Possibilities of increasing production efficiency by implementing elements of augmented reality

Justyna TROJANOWSKA [1]*, **Jakub KAŠČAK** [2] ⓘ, **Jozef HUSÁR** [3] ⓘ, and **Lucia KNAPČÍKOVÁ** [3] ⓘ

[1] Poznan University of Technology, Faculty of Mechanical Engineering, Department of Production Engineering, Piotrowo Street 3, 61-138 Poznan, Poland

[2] Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Computer Aided Manufacturing Technology, Šturova 31, 080 01 Prešov, Slovak Republic

[3] Technical University of Košice, Faculty of Manufacturing Technologies with a seat in Prešov, Department of Industrial Engineering and Informatics, Bayerova 1, 080 01 Prešov, Slovak Republic

Abstract. The publication reflects the current situation concerning the possibilities of using augmented reality (AR) technology in the field of production technologies with the main intention of creating a tool to increase production efficiency. It is a set of individual steps that respond in a targeted manner to the possible need for assisted service intervention on a specific device. The publication chronologically describes the procedure required for the preparation and processing of a CAD model. For this preparatory process, the PTC software package is used which meets the requirements for each of the individual operations. The first step is the routine preparation of CAD models and assemblies. These are prepared based on real models located on the device, and their shape and dimensions correlate with the dimensions of the model on the device. The second phase is the creation and timing of the disassembly sequence. This will provide the model with complete vector data, which is then paired with the CAD models in AR. This phase is one of the most important. It determines the location of the model concerning its relative position on the device, provides information on the relocation of parts of the model after the sequence is started, and essentially serves as a template for the interactive part of the sequence. The last two phases are used to connect CAD models with vector data, determine their position for the position mark, and prepare the user interface displayed on the output device. The result of this procedure is a functional disassembly sequence, used for assisted service intervention of a worker in the spindle drive of the Emco Mill 55 device.

Key words: production efficiency; production equipment; augmented reality; Industry 4.0; maintenance.

1. INTRODUCTION

This article is based on the knowledge from various areas in which this technology is currently being used. Some of them were in the past incompatible with this technology due to the lack of specialized software or unprofitability [1]. Currently, the boundaries of the availability of AR technology are considerably shifting. This can also be observed in the article published by Jonas Fegert *et al.* titled "Ich sehe was, was du auch siehst. Über die Möglichkeiten von Augmented und Virtual Reality für die digitale Beteiligung von Bürger: innen in der Bau- und Stadtplanung" [2]. This publication perhaps most clearly depicts the current state of AR and VR technologies, the use of which is set so that anyone can become a user of these applications and technologies and thus participate in the process of construction and urbanism.

The publication tries to follow this trend and gradually presents individual steps so that it is clear how we can achieve the creation of a user-friendly application, which is intended for the target group of users with a lower level of practical ex-

perience with AR [3]. This article points out the possibilities of using the elements of Industry 4.0 in an accessible form. It focuses on its direct implementation and its impact on the possible consideration of production efficiency.

The paper informs in individual sections about the current state and issues of this technology and describes the individual steps of creating a sequence. The introductory sections deal with the basics, that is, the preparation of 3D models, and their import and export in native formats. It continues with the usage of software for technical illustrations and consistently describes the issue of the hardware performance of output devices. At the same time, it presents a possible solution to this problem through the export of vector data and the optimization of CAD models for output devices with lower performance. The publication also presents the preparatory phase of creating a sequence in AR with all its possibilities. The result of the publication is the unification of previous steps, i.e. 3D models, vector data, time data, and position markers in specialized software. This enables the creation of an AR sequence with a reference point defined by a position marker. The sequence itself is defined to serve as a form of support for the maintenance of the Emco Mill55, performed by the worker. This accessible and repeatable process of implementing AR into production can have a rapid impact on the increase in produc-

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*e-mail: justyna.trojanowska@put.poznan.pl

J. Trojanowska, J. Kaščak, J. Husár, and L. Knapčíková

tion efficiency, worker safety, and service or machine maintenance.

