Virtual Simulation of Machine Tools

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Abstract. The article presents the use of VR tools for creating virtual simulations in which construction and functionality of production machines can be observed. As examples, the CNC machine feed drive and the Delta robot were presented. A virtual CNC machine was used to visualize its operation in the EON Studio environment. This visualization enabled a general analysis of the machine's operation and construction, visualization with various tools mounted in the spindle, as well as execution of the tool movement according to the loaded simple G-code. In turn, virtual model of Delta robot, in addition to the visualization of the action, was used to simulate the shape of virtual objects.

Keywords: Virtual Reality · Virtual simulation · Visualization · Machine tools

1 Introduction

Modern Virtual Reality (VR) techniques find their application in many phases of the product life cycle. VR solutions available on the market allow for the preparation of immersive, interactive environments with a high degree of realism. Virtual models are analyzed throughout the entire product life cycle, starting from the concept phase in which the future product can be visualized - then the so-called virtual prototype, and ending with the phase of withdrawal from life - creates, among others, interactive recycling instructions [1].

Virtual models are placed in created virtual scene in order to [2]:

– testing, improvement and development of the future product in the design phase (e.g. improvement of construction, ergonomics, simulation of operation),
– optimization of the remaining phases of the life cycle (including production preparation - virtual production processes, production - virtual assembly instructions).

When it comes to supporting virtual techniques in the design phase, the first results of research that show the measurable benefits of using VR in industrial design, appeared in the late 80's. Researchers [3] from the University of North Carolina have prepared a solution called Walkthrough, which was used to create virtual simulations of buildings (visualization of building forms, roof, façade and room layout). The digital model of the building was prepared on the basis of documentation provided by the user

J. Trojanowska et al. (Eds.): *Advances in Manufacturing II* - Volume 1, LNME, pp. 127–136, 2019.
https://doi.org/10.1007/978-3-030-18715-6_11

(customer). The analysis of the interactive version of the designed building allowed for the detection and improvement of errors before the actual construction works.

One of the main advantages of using VR solutions in design is the potential to reduce project costs [4–6]. Entities participating in the product life cycle (including designers, constructors, technologists, marketing experts) have the opportunity to familiarize themselves with the virtual prototype of the future product and the environment in which it will be used. Thanks to this, it is possible to detect potential errors (e.g. in construction) in the early phase of the project, while in traditional design you had to build a physical prototype to subject it to the necessary analyses.

The use of VR tools and techniques in the design and prototyping of products was the subject of works [7–10] implemented in the Virtual Design Laboratory, whose members are the authors of this publication.

The paper presents the use of VR tools for creating virtual simulations in which construction and functionality of production machines can be observed.

2 Materials and Methods

2.1 Virtual Reality in Design

The main task of CAx (Computer Aided, where "x" stands for Design, Manufacturing, Engineering etc.) systems is to support the shaping of product geometry, its visual and technical features. CAx systems do not deal with the interaction of the modeled product with other objects, in addition to very basic operations, e.g. collision testing in assembly modules. Do not confuse the digital design of new products or processes in CAx systems with virtual design and prototyping - the difference is primarily immersion or semi-interactive interaction [11].

Virtual Reality techniques, and in particular - virtual prototyping used in this context, therefore broaden significantly the spectrum of application of the model created in the CAD (Computer Aided Design) environment, allowing the placement of a digital model of the product in the presence of other virtual objects (in the virtual scene). The most important feature of the virtual environment is the mapping of the interaction of objects and their behaviors in response to user-triggered events, with the user's free interaction and immersion. Available 3D engines allow creating solutions so realistic that it is possible to test and improve the product only in the virtual space, without the need to create a physical prototype [1, 7]. The most important measurable reasons for using the virtual prototyping technique in design support are primarily the significant reduction of the functional evaluation costs of the new product [11], shortening development time by as much as half [12] or potential increase of its quality [13] and even environmental issues [14]. It is also possible to make quick decisions about the future shape of the product and eliminate its weakness before it has a physical form [15].

A product model existing only in a virtual environment, used throughout the design process to perform tests and trials aimed at its improvement and development is called a virtual model. It is a digital representation of a real product that can be used throughout the product's life cycle, in its appropriate places. The virtual model of the product is used in many fields of industry, including Automotive, aerospace, nuclear etc. industries. In these industrial branches, all stages of designing, testing and improving the product as well as the preparation of its production are currently based only on the virtual model, the product obtained in the virtual design process is completely prepared for production [5].

