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Employee Training in an Intelligent Factory Using Virtual Reality

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ABSTRACT The article presents the results of research on the impact of virtual reality on the effectiveness of training employees performing production tasks. The research was carried out in the Smart Factory laboratory, which is a model of a smart factory functioning in accordance with the concept of Industry 4.0. A prototype VR system and its building process were presented, starting with the digitization of the laboratory, through logical programming and connecting peripheral devices. The subject, scope and plan of conducting comparative studies of operator training at both real production stations and in a virtual environment were presented. As a criterion for comparing the results achieved by individual groups subject to the study, the following were adopted: the time to complete the production task and the number of non-compliant products achieved in real conditions.

INDEX TERMS Industry 4.0, virtual reality, smart factory.

I. INTRODUCTION

The ongoing customization of products requires production systems to have an ability of quick response to customer needs. Therefore, effective product design and production control must be indispensable components of the intelligent factory of the future [1], [9]. This requires innovative and intelligent solutions not only in terms of object (e.g. Internet of Things), but also process (e.g. Knowledge Based Engineering) [8]. Only then will it be possible to fully use the production potential of an enterprise with modern technical resources in line with the concept of Industry 4.0 [7].

Although the basic element of an intelligent factory are cyber-physical systems, human still is an inseparable element [2]. In such cases, intelligent production systems are increasingly enriched with techniques from the field of VR (Virtual Reality) or AR (Augmented Reality) [3]. Undoubtedly, these techniques will increasingly become a factor enabling flexibility in cyber-physical systems and ensuring their user-friendliness and ease of use [12], [22].

The need to constantly adapt production systems to changing customer requirements forces the introduction of new methods in the field of process organization or production control [23]. In this context and with regards to the implementation of solutions for automation and computerization of data flow, practice and training of employees in new conditions are of particular importance. VR systems undoubtedly contribute to the implementation of these tasks without interfering with the real production processes and incurring excessive or unjustified financial expenses.

The authors decided to analyze a possibility of using VR for training of simple assembly operations performed on the production line. As part of the research, it was attempted to determine the impact of training in VR on the time of assembly operations as well as product recognition time and quality of assembled products. The recognizing of new products is crucial in Smart Factories and flexible manufacturing systems in general.

II. VIRTUAL REALITY TRAINING APPLICATION

VR systems are IT solutions supporting more and more areas of the economy (medicine, entertainment) but also used often in various production processes [20]. In both industrial and entertainment applications, 360 degree virtual images [29]–[31] and videos [32] are frequently used. In this types of applications it is important to either track user head and eye movement or predict them [33], to sharpen image in places that the user is currently looking.

The VR application is a basic element of the entire virtual reality system, that contains virtual object models placed in the appropriate environment, providing the user with interaction and immersion [5]. The most popular types of VR engineering applications currently used include virtual simulations of production processes, assembly and

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disassembly operations, virtual work stations and product configurators [6]. Depending on the phase of the product life cycle for which the VR application is created, it can be used for product design and testing, visualization of production processes or employee training.

Virtual reality systems are currently eagerly used in the training area [18]. Currently, there is a very large selection of various equipment, enabling not only photorealistic visualization of the real environment (including VR helmets), but also allowing the user to interact directly with its components (e.g. haptic devices, position tracking and orientation systems), thus enhancing the feeling of immersion [4]. By integrating the equipment with a properly prepared VR application, a specialized simulation environment can be obtained, in which the training takes place in accordance with the conditions that occur in reality. Training VR applications allow to increase efficiency of procedural knowledge transfer. In VR, it is much easier to perform repetitions of learned activities or to present undesirable or dangerous situations. Their scalability and adaptability is also an advantage. VR application can be prepared in such a way, that the presented content flexibly adjusts to both the specific user and the changing conditions of the simulated process [27], [28].

VR training applications are used in many different industries. Gorecky presented the VR training application as part of the VISTRA project [11]. This solution was presented on the example of the process of assembling car parts, using various techniques and methods. It should be emphasized that the whole system has been enriched with a specially prepared knowledge base, and when designing the user interface an intuitive interaction, known from computer games (game-based user interaction), was assumed. Abate and co-authors presented the ViRst person system, intended for training in the field of aircraft technical maintenance, using haptic devices [13]. Angelov described a training VR system for the energy industry [10], and in the paper [16] by Fast, the application intended for learning the welding process was presented. Lin and co-authors developed a VR application designed to learn how to operate an NC machine tool [19], and Wasfy used a virtual environment to train wind tunnel operation at NASA [21]. The use of VR systems for training in the automotive industry [17] (by Langley and co-authors) or in aviation, reduce its time by up to 75% [24]

In their article, Debevec *et al.* [15] describe a virtual factory that is an effective tool for training production process planners. It allows to perform a production plan or schedule in a virtual environment, without consuming materials, energy and without interrupting the production process. The virtual factory can also be used to design new production systems or to improve existing ones [14].

