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VIRTUAL REALITY TECHNOLOGIES IN VIRTUAL MANUFACTURING – NOTES ON CURRENT TRENDS AND APPLICATIONS

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ABSTRACT

This paper reviews current status of Virtual Manufacturing and aspects of application of VR technologies in manufacturing. Major domains of application of virtual manufacturing are discussed followed by some actual applications from all three paradigms. Bearing in mind the costs involved with the introduction of Virtual Reality technologies in academia and industry, orientation towards the so called low-budget VR technologies is proposed. Accordingly, a domestic example of such low-budget experimental VR platform is presented.

Key words: *Virtual Reality, Virtual Manufacturing, Ttechnology of plasticity*

1. INTRODUCTION

The term Virtual Manufacturing (VM) was popularized by the beginning of the nineties of the twentieth century, as the result of the U.S. Department of Defense Virtual Manufacturing Initiative. Save for some obscure military projects, the beginning years of development and research in this area were limited to aeronautics and automobile industry, as well as several academic circles in the leading industrially developed countries. 1993 saw the intensifying of research and implementation of virtual manufacturing methods in wider industry.

Manufacturing engineering has recognized in virtual manufacturing a possibility to identify and resolve numerous design- and technology-related problems at the earliest possible stage, before they actually occur in the physical realization. Such activity can be beneficial in terms of enhanced product quality and substantial cost reductions.

Virtual manufacturing is a common denominator for a number of activities which are performed entirely in a computer environment, with the goal to model, visually render, simulate and optimize the method for manufacturing a product. This idea can be formulated in different ways, which is why the literature abounds with definitions of virtual manufacturing. Thus, Shukla [15] reports that VM is an integrated, artificial manufacturing environment which is used to advance the process of decision-making and management on all levels.

Adverb artificial implies that such environment is computer-generated, with no real ability to manufacture a physical product. In a similar definition, Iwata and Onosato claim that VM represents a computer system which is capable of generating information about the structure, states, and behaviour of manufacturing system as can be observed in a real manufacturing environment [5].

In a similar vein, this definition implies that VM generates information, not physical products and materials. It is well known that decisions made in the early phase of product development cause 65-75% of the total costs. Due to the fact that VM allows modifications and adjustments to be made on virtual prototypes, it has potential to reduce costs significantly.

2. PARADIGMS OF VIRTUAL MANUFACTURING

Virtual Manufacturing deals with all phases of product life-cycle. More precisely, one can distinguish between the three characteristic application domains, or paradigms of Virtual Manufacturing [9,11,15]:

- design-centered,
- production-centered and
- control-centered VM (Fig.1).

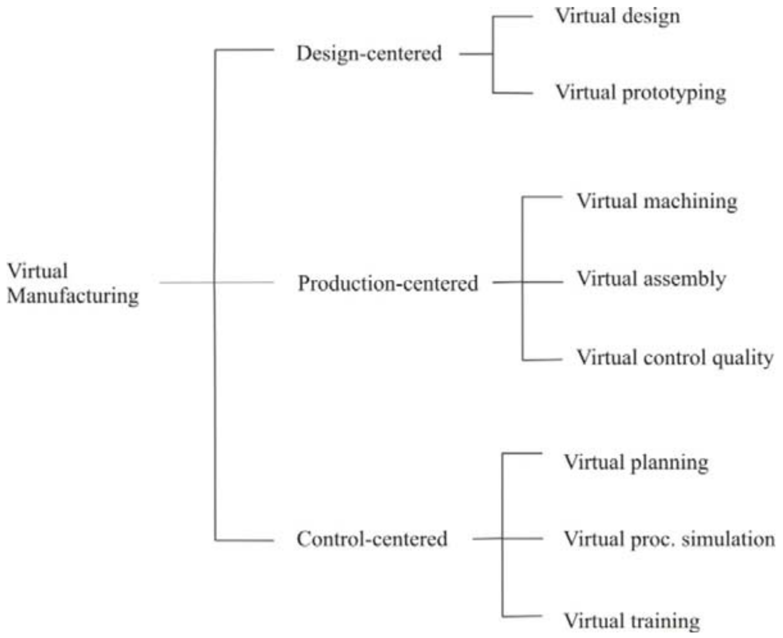

Figure 1 - Three basic paradigms of Virtual Manufacturing and their main branches

2.1 Design-centered VM

The task of design-centered Virtual Manufacturing is to allow user to obtain optimal product design solution as well as to generate preliminary variant of process plan. Therefore, output results from this phase pertain to product model, virtual prototypes and costs assessment.