In the case of design support, a virtual product should be identified with a virtual prototype, as long as iterative optimization of the construction takes place. Virtual prototype, created on the basis of 3D CAD data or coming from 3D visualization systems, are tested in a virtual environment and based on them makes structural improvements until it is verified positively. Then the design phase can be considered finished and go to further phases - preparation of production, production of a physical prototype, etc.

2.2 Method of Creating a Virtual Reality Application

The most important component of the Virtual Reality system is the VR application, which should be understood as a closed (in the programming, logistic and functional sense) whole, functioning as an executable program (requiring a selected operating system and using specific VR equipment). The main task of the creators of VR applications is to create an interactive, three-dimensional environment that will provide the user with the immersion and realism of simulation, as well as the interaction with digital elements [16].

The two basic types of VR applications are applications oriented to a single object (usually the virtual model of a specific product) and the environment (virtual scene). The division of application types is shown in Fig. 1 [2]. From the point of view of the topic of the article, the most important types of VR application applications include virtual simulations of machines and devices [17].

Preparing an interactive VR application is a complex and time-consuming process. The basic stages of creating a virtual application are shown in the diagram (Fig. 2), taken from works [2].

The first stage is preceded by works related to [2]:

- selection of VR equipment (depending on the needs, e.g. providing the effect of force feedback or full immersion),
- VR software selection (criteria: license cost, availability, ease of programming and operation, compatibility with selected VR equipment),
- preparation of data for the application (3D models: products, items, infrastructure elements, 2D data: textures, user interface graphics, predefined lighting and shading maps).

The first step in the stage of visualization preparation is the transfer of digital data (conversion to a form recognizable by a dedicated environment), most often using external software that ensures the integrity of individual parts of 3D CAD models. The imported models are assigned:

- appropriate textures (2D graphic patterns, placed on a 3D object to imitate the appearance of the material, invoice, etc.),

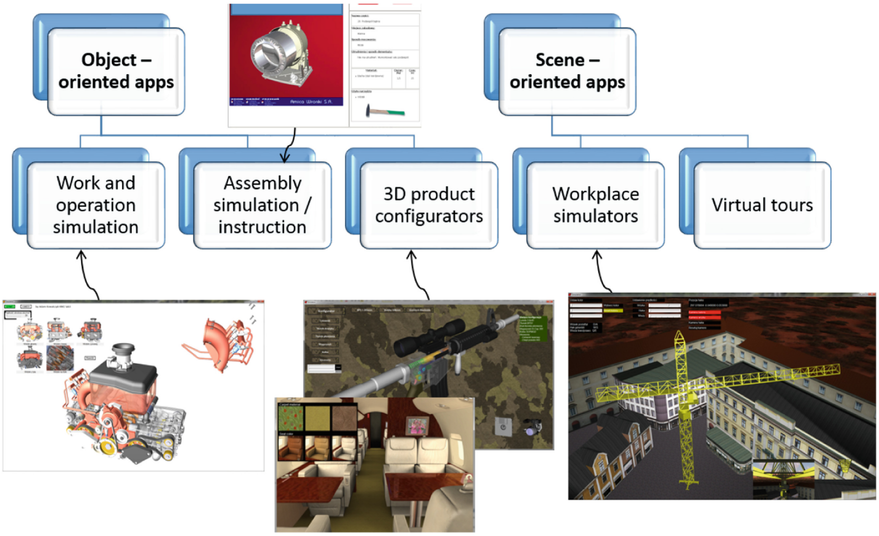

Fig. 1. Examples of VR applications types [2].

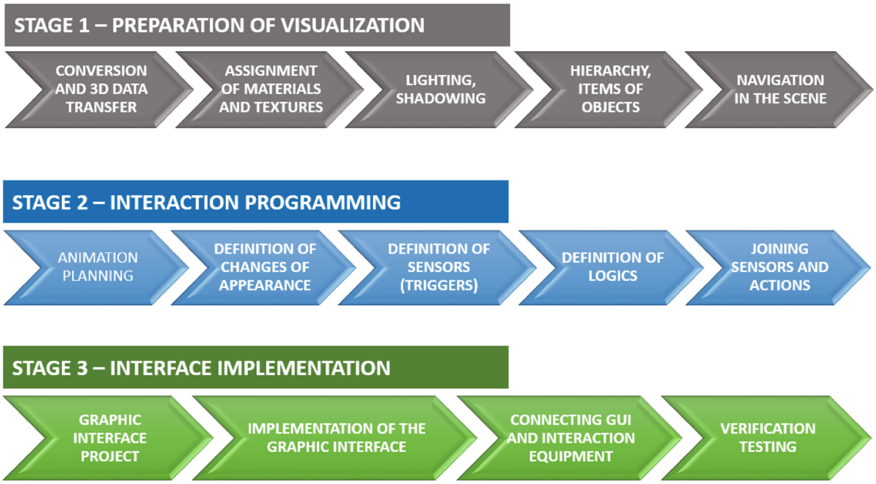

Fig. 2. Stages of the VR application building process [2].