An innovative training method was presented by the authors who created the virtual training system they built for learning forklift operation [25]. The presented application offers both theoretical lessons and practical exercises. After the training the user has the opportunity to check the acquired knowledge and skills by taking the exam. The studies confirm the effectiveness of such a solution and its attractiveness. Virtual training turned out to be carried out in a shorter than traditional one - users managed to acquire knowledge within an hour, which in standard conditions normally takes one day. In addition, the training can be performed independently, without constant presence of the instructor [26].

FIGURE 1. View of the SmartFactory laboratory.

III. SMARTFACTORY LABORATORY AND THE SUBJECT OF RESEARCH

The SmartFactory laboratory of the Poznan University of Technology was designed to conduct research in the field of various solutions of the Industry 4.0 concept. It allows to simulate processes that occur in a real production system. It consists of an automated production line in the form of three transport loops, next to which there are production line work stations, as well as a warehouse of raw materials and finished products. A number of solutions in the field of automatic data identification (RFID, RTLS) have also been implemented, allowing to control the flow of information through an original IT program called 4Factory. The laboratory is shown in Figure 1.

The subject of the research is the training of operators of the implementation of the production process including the assembly of products from parts in the form of lego blocks. Lego blocks have been adopted as the basic element of building finished variant products. As a result, full flexibility was provided in terms of product construction in accordance with the idea of customization of production, which is the basic goal of the concept of industry 4.0. Using Lego blocks is a widely accepted idea in prototyping and testing of processes related to multi-variant products and elastic production. An example of a product is shown in Figure 2.

The production process includes the implementation of 6 assembly operations carried out at subsequent production stations. Subassemblies and finished products are moved on an automated line through transport pallets (Figure 3). The line is controlled by a PLC controller and RFID systems. Production stations are equipped with flow racks that allow storage of containers with parts and units for assembling customized products. The shelves are also equipped with RFID reading heads enabling their identification.

The basis for starting the production process is the schedule prepared in the 4Factory program. After the pallet stops,

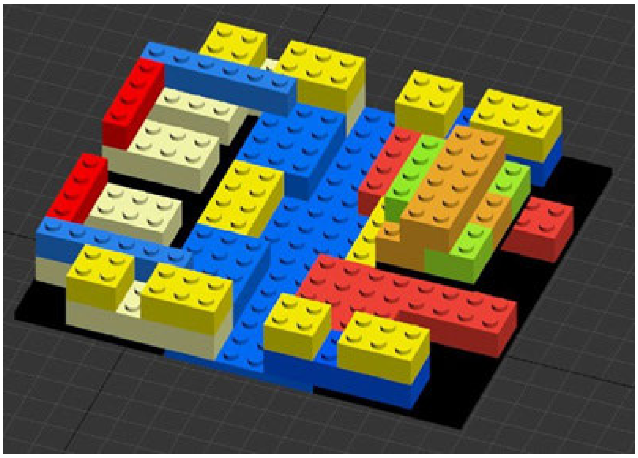

FIGURE 2. An example of a product made of Lego blocks.

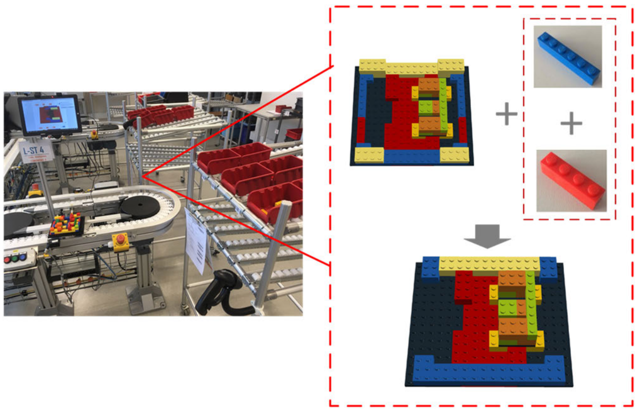

FIGURE 3. Example of assembly operation in smart factory lab.

operator at the production site must first identify the product, so that the scope of assembly tasks can be properly determined.