As opposed to conventional CAD, where the user is confined to a limited interaction with the geometric product model, design in virtual environment allows him a number of advantages. Due to stereoscopic projection and a degree of immersion (depending on the system in hand) designer can interact with the model in a more natural way, which, in turn, brings creativity and greater efficiency to the fore. In addition, the quality of design solution benefits from the fact that designer can, at the earliest stages of design, share the end-user's perspective of the product.

2.2 Production-centered VM

Production-centered Virtual Manufacturing allows optimal use of manufacturing resources (machine tools, tooling, fixtures, etc.). Using simulations, assessments of alternative process plans are made prior to engaging in costly physical manufacture. This VM stage takes product model from the previous stage as input, while the outputs are: virtual production plan, novel process plans, costs of manufacture and delivery deadlines. During this stage, simulations are focused on machining, assembly and quality control.

2.3 Control-centered VM

Finally, control-centered VM paradigm takes in product model and process plans resulting from the previous two stages and focuses on material flows and optimal production control. Through simulations, user can arrive at an optimal production process, as well as optimal production system. Simulations are primarily focused on planning and training.

3. APPLICATIONS REPRESENTING THE THREE VM PARADIGMS

Reviewed in this section are some of the more recent examples of application of VR technologies in the design-centered, production-centered and control-centered paradigm of virtual manufacturing. The section concludes with a brief review of the types of VR systems which are used in such applications.

3.1 VM applications in the domain of virtual design and virtual prototyping

Detailed Virtual Design System (DVDS) is a mechanical VR-CAD system. It is a multi-modal, multi-sensory system which allows users to interact with geometric model of a product within a VR environment [1]. Users can interact with the system using hand gestures, voice commands and 3D input devices. DVDS is implemented as a software layer which interfaces the VR hardware platform and a commercial CAD system (SolidWorks). The system incorporates stereoscopic display of geometric information, thus allowing users to perform geometric operations in a realistic 3D environment.

Developed at Fraunhofer Institute for Machine Tools and Forming Technologies, VRAx is a VR platform for design of parallel kinematics machine tools in an immersive environment [13,17]. One crucial difference between this system and other systems which attempt to integrate CAD functions into VR environment, is the fact that VRAx allows geometry created and modified in VR to be recirculated into the overall process [13]. VRAx features a three-layer architecture consisting of: interface, application core and data storage. The interface layer is based on VR technologies and allows visualization and interaction. The application core stores the machine tool model and the processing control unit, which is representation of the work-flow. Contained within the third layer is a digital product data model of machine tools with parallel kinematics which is integrated with simulation and calculation systems and databases required for expert analyses of machine models. CAD core is interfaced with VR system bi-directionally, which means that changes made in VR can be efficiently transferred back to CAD. This systems allows designers to develop their solutions based on special templates, working in an intuitive, enabling VR environment which allows them to interact with customer's and experts from various fields in order to create optimal solutions.

As regards virtual prototyping in the plastic forming domain, an interesting report is given in [18]. It describes a virtual prototyping of mold design through geometric analysis of mouldability for near-net-shape manufactured parts by feature recognition and geometric reasoning. A virtual prototype of a mold is generated through combination of automated and interactive approaches which allow evaluation of mouldability of a part in the early stages of product development cycle. The authors used volume decomposition and geometric reasoning to create a novel volume-based feature recognition method. This method allows recognition of all kinds of undercut features using a general algorithm and provide "reasonable computational efficiency" [18]. This allows assessment of geometric mouldability of a part in question, in an intuitive manner, through interaction with virtual prototype.