1.1. Theoretical increase in production efficiency using AR support

Regarding the perspective of using software and hardware enabling the implementation of AR technology in production, several relevant surveys are focused on this specific area. The survey published under the title "Augmented reality is changing marketing and sales supercharging sales through digital innovation" [3] and "The total economic impact of PTC Vuforia cost savings and business benefits enabled by industrial augmented reality" [4] were carried out on a sample of 150 manufacturing enterprises with the number of employees from 100 to 20,000+. The most expressed interest in the implementation of AR was precisely in companies with a number of employees in the range of 1000–4999, namely 29%, followed by 21% for the companies with a size of 5000–19999, 20% for 500–999, 19% for 100 to 499 and 10 % for companies of size 20000 and more [3].

Figure 1 reflects the level of positive response to the possible implementation of AR from different job positions and departments.
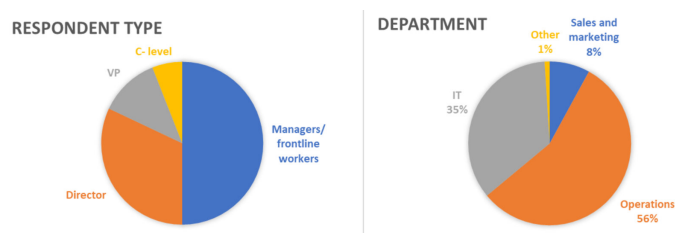

Fig. 1. Response to AR implementation across jobs and industries [3]

As we can see, the greatest interest in the sample of 150 companies is precisely in the area of management positions, frontline workers, and directors. While in the case of departments, IT and operational production constitute the majority. On this basis, we can claim that the concept of this publication, i.e. the creation of a sequence for assistance during a service intervention, is addressed to a relevant target group. Based on these surveys we can assume that:

- New opportunities will emerge for marketing and sales: product presentation options that have the potential to improve communication with the customer and the presentation of the offered products or services.
- Digital innovation with augmented reality: use of AR mainly in the field of increasing production efficiency. Either in the form of alternative AR technical documentation intended for employees with insufficient experience, service intervention assistance, various types of disassembly, assembly, or other assistance services played in the worker's field of vision.
- Examples of augmented reality: better presentation of products using AR and available Android devices, the possibility of expanding the target group for product placement.
- The value of AR for business: develop a compelling new virtual buying experience that uses AR to provide a more com-

prehensive way for buyers to understand and engage with products [3].

From the presented data, we assume that the most expected benefits resulting from the implementation of AR in the production process will be in the following areas:

- Improved knowledge transfer: 50% reduction in new hire training.
- Improved field service quality and productivity: 10% to 12% reduction in overtime spending.
- Improved documentation: 60% faster creation of technical documents.
- Reduction in spoilage, rework, and waste: 5% to 10% reduction [3].

The publication thus presents another possibility of using mixed reality technology, this time applied directly to the field of industrial production, intending to increase production efficiency. It is designed in such a way that even a worker with insufficient work skills can perform a simpler service intervention with its help, even without the necessary qualifications. The simulation gradually accompanies him through individual steps until the end of the entire process. The sequences created in this way can be applied practically anywhere. The possibilities of using different types of hardware, from 2D glasses, through Android iOS devices to fully 3D headsets, give this technology variability for its use in different types of industries and operations [4].

Based on the already mentioned surveys and research in the field of AR, we can draw several conclusions. The first one is that the software and hardware needed to implement AR technology are getting bigger and bigger. Thus, the impact group is expanding, and the technology is beginning to spread in areas where it was absent in the past. The second one is that this phenomenon creates increasingly user-friendly software and affordable hardware. And it is the combination of available technologies and software, which are relatively easy to use, which creates space for these technologies in areas such as industrial production. The expected increase in production efficiency using this technology is indisputable, as can be seen in Fig. 2.

Fig. 2. Predicted areas of AR impact based on a survey [4]

1.2. Use of software for technical illustrations to export vector data

Several model situations can be chosen regarding a simulation solution methodology to present possibilities of AR being implemented in maintenance operations. AR may be used to position jigs and fixtures in the machining process, as described

2

Bull. Pol. Acad. Sci. Tech. Sci., vol. 70, no. 6, p. e143831, 2022

in [5]. The use of interactive models is another possibility to create technical documentation [6], and train users to increase manufacturing workshop effectiveness [7].