Tasks carried out by operators include:

- getting acquainted with the assembly instructions that are displayed on the tablet,
- performing the sequence of assembly tasks in accordance with the instructions, including the activities of collecting the relevant parts from a bench rack and mounting in the product,
- confirming the execution of the assembly operation.

The number of assembly operations, as well as those related to the collection of parts from material racks obviously depends on the scope provided in the production manual.

Considering the possibility of implementing orders with a variable (variant) configuration, operators must constantly control the required scope of work. It takes a lot of concentration both in the Smart Factory laboratory and in industrial environment. A mistake may be easily made here resulting in the delay in the implementation of the entire production process. Therefore, proper preparation of operators through frequent training becomes key to the efficiency of this process. Carrying them out in real conditions often means discontinuation of production, and this, in turn,

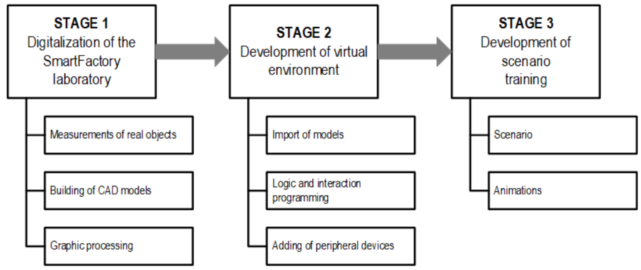

FIGURE 4. Stages of the system construction.

FIGURE 5. Digitization of the production line A-CAD model, B-graphic processing.

may contribute to delays in the implementation of customer orders. The use of VR systems for training purposes makes it possible to study the reaction and implementation of tasks by operators without having to stop the production.

IV. VIRTUAL REALITY TRAINING SYSTEM DEVELOPMENT

A. ENVIRONMENT AND INTERACTION

The developed Smart Factory laboratory virtual training system is designed for operators performing assembly tasks at individual production stations. It was developed in the form of an integrated IT system, including the application (virtual environment, user interface, logical connections between objects) and peripheral devices (VR goggles with a position and orientation tracking system). The individual stages of building the system are shown in Figure 4.

B. DIGITIZATION OF THE LABORATORY

The first stage comprised of digitization, i.e. measurements of real objects needed to conduct virtual training and development of digital 3D CAD models for them in Autodesk Inventor software. A complete model of the production line, shelving and parts of manufactured products was prepared. The authors desire was the accuracy of duplicating actual conditions so that the person trained in the VR system could later more effectively implement the acquired knowledge in practice. That is why CAD models were processed in the 3DS Max graphic program before further work (Figure 5), what included mostly texture (UV) mapping and adding appropriate materials, to obtain more realistic look of the machines in the laboratory.

C. VIRTUAL TRAINING ENVIRONMENT

The goal of the next stage of work on the VR system was to create a virtual, interactive environment that duplicates the actual Smart Factory laboratory. The Unity engine was

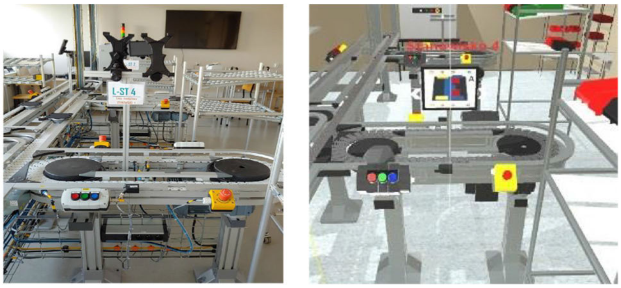

FIGURE 6. Construction of a virtual application in the unity engine.

used to build the application. Prepared 3D models were imported, and then the appropriate logical connections were programmed. As a result, a fully usable, digital model of the production line was created (Figure 6), where it was possible to start it, transport pallets to any stations or e.g. to stop in emergency (e.g. after pressing the emergency buttons). At the end of this stage, the application was connected to selected peripheral devices (VR goggles with controllers).

Working on a virtual station was possible thanks to the use of Oculus Rift CV1 goggles, equipped with two OLED screens with a total resolution of 2160 × 1200 pixels, working with a refresh rate of 90 Hz and a field of view range of 110 degrees. To track user movements, two sensors were used to identify the user in 360 degrees. The mapping of hand movements in virtual reality is realized through a touch controller being part of the Oculus Rift CV1 set.

