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VIRTUAL MANUFACTURING : AN OVERVIEW

CHETAN SHUKLA, MICHELLE VAZQUEZ, AND F. FRANK CHEN

Department of Industrial & Systems Engineering
ECS 442, University Park Campus
Florida International University
Miami, FL 33199.

ABSTRACT :

Virtual Reality (VR) allows a user to navigate and interact with a three dimensional and dynamic simulation of a real or fictitious world. Virtual Manufacturing (VM) is the name given to an evolving area of research that aims at integrating diverse manufacturing related technologies under a common umbrella, using VR technology. The scope can range from integration of the design sub-functions such as drafting, finite element analysis, and prototyping to integration of all the functions within a manufacturing enterprise.

Technologies for VR include the hardware for input-output and computation, the electronics for integrating the hardware systems, and the software. Each technology is made up of numerous sub-technologies. . These technologies are still in their evolving and developmental stage and further advances are required. VM can be used for concurrently simulating all the activities and functions involved throughout the life cycle of a product. Some example applications are presented.

KEYWORDS :

Virtual manufacturing, virtual reality, concurrent engineering, integration, agility, visualization.

INTRODUCTION :

Virtual Reality is an emerging technology that aims at generating a perception of reality in a human subject, using devices that stimulate more than one sense organ and a dynamic model of a real or fictitious environment. Virtual Reality allows its users to intuitively interact with the virtual environment and its objects as if they were real by immersing them in this three-dimensional computer generated simulation. This method of conveying information promotes understanding of complex systems even in people with limited past experiences or knowledge about that system.

Virtual Manufacturing (VM) is the name given to an evolving area of research that aims at integrating diverse manufacturing related technologies under a common umbrella, using VR technology. The scope can range from integration of the design sub-functions such as drafting, finite element analysis (FEA), and prototyping to integration of all the functions within a manufacturing enterprise such as planning, operation, and control.

The objectives of this paper include (i) to review the state of the art in Virtual Reality technology as applied to manufacturing, (ii) to enumerate current applications and provide a means to identify future potential application areas within the manufacturing scenario, and (iii) discuss current research progress and future trends.

WHAT IS VIRTUAL REALITY :

Virtual Reality is described in [Larijani, 1994] as *"a computer-synthesized, three-dimensional environment in which a plurality of human participants, appropriately interfaced, may engage and manipulate simulated physical elements in the environment and, in some forms, may engage and interact with representations of other humans, past, present or fictional or invented creatures"*.

[Hollands and Mort, 1994] mention different ways in which virtual environments can be experienced :

- In the "first person immersive" type of environment, the user wears a helmet or head-mounted-unit which acts both as a display and a tracking device allowing the user to physically manipulate the environment such as his/her field of view, often in conjunction with other tracking devices.
- In the "Window on the World" technique, the monitor acts as a window and a means to navigate and interact in the virtual environment.
- "Cab simulator" uses a physical mock up of the environment and provides means of interaction through real controls and virtual images on a screen, e.g., Flight simulators.
- "CAVE" was a system designed by the University of Illinois in which the user(s) wore tracking devices and shutter glasses to perceive the virtual image projected on the walls and floor of a closed room.

The aim of Virtual Reality is to make use of multi-media to generate a perception of a real environment and allow interactive experiences, and facilitate the evaluation of different scenarios with limited expense and effort, e.g., a virtual battlefield can be generated to test the effectiveness of a new military strategy.

WHAT IS VIRTUAL MANUFACTURING :

Virtual Manufacturing (VM) is an integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control in a manufacturing enterprise [Hitchcock et al., 1994]. As per Nahavandi and Preece, 1994, VM "... *can be described as a simulated model of the actual manufacturing setup which may or may not exist. It holds all the information relating to the process, the process control and management and product specific data. It is also possible to have part of the manufacturing plant be real and the other part virtual*". Virtual manufacturing is the use of computer models and simulations of manufacturing processes to aid in the design and production of manufactured products, [Lin et al., 1995]. Similar definitions are given by [Onosato et al., 1993] and [Kimura, 1993].

Lawrence Associates [1996], have identified three different types of Virtual Manufacturing paradigms that use Virtual Reality technology to provide the integrated environment:
(i) Design-centered VM : provides designers with the tools to design products that meet design criteria such as design for X;
(ii) Production-centered VM : provides the means to develop and analyze alternative production and process plans;
(iii) Control-centered VM : allows the evaluation of product design, production plans, and control strategy and a means to iteratively improve all of them through the simulation of the control process;

WHAT IS THE SIGNIFICANCE OF VM ?

VM aims at providing an integrated environment for a number of isolated manufacturing technologies such as Computer Aided Design, Computer Aided Manufacturing, and Computer Aided Process Planning, thus allowing multiple users to concurrently carry out all or some of these functions without the need for being physically close to each other. For example, a process planning engineer and a manufacturing engineer can evaluate and provide feedback to a product designer, who may be physically located in another state or country, at the same time as the design is being conceived.