The model situation includes the replacement of the milling mandrel and removal of the electric motor case cover, in order to conduct an unspecified inspection, and the sequence then contains the earlier mentioned spindle drive model (Fig. 1b). Next, it is imported to the technical documentation software, where individual parts of the sequence are chronologically placed, and effects and warnings are added [8]. The UI creation of the output device and unification of the AR sequence and all its elements into one unit is then described. Thus, the expected result is that the spindle drive model is displayed in the field of view of the user. The user follows every step in the sequence and carries out the steps for a service intervention. The UI should also provide adequate space for interactivity of the CAD model that is given by functions determined in advance, which makes it available in the UI and facilitates good control of the sequence [9].

The mentioned Emco Mill55 device, depicted in Fig. 1a, thus figures as an essential device for practical application. More precisely, the spindle drive is one of its parts, visible in Fig. 1b, on which a minor maintenance process is simulated. For this purpose, it is necessary to create dimensionally and geometrically correct 3D CAD models on a scale of 1:1. These will later serve as a means of transmitting visual information in AR for maintenance.
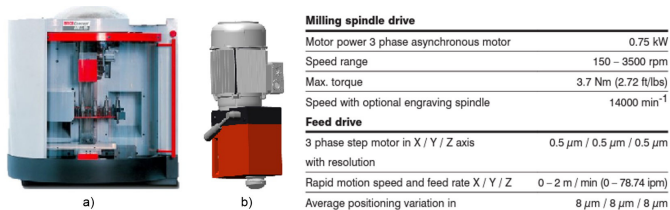

Fig. 3. Basic technical parameters of the device chosen for AR application

Sequence preparation will be shown in steps (i.e. an accompanying ARE for the worker is created). The sequence will next be used in the guidance of the user by the milling mandrel being replaced, and by intervening in the electrical box of the device motor [10].

1.3. Creation of a maintenance sequence in AR

A sequence that shows every step of maintenance visible to the user should also be displayed in the AR experience. Also, the interactivity of the user and the 3D CAD models is necessary. If the only form used as an instructional video was animation, it would limit the user's field of view and interaction to basic controls. Even so, the intention in this example is to achieve full interactivity of the user interface and 3D CAD models displayed in the user's field of vision. Their primary function should not only be controlling the sequence, resetting positions, and repeating individual actions. The UI should also have basic elements characteristic of CAD software, which will serve for better orientation and additional display of models in space.

The user should be alerted to imminent threats or important parts of the sequence [11].

We use Creo Illustrate to create the sequence. The program was originally created for technical documentation processing, creating assembly and disassembly plans, and animation presentations of CAD assemblies, or manuals. The software is essential to the entire process in this case because of its compressed PVZ output format. The PVI format is simply extracted, and vector data on the moving and positioning of unique CAD models is obtained and assigned to unique models in the AR sequence. This must be carried out in order to perfect and make the sequences as functional as possible for the output hardware characterized by a lower and diverse performance, making compatibility with complex animations difficult [12].

The CAD model of the spindle drive that was imported into the program environment, and all assembly elements, can be seen in Fig. 4a. This environment is identical to several commercially used CAD software programs. However, one difference is the ability to create sequences that are combinable with common CAD software features. An example of the possible arrangement of sequential images when creating a commonly named spindle drive assembly plan. The content displayed in the AR can contain several other types of available modifications, the layout of the images, and operation numbers on each image [13].
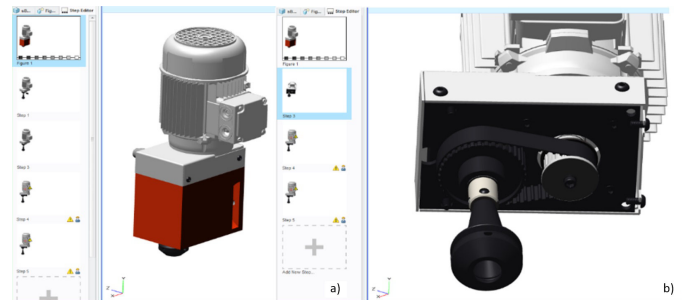