3.2 Applications in the domain of production-centered VM

One of the most recent efforts dedicated to virtual simulation of plastic forming processes is a virtual injection molding system presented in [19]. It is a low cost, desktop-based system which utilizes VR technology, FEM analysis, motion simulation and scientific visualization. Stereoscopic graphical interface allows user a realistic and cohesive view of mold structure and assembly, while FEM analysis enables early detection of possible defects in the course of the molding process. Plastic product and molding machine are simplified and represented as tetrahedral meshes with texture, while molding parts are designed in a CAD package and imported in a standard STL format. The molding process is simulated through four characteristic stages, namely [19]: filling/packing, cooling, residual stresses and shrinkage. This provides a test bed for injection moulding, thus avoiding expensive and time-consuming physical experiments.

Virtual simulation of the rolling mill is the result of the joint project by the RWTH Aahen and SMS Demag. It allows simulation of operation of a CSP (***C**ompact **S**trip **P**rocess*) rolling mill. [9,11,15]. Using high-end virtual environments, users of this simulation can interactively inspect a virtual rolling mill and watch simulations of particular manufacturing processes in a virtual environment. VR simulations can so far be rendered on a *Holobench* projection table, a projection wall (*PowerWall*), a semi-circular projection wall and in a CAVE environment.

3.3 Applications in the domain of control-centered VM

VIRTOOL is an EU supported project aimed at development of a "Virtual Manipulation to Simulate Machine Tool Processes". The project focuses on the design and development of a computer-supported learning environment for machine tool process by using the interactive 3D graphics and virtual reality techniques [16]. VIRTOOL offers user various possibilities to define the machining process, set-up the workpiece and tooling, operate the machine, etc. According to authors, the main benefits are more efficient training process, prevention of accidents which may happen in a typical real-environment training, cost reduction and increased availability of machines.

Also in the area of education and training, the Materials science virtual laboratory, reported in [4], allows a VR-based realization of various tasks related to microscopy. The simulation enables trainees and students to use virtual light microscope and virtual confocal microscope for material science. According to [4] the simulation allows selection of a sample of interest, an observation method, magnification, light, etc. Virtual confocal microscope also allows selection of scanning depth with additional benefit of choosing light, contrast, saturation and hue.

3.4 Types of VR systems used in Virtual Manufacturing

Practical implementation of the three VM paradigms requires use of VR systems of various configurations. In practice, these systems are classified into three basic types, namely, immersive, semi-immersive and non-immersive VR systems (Table 1). This classification is based on the degree of immersion they allow, and should be considered as conditional.

Table 1 - Classification of Virtual Reality systems

VR system type	Main features	Typical configuration
Immersive	- User has no visual contact with the real environment - Virtual scene responds to user reactions - User unable to perform operations in real environment.	- HMDs, 3D pointers / haptic glove - CAVE system, LCD stereoscopic glasses, 3D pointer/ haptic glove
Semi-immersive	- User able to perform operations in both virtual and real environment - Pronounced sense of presence in the virtual environment - Limited ability to perform in real environment.	- CAD workstation with stereo graphics adapter and CRT monitor, LCD stereoscopic glasses - AR system with a semi-transparent HMD - Active and passive wall projection systems, VR tables
Non-immersive	- User perceives 3D scene as part of real environment. - User entirely able to perform in real environment - Diminished sense of presence in virtual enviroment.	- CAD workstation with 2D or 3D pointer, VRML browser

Further stratification can be made within types. For example, the most sophisticated (and cost-intensive) CAVE systems differ by the number of projection screens (sides) (2,3,4 or 5) and thus can be classified into lower-medium- and higher-cost immersive systems.

4. LOW-BUDGET VIRTUAL REALITY TECHNOLOGIES

With some exceptions, most of the applications described in section 3 utilize medium- or high-end VR technology, the price of which ranges between several hundred thousand- and over a million dollars. Significant penetration of VR technology into academia and industry in the region, requires introduction of readily available, low-budget VR technologies. Such an example is an experimental VR platform at the Laboratory for Plastic Forming Technologies, Institute of Production Engng., Faculty of Technical Sciences, Novi Sad [14].

4.1 Experimental desktop-VR platform

This experimental platform is based on a PC graphics workstation, with a stereo graphics card (Fig. 2) which operates with double refresh rate. Having in mind that the user which wears LCD shutter glasses has a field of view which is limited to the size of the monitor screen, this platform is equipped with a 22” CRT monitor. Stereoscopic LCD shutter glasses function in a wireless mode, while the synchronization between the stereo graphics adapter and the glasses is performed by an infrared emitter.

