Factory Virtual Environment Development for Augmented and Virtual Reality

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Abstract—Machine visualization is an area of interest with fast and progressive development. We present a method of machine visualization which will be applicable in real industrial conditions according to current needs and demands. Real factory data were obtained in a newly built research plant. Methods described in this paper were validated on a case study. Input data were processed and the virtual environment was created. The environment contains information about dimensions, structure, disposition, and function. Hardware was enhanced by modular machines, prototypes, and accessories. We added functionalities and machines into the virtual environment. The user is able to interact with objects such as testing and cutting machines, he/she can operate and move them. Proposed design consists of an environment with two degrees of freedom of movement. Users are in touch with items in the virtual world which are embedded into the real surroundings.

This paper describes development of the virtual environment. We compared and tested various options of factory layout virtualization and visualization. We analyzed possibilities of using a 3D scanner in the layout obtaining process and we also analyzed various virtual reality hardware visualization methods such as: Stereoscopic (CAVE) projection, Head Mounted Display (HMD) and augmented reality (AR) projection provided by see-through glasses.

Keywords—Augmented reality, spatial scanner, virtual environment, virtual reality.

I. INTRODUCTION

WE are working with the visualization of objects in a real factory. Therefore, we must obtain data about the 3D workspace for use in the virtual environment. This scene could be designed manually in software for civil engineering, captured using various photogrammetry methods or obtained by a spatial scanner. Hoffman [1] determines that the main advantages of scanning over traditional methods are faster measuring speed, higher precision, and enhanced safety and reduced costs. For our case study we used a brand new research factory. The production-floor was empty and therefore it gave us a perfect opportunity for developing virtual areas. Machines, material and conveyors could be

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placed, utilized and moved by digital commands. Wan [2] describes use of augmented reality data and concludes that the best usable environment is an existing non-empty factory.

There are visualizations of virtual machines which include tools for simulations of cutting processes, moving part of a machine or moving material. e.g. Min [3] suggests a virtual environment with a fully functional controller in simulations. He also divides user interfaces (UI) for virtual environment into:
- commercial virtual factory applications
- virtual operator panels which look like the real machine
- data responding tools

Virtual reality tools, trainings and comparison of system functionality and features for training car service maintenance processes is described in [4]. The most important conclusion in this paper for this study is the fact that too much simulation could impair less expert trainees´ performance when used during on-the-job training, or in real world procedures, he concludes there may be problems with virtual tools.

We present several methods for visualization of a virtual environment. We compare use of traditional monitors-projection and stereoscopic wall (CAVE – Computer Aided Virtual Environment) and Head Mounted Display (HMD). We discuss each method's advantages and disadvantages. Problems with visualization and use of HMD´s are expounded in [5]-[7]. We are using one of the most progressive HMDs, Oculus Rift (which will be commercially on sale in 2016). In this study we compare development of the virtual environment and use in the CAVE, Oculus Rift HMD´s, 3D monitor and visualization in 3D augmented reality glasses. Moreover, we adjusted the environment for use in a real factory with AR glasses Vuzix STAR 1200 XLD. Designing augmented reality virtual tools for use in a mobile device is summarized in [8], [9]. This paper describes the designing process of creating the environment. Gobrunov deals with a flight control in augmented reality application. He describes an experiment with 36 participants and Vuzix STAR 1200XLD. He concludes that AR glasses in comparison to a desktop screen have a "much more natural character of the interface" [10].

The experience of creation and use of the designed environment will be beneficial to future research and gives us advice.

II. SCANNING

First of all there we needed real factory data. We used a research factory: the production-floor is in Fig. 2. The method is discussed in the introduction. In our case we work with very high accuracy data and it helps us take into account parts such

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as cable routing, pipelines and fire extinguishers. Our accuracy was a maximum of 1 millimeter on faces and 2 mm in corners and radiuses. Working at this detail allows us to give feedback and discuss real layouts for use in the layout planning industry.

Comparison of 3 scanning systems is provided by Chae in [11]. He compared scanner and post processing programs from Leica (Switzerland), Trimble (USA) and Rieger (Austria). He concluded that the scanner from Leica showed the best performance. Therefore we scanned our hall with the Leica ScanStation C5 which operates in a radius of 35 meters with accuracy of 4 mm. Scanning speed is 25 000 points per second with field of view 360°x270°. Laser safety class is 3R. The scanner is shown in Fig. 1.

Fig. 1 Spatial scanner Leica ScanStation C5

Fig. 2 The scanned factory with participant

The production floor was scanned using the "position to position" method where we stationed targets with markers around the scan positions so that later we can connect together all the scanned data from each scan position. Therefore targets were spaced out with visibility from as many scan positions as possible to provide consistency of all data. It also enhances accuracy. We scanned 25 scan positions in medium resolution setting and each position took 15 minutes. The "medium resolution" mode is the one of four speed modes of the scanner. For example, "highest resolution" mode takes 150 minutes and creates a point cloud with the highest number of points. The most effective work with the scanner is scanning in a lower resolution setting and finally scanning again the most important parts and details in the high resolution mode.