Fig. 4. Demonstration of timing sequences using animation frames

1.4. Adding individual operations to the AR sequence

As mentioned above, the creation of individual sections of sequences, and their complexity, is dependent upon the displayed action. The creation sequence introduction, which includes two steps that guide employees in replacing the milling mandrel, can be seen in Fig. 5. As visible in Fig. 5a, the first phase shows a highlighted handle in order to alert a user to notify the model. This is achieved by the use of a "Flash" function, and by the creation of the color that should be used to highlight the model. The second phase includes the rotation of the handle in the de-
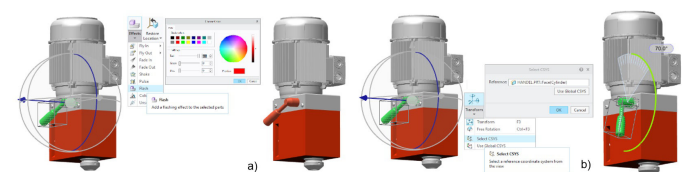

Fig. 5. Creating instructions for additional manual operations

J. Trojanowska, J. Kaščák, J. Husár, and L. Knapčíková

sired direction (Fig. 5b). These two steps form the base of the release sequence of the milling mandrel.

The user is alerted to the release of the milling mandrel in the next phase of the sequence through the use of the same highlight function as seen in the first step. The image of the sequences is next expanded with "fade out" and translation features. These changes introduce the display of a user's warning of the milling mandrel release, the display of the distance and direction of which the component must be extended, and the removal of this from a user's visibility. The sequence end is made up of the rotation of the spindle drive assembly, and the approach of the distribution part of the electric motor.
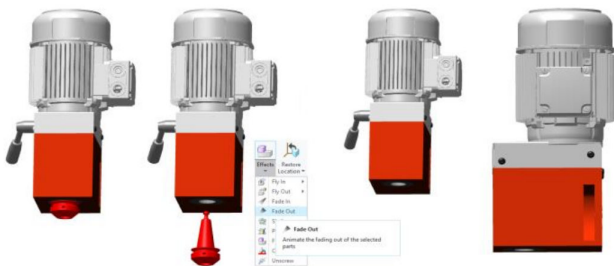

Fig. 6. Showing the disassembly sequence with parts removed in previous operations

Removal of the electric motor case cover constitutes the last part of the sequence. This action included four functions: highlighting of the screws to be removed (carried out in the same manner as the two previous steps), the addition of an animation of unscrewing bolts in a preselected direction, and their removal with the case cover, and finally, display of the contents of the case that includes alerts (Fig. 7).
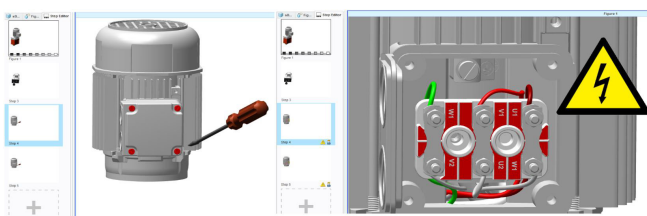

Fig. 7. Example of adding a high voltage warning to a sequence

After images in the sequence are defined, and functions to all components added, files are easy to save in PVZ format, which is a compressed file that contains individual CAD models and vector data. This file format is dissatisfactory for use with Android and iOS devices for which the sequence is prepared. Thus, only the PVI file that contains the vector data is extracted from it. All parts of the sequence created are repeatable, and component positions are resettable [14].

2. CREATION AND DEFINITION OF THE KEY FEATURES OF THE APPLICATION AND UI

The previous sections described the timing procedure and preparatory phases for the creation of the AR experience. The following sections detail the individual steps that are necessary

for linking CAD models, timing, and vector data. The result of this process will be a functional application simulating a maintenance intervention on the equipped EMCO Mill55. The sections also describe how to create the user interface of an application displayed by an output device, as well as assign functions to its specific controls.