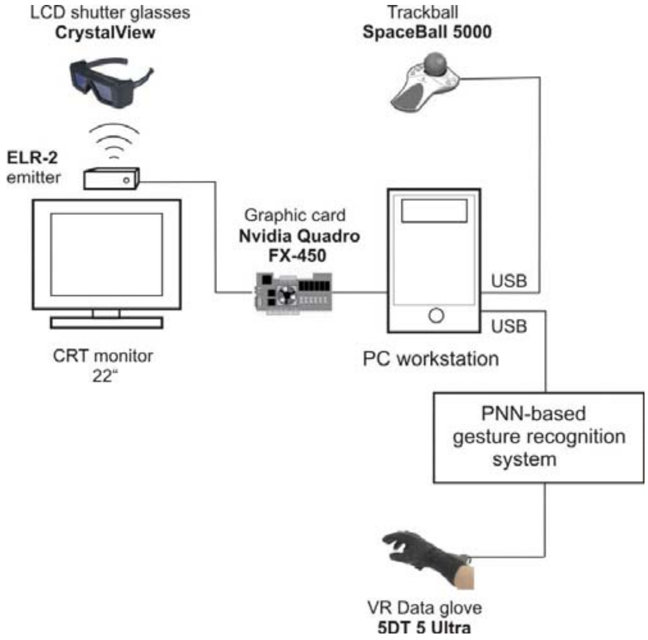

Figure 2 - Architecture of experimental desktop VR platform at the Laboratory for plastic forming technologies, Institute of Production Engineering, Novi Sad

As can be seen in Fig.2, the platform has two 6 DoF input devices - a data glove 5DT 5 Ultra and a trackball - Spaceball 5000. Software platform consists of OS *Windows XP,* CAD/CAE/CAM system *NX* and a VR CASE tool *Vizard (WorldViz).*

Integration of the data glove into the VR system is performed by a custom-developed recognition system for static gestures which is based on a probabilistic neural network (PNN) [10]. The PNN-based gesture recognition system allows two basic advantages over conventional approach: (i) better gesture recognition rate and (ii) enhancement of standard gesture library with new static gestures. Acquisition of a magnetic tracking system is in progress, which will allow the data glove to be used for dynamic gestures within the simulation space.

5. CONCLUSION

Projections for the future of forefront manufacturing in the industrially developed countries show that the manufacturing activities in the year 2020 shall be focused on: modelling and simulation, integration of human and technical resources, instantaneous transformation of information, reconfiguration of manufacturing enterprises, multi-disciplinary optimization, intelligent manufacturing processes and education and training [2]. This will require extensive application of VR technologies, that is, virtual manufacturing. However, high-end and medium VR technologies and systems require high initial investments which is almost certainly a prohibitive factor for the introduction of virtual technologies in the less developed countries. One of the possible solutions lies in the so-called low-budget VR technologies which could allow faster penetration of VR and VM in academia and industry. The domestic example from the Laboratory for Plastic Forming Technologies shows that minimal initial investments into VR technologies and their integration with conventional information technologies can produce entry-level VR systems. This, in turn, shall allow a broad-scale application of VM in academia and industry.

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TEHNOLOGIJE VIRTUELNE STVARNOSTI U PROIZVODNJI - STANJE I PRIMENA

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REZIME

U radu je učinjen osvrt na aktuelni status virtuelne proizvodnje, sa aspekta primene virtuelnih tehnologija. Diskutovani su glavni domeni primene virtuelne proizvodnje, pri čemu su takođe razmatrani i primeri primene tehnologija virtuelne stvarnosti u sva tri domena - paradigme, virtuelne poroizvodnje. Imajući u vidu vrlo visoke inicijalne troškove koji su povezani sa uvođenjem VR tehnologija u naučno-istraživačke institutcije i industriju, predložena je primena takozvanih niskobudžetnih virtuelnih tehnologija. U nastavku je sažeto predstavljen jedan domaći primer eksperimentalne VR platforme koja bazira na niskobudžetnim VR tehnologijama.

Ključne reči: *Virtuelna stvarnost, virtuelna proizvodnja, tehnologije plastičnog deformisanja*