– normal maps and bounce maps (assigning individual pixels of a 3D image to the vertices of a 3D mesh, in order to obtain a more realistic appearance of objects),
– so-called. material properties (a set of features describing the appearance of a given object in a VR environment).

The scale and location of digital data in the virtual scene are also determined. Subsequent works rely on appropriate lighting of objects and adding shading effects (among others based on the location of objects and lights casting shadow). The last step in the stage of visualization preparation is to develop a way of navigating the virtual scene (camera position change control, e.g. a camera directed at the central point or the so-called first person camera - user's free mode).

The second, key stage in creating a VR application is programming interaction, i.e. behavior of virtual objects. Most often these are specific movements, which are a response to an event generated by the user (e.g. by clicking the mouse, pressing a button on the keyboard, entering a defined collision area) or by another object [1]. Other examples of object behaviors are:

– dynamic change of geometry or change of appearance (e.g. different color, texture, scale, cross-sections),
– deformation of 3D objects (so-called animations with model deformation),
– collisions (e.g. by adding collision objects).

Programming of specific behaviors is carried out using traditional programming methods (C++, Visual Basic, Python) or visual (with numerous logical conditions to handle events), consisting in defining connections between the so-called nodes exchanging data of various types (Fig. 3).

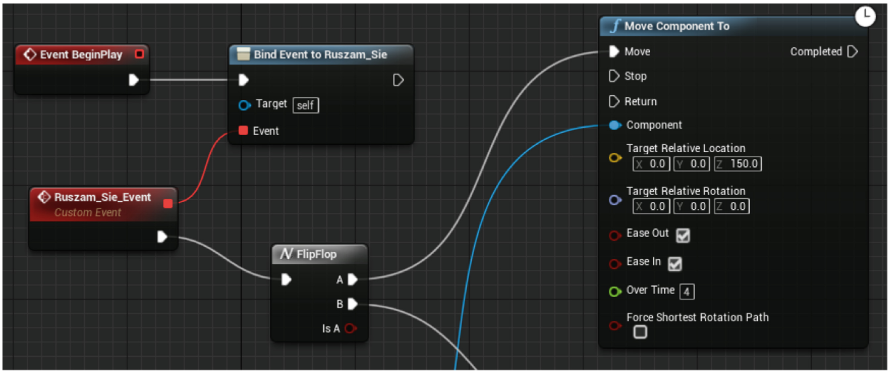

Fig. 3. Visual programming (on the example of Unreal Engine) [16].

The third stage of building a VR application is work related to the construction of a graphical user interface - GUI, which will work with selected interaction devices. We're talking about solutions based on:

– peripheral devices (e.g. mouse and keyboard),
– advanced electronic equipment (e.g. tracking systems, gesture recognition systems).

The main goal in the process of creating the user interface is always to achieve the desired degree of intuitiveness and transparency for the purpose of running defined functions in a virtual environment [2]. The last step of the third stage of building the VR application is the testing phase in which you verify:

– the geometry of 3D models used in the simulation,

- correct operation of the GUI,
- functionality of the application as an integral whole,
- cooperation with specific VR equipment.

3 Examples of Virtual Simulations

3.1 CNC Machine

The typical CNC (Computer Numerical Control) milling machine feed drive consists of many elements that influence on the machine important parameters like movement stability and positioning accuracy. The design of complex CNC milling machine feed drives requires laborious and time-consuming calculations supported by experimental tests. Therefore the modelling, simulation and visualization techniques may be very useful and may facilitate the design process. The simulation and visualization in VR environment may show the week points of the drive. Moreover, the changing and optimization of several drive control parameters may be tested and validated [10].

Complicated simulations were performed in Matlab-Simulink environment and based on the obtained results, the drive functioning and influences of different drive parameters were later visualized in VR system. What was more important, the visualization could be based on the model simulations results and on that way we could avoid complicated calculations of the real behaviour of the VR system. The visualization of the whole machine tool using the CAD model of machine tool and models of the feed drives developed in Matlab-Simulink and Sim Scape in EON Studio software is presented on Fig. 4. Virtual model was used to simulate the real work of the whole CNC machine tool (contouring operations, changing tools, etc.) This whole research could be very useful to machine tool producers, because they could change their practice of making very expensive real prototypes of the CNC machine tools, with creating virtual prototypes of machines [10].