This section is a sort of summary and connection of classic 3D modeling and the common outputs associated with it with mixed reality technology. By replicating the following steps, it is possible to create similar sequences that can be beneficial in other areas.
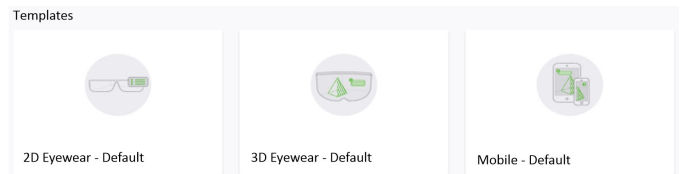

Fig. 8. Software predefined options for output devices

2.1. Selection and modification options for output devices
As mentioned above, thanks to the high demand for these technologies, many kinds of specialized software are entering the market [15]. The PTC Creo software package is used, which contains three kinds of automated programs, which results in cooperation in an interactive sequence in AR. This software package is made up of PTC Creo Illustrate (purpose and use were described above), PTC Creo 8.0, and Vuforia studio.

This is a freestanding program focused on the preparation of the UI for the devices shown in Fig. 6. The preparation consists of two parts – the front end and the back end. The front end is the visible part of the UI and contains all elements of the model controls, which ensures the interactivity of a user with the model in AR. This part has optimization for three types of devices [16].

In order to see collected data in real-time in Vuforia, an application must be created in the Vuforia Studio. First, a new project is created in Vuforia Studio by opening the program and selecting the option to create a new project. There are several options to choose from, including smart devices (Fig. 9a), 2D glasses (Fig. 9b), and a 3D virtual reality headset (Fig. 9c). The default "Mobile" option is chosen for this example.

Fig. 9. A sample of usable output devices

The chosen mobile device was Android because it is readily available and is possible to integrate into production and the condition in which the technology requires. Headset devices, both 2D and 3D, present a nonstop image from the sequence in

4

Bull. Pol. Acad. Sci. Tech. Sci., vol. 70, no. 6, p. e143831, 2022

the user's field of view. Because the negative effect is unknown, no defined percentage of the field of view would be safe, so we chose a device with a temporary view, in line with the needs of the worker. The device is a Lenovo M10 Plus, which has a 1900×1200px resolution, which is set as the default setting for the UI.

2.2. The final step, UI creation in Vuforia studio

The program user interface is displayed after the project is named. The 2D part is the first part of the program and will be visible on the Android device (Fig. 10). The UI is adapted in this part of the sequence preparation by altering its dimensions and adding buttons and functions, which can replace standard CAD functions. Figure 10a shows the interface design with options to start the sequence, reset the CAD model position, rotate the whole assembly, and remove warnings. Figure 10b gives a preview of the created interface [17].
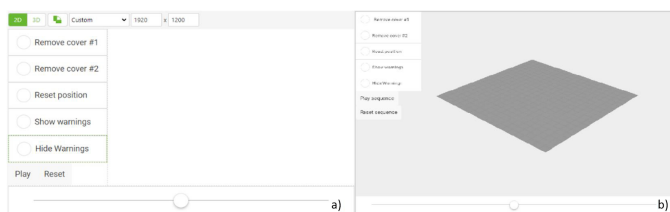

Fig. 10. UI settings for the output device

The last part follows the end of this phase, and therefore, the Vuforia Studio on the backend setting of the sequence, its interaction, and control.

3. CREATION OF A MAINTENANCE SEQUENCE

The last phase of sequence preparation is made up of the backend settings being performed in Vuforia. It consists of a summary and definition of all the previous steps of a complex application. The individual steps necessary to complete this sequence are dealt with in this section and use elements from the preparation described in previous sections [18].

The preparation phase is extensive and begins with the import of a CAD assembly in STEP format, placement and assigning a market, assigning a CAD function to specific buttons on the UI, and the importing of a PVI file to obtain vector data for timing and model positions in the sequence. Additionally, every option is editable with JavaScript expression.

When it comes to importing data used by output devices, the software allows us to optimize them. Without this process, the use of devices with lower computing power would be practically impossible. This process is relatively simple and is part of uploading the CAD file to the ARE back end. During recording, the software processes the model for us in three levels of detail. These are designated as high/medium and low. They are distinguished by the number of polygons forming the surface of the used models. A device with a lower computing power, or a device used in areas where it is not possible to be covered by a sufficiently stable Wi-Fi network, can use models with a lower

polygon network. This will subsequently reduce the requirements for the computing power of the device and at the same time the data flow required for the ARE display.