D. TRAINING SCENARIO IN A VIRTUAL ENVIRONMENT

Preparation of the training scenario in a virtual environment included programming two areas in the Unity environment. The first concerned familiarizing the operator with the equipment of the production system, while the other was related to the mapping of the implementation of assembly tasks.

In order to create interaction with controllers, they were defined with elements such as colliders, rigid bodies, scripts and animations. This made it possible to simulate various real situations and phenomena, e.g. hitting one object with another or kinematic animations.

The training scenario regarding familiarizing the operator with work stations was designed in the form of graphical user interface elements displayed in 3D space. For this purpose, canvas objects were used, containing texts with instructions placed in front of the operator (Figure. 7).

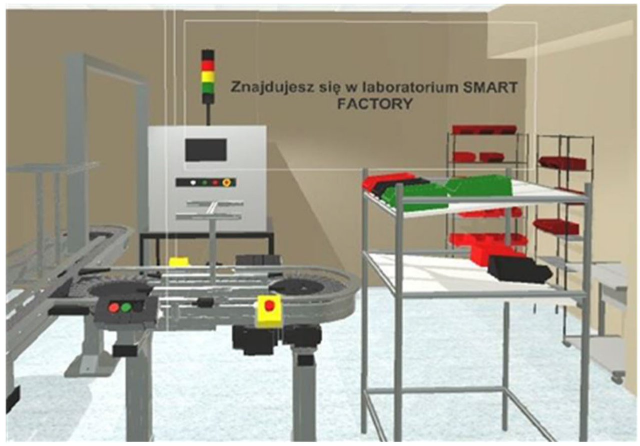

FIGURE 7. Commands of the workplace instruction.

The instruction contained eleven steps. After reading each of them, the user goes to next one. For this purpose, a sphere object was added to the scene (Figure 8) and scripts from the Virtual Reality Toolkit (VRTK), were added to it. Thanks to these scripts, after the virtual hand entered the collision zone with the sphere and a trigger was pulled on one of the controllers, the displayed instruction step changes to the next.

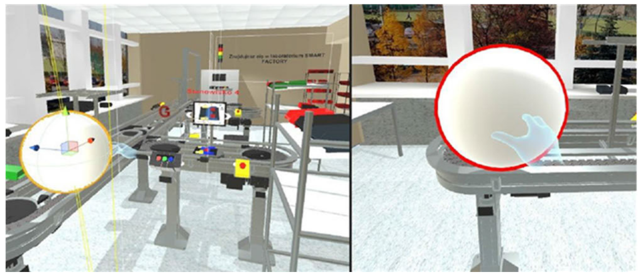

FIGURE 8. Workplace instruction in a virtual environment. Visible sphere as a 3D interface element in the application.

After the on-the-job training, a trainee starts the assembly task in a virtual environment. In the first step, the participants have to identify which product would be a subject of assembly tasks, and then have to find the appropriate assembly instructions. To make this operation possible, arrows are placed next to the virtual tablet, allowing free selection of the appropriate instruction (Figure 9).

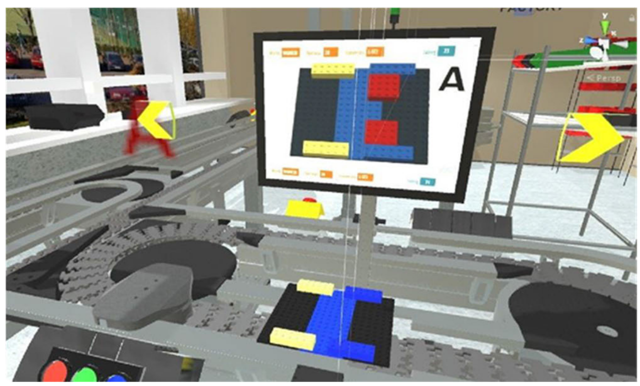

FIGURE 9. View of the VR application during the implementation of the assembly task.

The application also provides for the lack of instructions for one of the products to reflect the real situation. After completing all the tasks included in a given instruction, the operator starts moving the pallet to the next position using the blue button. Bearing in mind the employee training process and trying to faithfully reproduce the realities of the production process, VR applications have not been limited only to performing correct activities. The person carrying out the task can accomplish them in any way, and thus also erroneous, e.g. putting the assembly on the wrong shelf or collecting the wrong part in a given sequence.