When the scanning was finished the data was downloaded and merged together in a Leica Cyclone specialized software, where the point clouds were cleared, filtered and the noise removed. We obtained one final point cloud. This environment was exported into universal data format.

III. DEVELOPING THE ENVIRONMENT

The point cloud represents an environment without any interactive elements or objects. In this stage we imported our workspace into CloudCompare software. This package allows us to color the point cloud, change the shape and design and to correct the positions of the machines. We placed CAD models of the machines into the point cloud hall (Fig). These models are modified for additional adjustment by the user. Therefore we designed the layout and placement of models for the best experience and opportunity to provide all possible modifications.
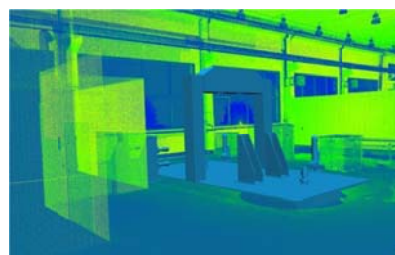

Fig. 3 Point cloud with CAD model of testing machine

The environment allows moving a pasted object. We also developed our own software for point cloud import and fast, easy and user-friendly placement of CAD models. Movement of the testing machine for dynamic examinations in our software is shown in Fig. 3. It is important to allow the user a wide range of modifications such as movements, rotations, enlarging, scaling, cutting and hiding. These functions guarantee full scale application of the output for users' needs and possible modifications. In this case we must be prepared for visualization of all possible users' ideas because the main advantage of virtual reality is real-time visualization of users' concepts during brainstorming. Experience with this kind of use of virtual reality gives us feedback for applying functions to the model and the environment.
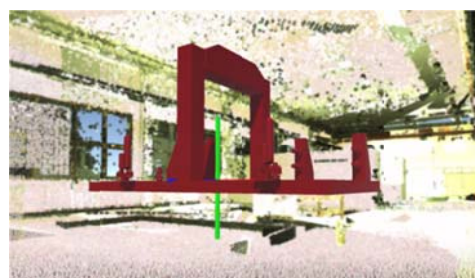

Fig. 3 Movement of the testing machine

IV. UTILIZATION FOR VIRTUAL AND AUGMENTED REALITY

Final modification of the environment and applying of functionalities is provided in the developed software. This software allows us to use a wide range of devices for visualization and navigation, in particular the virtual environment. We used HMD Oculus Rift, 3D monitor and one

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wall stereoscopic projection with the IS-900 tracking device (CAVE). A user in the 3D CAVE is browsing the environment in Fig. 4. The main advantage of using CAVE is the fact that the number of observers at the same time is not limited. One person controls the environment with trackers and wand but all the others have the same kind of experience and can discuss details online. Oculus Rift provides a higher level of immersion without disturbance from the surroundings. The environment in Oculus Rift is so realistic for the user in a standing position that people naturally move parts of their body when they are inside. This one projection has a big advantage in tracking of the user's view. The version for Oculus Rift has a function for activation of an action by looking for 3 seconds at the target. Many participants found this joystick-free version useful. The 3D monitor is the simplest way to view the environment without the quality and possibilities of the previous cases. Another method for visualization and interaction with the environment was realized and tested in augmented reality. We exported our environment into glasses for augmented reality, Vuzix STAR 1200 XLD. The glasses are shown in Fig. 5. This device has Quantum optic see-through displays which allow 35° diagonal field of view which looks like a 75-inch virtual screen as viewed from ten feet (~3 m). It was also equipped with a 1080p camera for reading markers, and earphones. An advance of this Vuzix product is a 6 DOF gyroscope and accelerometer tracker which obtains the participant´s position data and sends it to the computer.

Fig. 4 Environment in the CAVE viewed by user

Fig. 5 The augmented reality glasses Vuzix STAR 1200XLD

One of the basics of augmented reality is connecting the virtual data to real objects, in our case to the empty research factory. It is provided by targets called markers. Koch [12] divides markers into: ID marker, barcode marker, QR code, picture marker, markerless marker, 3D point map and CAD edge model. We work with markerless technology and we connect our object to the presumed position in the hall. A participant wearing Vuzix STAR 1200XLD in the factory hall is shown in Fig. 6. This environment contains factory models

which are commanded from a smartphone application. Glasses are connected to a Motorola Photon because of its portability and simplicity. The participant turns on the application with the virtual environment, connects the smartphone to the 3D glasses and when he puts on the glasses the environment is captured by camera and the application locates the markers. When a marker is found, the application projects the environment on to the corresponding position. The participant is then able to interact with objects and machines in the same way as in the virtual reality version.