The software is specialized, its features are easy to use and intuitive; however, the process is extensive. Thus, the next section covers what is necessary to complete the sequence [19].

3.1. Determining the location of the position marker

The ThingMark placement in Vuforia Studio directly corresponds with where AR Experience places the model in Vuforia View. This corresponds to its rotation and placement. The ThingMark can be rotated in the program, or the printed ThingMark can be rotated to the position desired so that the application is displayed correctly in the Vuforia View program [20].

The possibilities for positioning the marker are shown in Fig. 11. The figure shows there are several variants available. Figure 11a shows the first – it is the location of the position mark in space. This means that the position mark would be placed somewhere on the frame of the milling machine, and the displayed model would be projected at a specific distance from it, making this method good for the visualization of interactive CAD models over a 2D technical drawing. However, because of the complicated shape of the device that the sequence is to be run, it is not good for this solution. This is due to the position marker always needing to be in the camera range of the output device, which in this situation causes complications where the position marker is not in focus [21].
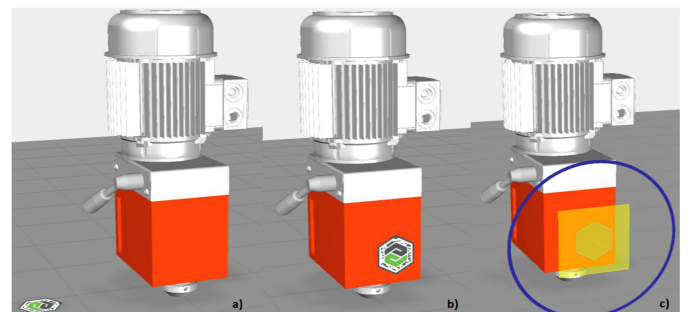

Fig. 11. Variants of position target placement during the sequence

The position mark locations seen in Figs. 11b and 11c are practically the same. Regarding the first variant, the position mark is placed directly on the spindle drive.

Such a location provides a position mark in a satisfactorily visible place and overlaps the CAD model with an actual object. The sequence placed this way is most suitable because the CAD model was formed on a 1:1 scale. Figure 11c shows the practically same maker location; however, the position marker is not seen during sequence display, which is more or less an aesthetic point and does not affect the desired result.

The upload and assignment of the above-mentioned PVI file to the "play sequence" button, which is displayed on the UI, is shown in Fig. 12. Because the software is specialized, implementation of these functions is simple, and functions are assigned to all buttons and objects displayed in the AR.
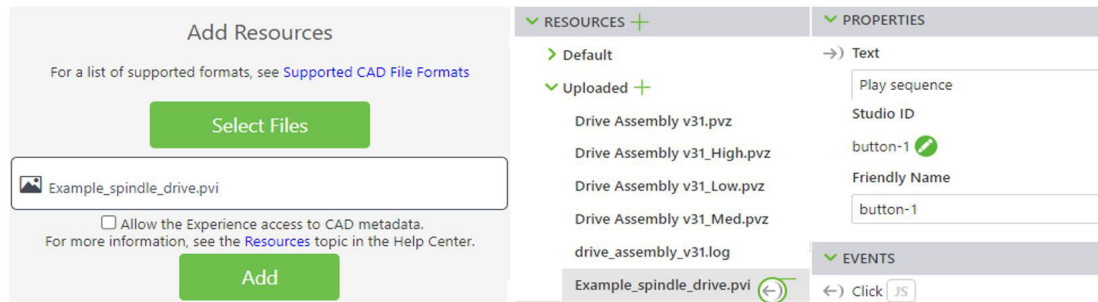
Bull. Pol. Acad. Sci. Tech. Sci., vol. 70, no. 6, p. e143831, 2022

5

J. Trojanowska, J. Kaščák, J. Husár, and L. Knapčíková

Fig. 12. Assigning the "start sequence" function to a specific application button