V. RESEARCH PLAN

The basic goal of the research was to determine the effectiveness of using virtual reality techniques for training production employees carrying out assembly tasks in the Smart Factory laboratory. The study was conducted on a two test group of 20 people at the age of 24-26 (12 male and 8 female in each group). None of the people had any previous contact with the processes carried out in the laboratory and were not familiar with the specifics of assembly tasks. The first group of people was subjected to training in real conditions, which included:

- familiarization with the elements of the production station equipment and its operation,
  - familiarization with the assembly instructions,
  - test execution of the assembly operation for three products.

After completing the training, each participant in the group performed the actual realization of production orders.

The second group of participants was trained in a virtual training environment. The training included:

- presentation of VR equipment elements,
- familiarization with the operation of VR equipment,
- familiarization with the operation of the training application in the form of instructions.

Completed training by a given participant was the basis for the implementation of relevant production orders in real conditions.

VI. TEST RESULTS

A. COLLECTION OF DATA

The study covered 20 people where 10 people conducted training in a VR environment and the rest were trained in a real environment. After completing the training, the task of each participant was to make three products in a real production system. The participant's performance of a given operation was subject to time measurements:

- product identification (recognition of which product is subject to the operation) along with finding the appropriate assembly instructions,
- assembly of the given product (from the beginning of the assembly of 1 part to the end of the assembly of the last part).

The quality errors of the products resulting from the assembly operation carried out by the operator were also measured during the tests.

B. RESULTS AND ANALYSIS

The results of the average product identification times and the assignment of the appropriate work instructions indicate that participants trained in the VR environment carried out this task faster for all types of products (Figure 10).

This indicates that training in a virtual environment has undoubtedly contributed to greater product knowledge and attention to their characteristic design features.

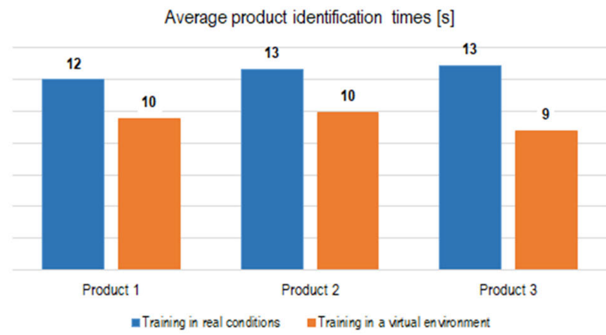

FIGURE 10. Comparison of average product identification times.

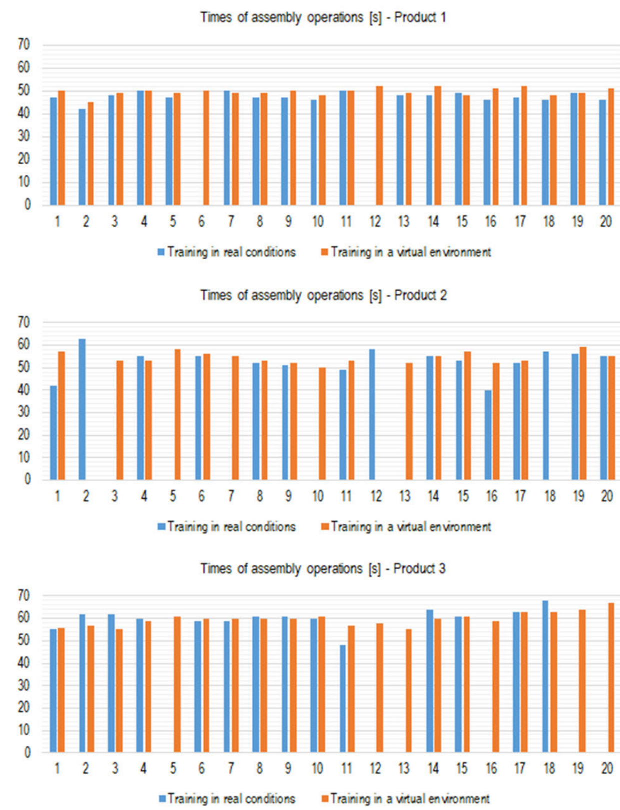

FIGURE 11. Times of assembly operations.

The analysis of assembly tasks implementation time indicates the advantage of trainees in real conditions, who achieved better results for the first two products (Product 1, Product 2). However, for product 3, the average execution time was identical for both training groups (Figures 11, 12).