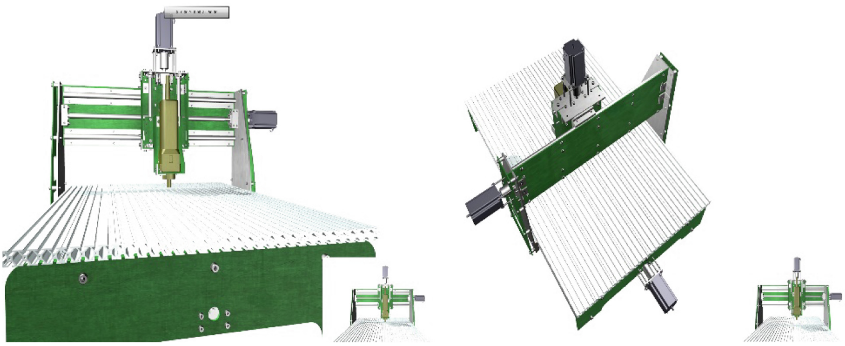

Fig. 4. Visualization of CNC portal machine tool in EON studio software [10].

3.2 Delta Robot

Just like in the case of a CNC machine, the Delta virtual robot model was used to analyze the operation and construction of the device itself, such as the implementation of the work tip displacement in accordance with the loaded G-code (Fig. 5).

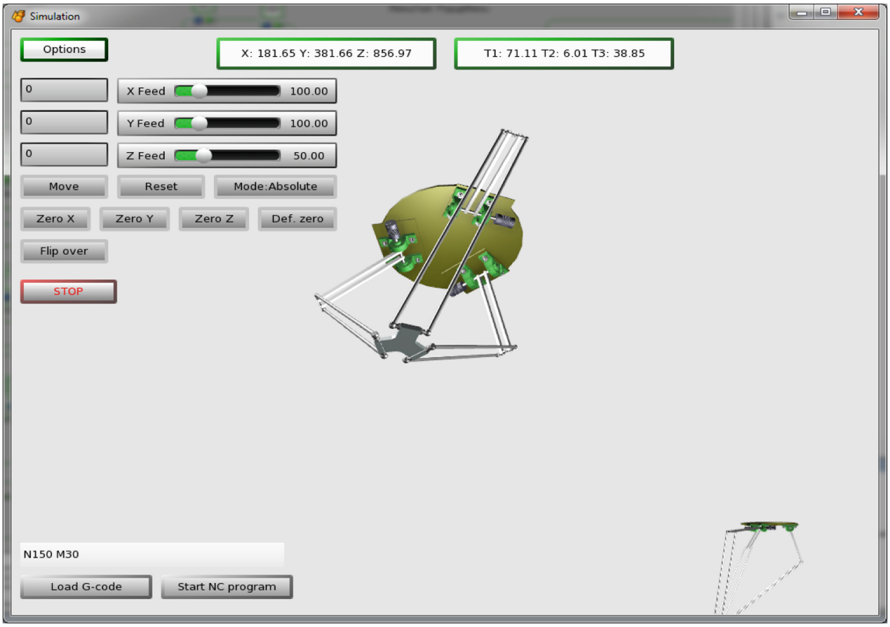

Fig. 5. Visualization of Delta robot in EON studio software.

Research experiments were also planned in which simulation of the shape of virtual objects was tested [16].

By definition, the main task of the Delta robot as an active touch device was to simulate the shape of virtual objects. Therefore, as part of research, an experiment was carried out which simulated the shape of the upper surface of the virtual cuboid by the final effector. The task of the person testing the simulation was to try to touch it. The following were visualized in the prepared VR application (Fig. 6a):

- digital robot model,
- a block of a virtual rectangle of blue color.

In order to map the shape of a virtual cuboid (defining the working space of the Delta type manipulator), the coordinates of all vertices of the cuboid had to be included in the script limiting the position of the digital robot in space.

