player will be able to display details on the machine condition via the AR goggles. In this way, he/she may assess if maintenance is advantageous at a given moment.

The second module of the game is related to the most commonly presented AR application – presentation of tips for an employee during work. Tips are displayed during repairs and maintenance in the form of instructions and indications of which elements should be used at a given moment.

Gaining points: points cannot be acquired during downtime, so the player should perform repairs and maintenance as quickly as possible and schedule them as appropriate since the machines not maintained for a prolonged period fail.

Level of difficulty: the level of difficulty is increased by increasing the probability of failure and by shortening the time after which it is required to maintain the machine.

5. CONCLUSIONS

The concept of Industry 4.0, sometimes called the fourth industrial revolution or the digital revolution, is aimed at going beyond the traditional production systems through full integration of the physical world and a virtual world. In new production systems, everything should be connected: from machines, tools and employees, to products and clients. To achieve this goal, there are many associated technologies that, when introduced, may facilitate the implementation of the concept of Industry 4.0.

These technologies include: Internet of Things, big data, cloud processing, augmented reality, robotics, cooperating robots, and additive manufacturing (the process of manufacturing three-dimensional objects on the basis of computer models, e.g. using 3D printing).

The implementation of entirely new solutions in industry will require new competences and skills from employees of factories of the future. Development of these skills, in particular cognitive resources and abilities of employees, may be carried out with the use of training games and virtual reality. This article describes examples of two such skill- and ability-oriented games (e.g. multi-tasking, quick switching between tasks, observation and analysis of numerous sources of data, etc.) associated with the production process management and with the use of additional information presented via augmented reality.

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Zastosowanie gier i rzeczywistości wirtualnej do szkolenia kompetencji związanych z Przemysłem 4.0

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Streszczenie. Wdrażanie koncepcji Przemysłu 4.0 i cyber-fizycznych systemów produkcji CPPS (ang. *Cyber-Physical Production System*) wymaga wprowadzenia zmian w procesach produkcji oraz sprawia, że od pracowników oczekuje się nowych kompetencji i umiejętności związanych z wykonywaniem zadań roboczych w przemyśle produkcyjnym. Zakłada się, że pracownicy fabryk przyszłości (ang. *Factories of the Future*) będą musieli częściej wykonywać bardziej złożone zadania, takie jak obserwacja i regulacja wysoce zautomatyzowanych złożonych procesów, a także nadzór i wydajne wykorzystywanie maszyn. Kolejnym zagadnieniem jest wykorzystanie systemów rzeczywistości wzbogaconej AR (ang. *Augmented Reality*) w celu dostarczenia dodatkowych informacji pracownikowi. Z tego względu narasta potrzeba rozwijania umiejętności radzenie sobie z dużą ilością danych oraz interakcja z maszynami, gdyż będzie to podstawowa umiejętność niezbędna do wykonywania zadań pracowników fabryk przyszłości. Do doskonalenie nowych umiejętności i kompetencji mogą być zastosowane gry szkoleniowe realizowane w środowisku wirtualnym VR (ang. *Virtual Reality*).

Słowa kluczowe: Przemysł 4.0, zarządzanie procesem produkcji, rzeczywistość wirtualna i wzbogacona, gry szkoleniowe