This product was characterized by a greater number of assembly parts and thus a greater degree of complexity of the assembly task. Thus, it was the most labor-intensive product. This may indicate that trainings in VR contribute to better perception and faster identification of construction and task details necessary to be carried out in real conditions, and, as such, better for learning more complex than simple assembly tasks.

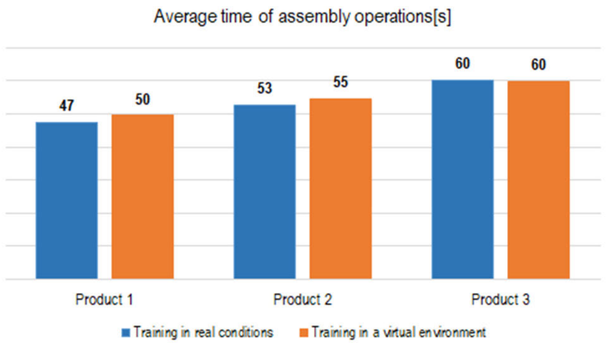

FIGURE 12. **Average time of assembly operations.**

TABLE 1. **Comparison of the number of errors made by operators.**

	Operators trained in a real environment	Operators trained in a VR environment
Number of manufactured products meeting quality requirements	39	51
Number of quality errors	8	5
Number of not manufactured products	13	4

As a result of the non-compliance analysis, 8 defective products were found in the group trained in real conditions and 5 defective products in the group trained in a virtual environment. The occurrence of incorrectly installed parts or their color was classified as a defective product. The study assumes that the participant has a maximum of 2 minutes to carry out assembly tasks for a given product. After this time, the task was interrupted and participants were asked to carry out another task. The results indicate a higher effectiveness of training in the VR environment because this situation occurred only four times. However, among the participants of the training in real conditions this situation took place thirteen times (Table 1).

The results show that training in real conditions allows operators to complete the assembly task in a shorter time. At the same time, the times obtained by training participants in the VR environment for all the production orders are only 3% longer.

However, taking into account the structure of this time, trainings in the VR environment contribute to a more effective identification of parts or products, which directly resulted in a smaller number of errors. The longer time needed to complete the assembly task indicates that perhaps the training in the VR environment was too short and the training scenario was unclear to the participants. The main problem, however, turned out to be a vague representation of precise assembly in the VR application.

VII. CONCLUSIONS AND FUTURE WORK

The developed VR system has been prepared for training employees/operators of the production system, operating in accordance with the concept of Industry 4.0. In the idea of an intelligent factory, man will continue to play an important role in the production process, which is why so much depends on his preparation and training. The proposed solution, using VR techniques, seems to be one of the best solutions for conducting employee training, because it can be fully integrated with a real production system.

The solution of the training system presented in the article in the VR environment requires several improvements. However, the conducted tests confirm its effectiveness despite longer times of assembly implementation. It should be emphasized that despite conducting the training in a real laboratory environment, it can be assumed that this would require excluding the production line from ongoing production, which will result in performance losses. Thanks to the use of the VR system, training can be conducted at any time, as long as employees have access to a computer and VR peripherals.

After testing, the following conclusions can be made:

- virtual reality training improved identification tasks, but did not improve assembly operations' speed,
- virtual reality training could improve qualified products number, products meeting quality requirements,
- it is necessary to change the form of initial instruction in the VR application from the instruction displayed on the wall to an interactive instruction,
- virtual laboratory should reflect the real laboratory and its elements in even more detail, including tablet operation,
- problems with tracking the position and orientation of the user and his hand in the VR application could be solved by the use of an additional optical sensor,
- effect of sudden change of position - 'rejecting' the user should be solved by using the VRTK script compatible with the version of the Unity software used,
- modification of the collision areas of both the part and the virtual hand would allow easier gripping and assembly of parts.

In addition, the developed system has limitations, the minimization of which will be the basis for further work. Currently, the scope of simulating the production of any configurations of designed products is limited. The system recognizes only those configurations (variants) that have been previously uploaded to it. In the future, this system should be integrated with the program for designing new products, so that it is possible to simulate new (i.e. future, never launched in reality) production processes and at the same time train employees to work with them. This task requires the development and implementation of an appropriate knowledge base on design processes, thus creating a KBE class system.

Future work will include more behavior analyses of users such as head tracking and eye tracking. Authors plan to gather data using HTC Vive Pro Eye or new HMD that has embedded eye tracking utility. The gathered data will be used to analyze user behavior to improve application to train workers more effectively.

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