4. RESULTS

As a result of the unification of all actions from the preparatory phases, which are located in the resulting software, the AR display is visible in Fig. 13. This image can be viewed by the user through an android device when the machine is out of operation. The Android device was chosen precisely for the questionable use of continuously worn 2D or 3D glasses, which in certain situations can be distracting for the worker. Such a permanent overlay of the field of vision of a worker working in production could therefore conflict with the conditions of health and safety standards at work.
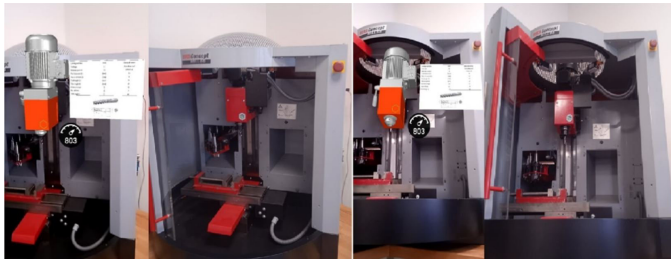

Fig. 13. Visual demonstration of the actual EMCO mill 55 and the state at the start of the AR sequence

As can be seen in the already mentioned Fig. 13, the output device uses its camera to scan the position mark located on the spindle drive cover. Subsequently, the entire sequence is loaded in its starting phase, and its location is determined by the already mentioned positional marker. Additional information displayed in AR can be changed. For this publication, the information about the used tools was chosen interpretatively. As can be seen, the placement of the CAD models within the sequence is identical to the real placement of the machine components. This will make it possible to precisely follow the steps in the individual phases of the sequence. The assistance sequence created in this way subsequently accompanies the worker from turning off the device, opening its cover, removing the tools, and going through the individual steps related to the maintenance of the device. As already mentioned, sequences of a similar nature can be created for various types of situations thanks to the availability of specialized software. One of them can be experimental determinations of cutting speed on the surface character of machined parts or their use in DMLS technology.

5. CONCLUSIONS

Currently, there is a noticeably increased demand for mixed and virtual reality technologies in various industries, education, or various fields of research. This increased demand has been one of the main factors behind the increased rate of development of this technology. The rapid development in this field has caused a massive expansion and increase in the availability of specialized software and hardware supporting this type of technology. Thanks to these factors, it is possible to use mixed and virtual reality technologies even in industries for which it was not primarily intended, or where its previous use was economically inefficient.

The presented article summarizes the possible use of augmented reality technology from different areas and applies them to a specific case. This is used to navigate the worker during a minor service intervention in the spindle drive of the EMCO Mill 55 device. To create this sequence, a complex PTC software package was used, the use of which consisted of four phases. The first phase was about creating a 3D model of the spindle drive in scale and exporting it in STEP format. In the second phase, advanced software was used for creating and editing technical documentation. This software facilitates the creation and timing of 3D animations and their extension with other animation elements or alerts. In this case, an important factor is a possibility of exporting separate vector data, which are part of the animation created in this way. The third phase consists of merging the 3D model and vector data in the software environment to create the visible part of the AR sequence. The previously mentioned vector data are important in this process. These will enable a significant reduction in the volume of data sent to the output device since the sequence does not contain complete animations, but only vector data associated with the imported 3D model in STEP format. In this way, the otherwise static 3D model becomes an interactive part of the sequence, reacting to gestures, or individual UI elements, such as buttons, etc. The final phase consists of choosing the output device and optimizing the UI and CAD models. These optimization elements will enable the use of the sequence even on a device with lower performance.

The result of this activity is the already mentioned functional sequence in AR, displayed on the output device through an application with a modified UI. The functions of this UI are fully interactive with the imported model. Due to the correct placement of the position target, the imported model is overlapping

6

Bull. Pol. Acad. Sci. Tech. Sci., vol. 70, no. 6, p. e143831, 2022

the original model of the spindle drive on the machine, thus serving as the point of origin for the sequence. Such placement of the model in cooperation with interactive elements thus serves as a form of a virtual assistant during the aforementioned service intervention. The use of similarly situated sequences can be different, and they are significant benefits, for example, in the field of training new employees or increasing production efficiency. The presented sample or the application to the production machine EMCO mill 55 is a practical representation of the described steps. According to estimates so far, which are interpreted in the already mentioned studies, the integration of this technology will bring up to 30%-time savings in the training of new employees or service interventions. Currently, further research into the use of ARE in the field of production is underway, and its results will be published subsequently.

ACKNOWLEDGEMENTS

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