Steyn [13] makes a case study of an object on a conveyor using a marker based augmented reality application. A measurement and safety study is presented. We enhance these findings of "live" augmented objects in the scene which is shown in Fig. 7.

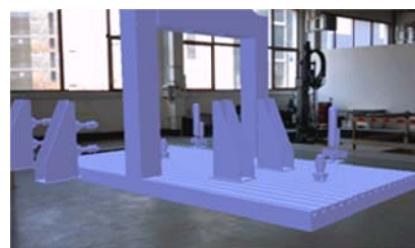Fig. 6 Participant in the factory wearing AR glasses

Fig. 7 Visualization of augmented object

V. Discussion and Conclusion

We presented the development of a virtual environment in this paper. We compared conventional CAD based layout developed with 3D scanning. This is the fastest and most customizable layout making method. In comparison to a layout modeled in 3D CAD software it is much faster and the scanned data visualize all dimensional and shape changes which could not be documented in the factory structure data. The scanner method is also beneficial in very complicated scenes with many details and accessories. The cost of a scanner could be calculated by price per scanned hour with additional processing of the data compared to the cost of a CAD designer´s time with the cost of the program license. In our factory a cheaper version is scanned in the factory from 200 m^2. It is also based on the number and scale of details.

The process of scanning and processing the data is described with special accent on the part of variation of embedded CAD models. This part should be performed by experienced workers with a background in scanning and processing of point clouds for correctness and quickness.

The designing process is based on the authors' experience

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with users of virtual environments and their needs and expectations. Therefore an environment is developed with many opportunities.

The next phase after obtaining the data is the visualization phase. Input for this visualization was the original scanned point cloud with additional 3D models. The output was more monitored factors such as understandability of the environment for the end user, price of the solution, time needed for adjustment and calibration, time needed for model preparation by a developer, level of immersion, cyber sickness and time for operator training. As mentioned, more options were compared. These factors were monitored using a questionnaire.

There were 42 participants in this questionnaire. Users had different experiences with virtual reality. They had technical backgrounds and they were from 19 to 58 years old. We compared participants' feelings of immersion on a scale from 1 to 5. 1 is the best and 5 is the worst. We also researched the reality of each method. The understanding of the interface and user-friendly environment was given as 'usability'. Functionality of added machines and devices and operability with them was indicated in the question about functionality. Any bad feelings ('cybersickness') from the devices were asked about. And finally, participants were asked about their experiences from the virtual tour.

TABLE I
QUESTIONNAIRE RESULTS

	3D monitor	Oculus Rift HMD	CAVE	AR Vuzix
Immersion	4	1	2	2
Reality	4	1	1	2
Usability	1	2	3	3
Functionality	2	1	2	1
Cybersickness	1	5	2	2
Experience	4	2	2	3

From the questionnaire (outputs shown in Table I) we can say that Oculus Rift had the best immersion and feeling of realism, but CAVE has almost the same level of reality as Oculus Rift´s. The worst immersion and realism was shown by the 3D monitor because it provides just a simple 3D environment. But people were familiar with using the environment by mouse and keyboard really fast and therefore it has the best usability. Functionality of Oculus Rift and Vuzix AR glasses is better because these environments were more advanced and users found it more interesting in comparison with the other two versions. The most frequent problem was with cybersickness in Oculus Rift caused by its realism and high degree of virtualization. Questionnaires ranked Oculus rift and CAVE as the most interesting and enjoyable versions.

The whole environment is visualized in four versions. Virtual reality versions with 3D monitor, Oculus Rift HMD and CAVE are remarkable for their display credibility and possibility to be shown anywhere. The most advanced environment was realized in Oculus Rift HMD, but the most time consuming for preparation and programming was AR

environment. Utilization and creation of the application for the Smartphone took 3 times longer than the conventional virtual environment. The usability corresponds to the advance of the environment and with using tools. So, for users the fastest method was the simple PC with 3D glasses and 3D monitor. Using Oculus Rift is almost as automatic but for a few people it took more time to use it properly. Use of CAVE is specific and needs 2 minute training and the augmented reality glasses version needed permanent help from the instructor for beginners.

The augmented reality version is based on use directly in the research hall by one user who cannot discuss ideas with colleagues at the same time (each user has their own application with their own AR glasses and a different virtual world), but the AR version offers the option of interacting with real objects. These objects must be designed by the author into virtual reality. We found some problems with use of AR glasses in sunny conditions. The augmented object had poor visibility in extremely brightly lit conditions. Each approach has specific usability and benefits.

Future research will be connected with virtualization of virtual objects in the virtual reality environment. There is also potential for future research on applying development of virtual worlds to other applications and developing applications with other functions and possibilities.

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