In practice, the four tops of the upper surface were important (due to the fact that the end effector platform made movements parallel to the reference plane). Thanks to this, the touch device could not move beyond the designated area. Attempting to touch the upper surface of the cuboid involved a change in the user's hand position, which in

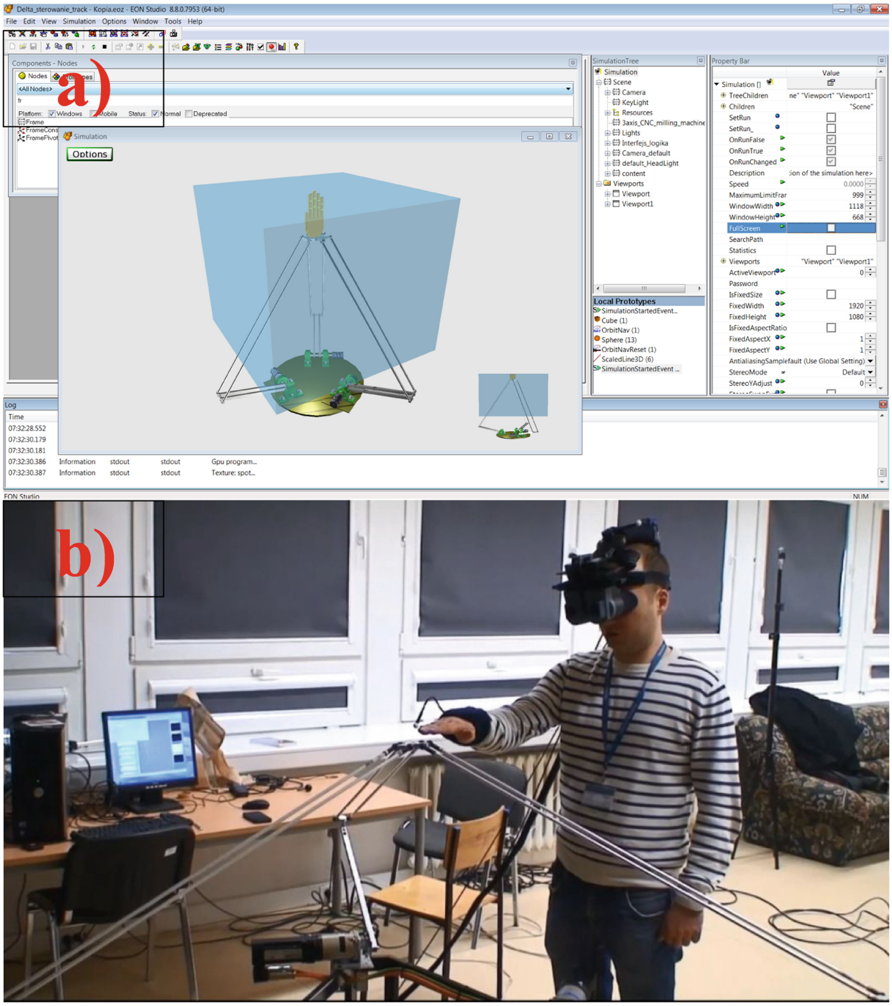

Fig. 6. a-Graphical interface of the test application operator (virtual robot displacement control), b-Contact with the end effector of the Delta robot on the physical stand.

turn was recorded by the tracking system (a marker was placed on the user's hand, the object was tracked in real time). The task of the actual manipulator was to set the working tip in the position enabling contact (i.e. near the shadowed hand of the user). In this way, the person testing the simulation had the impression of contact with a virtual object (in practice it was a physical artifact imitating a flat surface of a digital cuboid, placed on the effector, Fig. 6b). To further enhance this feeling, the VR application uses a digital hand model whose current position was registered by the tracking system. Data about the current position of the digital hand was used to control the position of the working tip of the virtual robot [16].

For the purposes of visualization of angular displacements of the arms and linear movement of the virtual device's working tip, the necessary simulations of the kinematic constraints have been defined in the simulation project. The VR application also implements the workpiece positioning algorithm (reverse kinematics). To keep the behavior of the virtual device close to the real one, the operator of the test application monitored the speed of its movement on an ongoing basis. Each time the robot changed position, the angular coordinates of its arms were automatically calculated and the motion animation was displayed. All logic functions have been programmed with the support of classical techniques (scripts prepared in VBScript) and visual techniques (defining connections between nodes).

4 Summary

Engineering applications of Virtual Reality, especially in the design and construction of machines and in production engineering are a key issue for the authors of the article. The presented examples of the use of a VR for creating interactive simulations of machines and devices are usually a prelude to further research work, and Virtual Reality as a set of modern technologies is an important element of the whole concept of Industry 4.0 [18, 19]. To sum up, virtual techniques play their role, as mentioned earlier, at various stages of the product life cycle. The most important applications are product design, process virtualization and digitally supported workstation training.

Acknowledgments. The research work reported here was partially financed by Polish Ministry of Science and Higher Education.

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