Another important contribution of VM is Virtual Enterprise (VE). Lin *et al* [1995] defined a Virtual Enterprise as *"a rapidly configured multi-disciplinary network of small, process-specific firms configured to meet a window of opportunity to design and produce a specific product."* Using this technology, a group of people, or corporations can pool their expertise and resources and capitalize a market opportunity, by sharing information in a VM environment. The principal advantage of this technology is its ability to provide a multi-media environment, enhancing communication at all levels in a product's life cycle.

TECHNOLOGY FOR VM

Technologies for VM include the hardware for input/ouput devices and computation, the electronics for integrating the hardware systems, and the software. In order to make VM fully applicable, further developments in a number of the areas are necessary. Some software related technologies are discusses in Lin *et al* [1995]:
(1) Visualization : presentation of diverse information to users in a meaningful, comprehensible and intuitive manner; (2) Environment Construction : development of a working environment, much like an operating system for a computer in principle, so as to facilitate visualization and other VM functions; (3) Information representation : the representation of diverse information with respect to methods, semantics and grammar; (4) Meta Modeling : constructing, defining, and developing models that accomodate inter-model interaction; (5) Integrating Infrastructure and Architecture : the architecture of hardware and software infrastructure; (6) Simulation : the process of designing a model of a real system in a computer, (7) Methodology : The method used for developing and using VM systems; (8) Manufacturing Characterization : capture, measurement and analysis of variables that infulence material transformation during manufacturing by means of VM; (9) Verification, validation, and measurement of VM system.

As described in the previous section, one of the significant contributions of VM is towards the enhancement of communication within an enterprise. This brings forth a number of areas requiring research such as, (1) methods to evaluate the effectiveness of this new medium, both by itself and in comparison to other media, (2) measurement and optimization of ergonomics aspects of the interfaces with respect to human-machine, and human-human interaction through the equipment and VM environment.

Hardware encompasses the following technologies :
(1) Input/Output devices, such as cathode-ray tube (CRT) based or liquid crystal display (LCD) head-mounted displays (HMD), the commonly available computer screens, projection systems, goggles and glasses for visualization, instrumented gloves with flexible fiber optics, body suits, treadmills, joysticks, touchpads, forceballs for tactile interface and navigation, microphones, synthesizers, headphones and speaker systems for audio; (2) Intrumentation to store/retreive information related to the input/output devices and interface them with the computing system; (3) The computing system to support all the instrumentation, data storage, and computation at high speeds, e.g., speed of rendering high quality images so as to generate a perception of reality in the user requires very high computation power; and (4) The network architecture (star, bus, ring), the hardware systems at different sites (Mini-computers, UNIX/VAX workstations, PCs), and communication hardware (fiber-optics, copper wires).

Many of these technologies are in their developmental stage, though these conditions are likely to change with the availability of greater computation power and speed at lower costs. It has also been observed that developments in software lag far behind hardware[Larijani, 1994].

APPLICATIONS OF VM

Applications of VM encompass the entire life cycle of a product. Reported developments include a virtual space decision support system by Imamura and Nomura [1994] at the Matsushita company in Japan. This system applied towards the marketing and sales of kitchen furniture, allows customers to experience

a kitchen environment and evaluate alternatives and select the best combination according to preferences. Their preferences are stored as drawings and subsequently transferred to the company' s production facilities.

Owen [1994] presented the work implemented at John Deere Company' s production facility, that used Virtual Manufacturing for the installation of an arc welding production system. The project involved using a Virtual 3-D environment for design, evaluation, and testing of the robotic production system. Part of the work was carried out at John Deere' s facility while part of it was done by Genesis Systems and Technomatrix Technologies. The VM approach helped shorten the design-to-manufacturing cycle-time.

DuPont [1994] presented an overview of Virtual Reality applications, and reported about Virtual prototyping being carried out at the Coventry School of Art and Design. These virtual prototypes are constructed in a computer at the beginning of the design process and allow the designer to perform tests on the virtual prototype such as a car beforehand, by walking around or through the design, examine its performance on a virtual road, sit in the driver' s seat, and check view lines, etc. Also reported were VM applications such as the virtual concurrent design and assembly of a landing gear, and simulation of side-impact collision to test vehicle safety.

Kim *et al* [1994] also reported VR applications including the use of VM by designers at Boeing Aircraft company for the ergonomic evaluation of their airplane designs for operation as well as maintenance. Another study used a VM environment to train robots. An operator' s movements were recognized, interpreted and stored in the form of robotic movement commands. Shenai described the Virtual Wafer Fabrication (VWF) infrastructure which provided a framework for the optimization of key process and design variables in the development of application specific semiconductor devices. Other application areas discussed in Larijani [1994] include machine-vision applications for diagnosis, fault detection, inspection and preventive maintenance, safety and maintenance training, ergonomic analysis. For example, new cab or shovel configurations for Caterpillar earth moving equipment are tested by real drivers for possible imbalances while handling virtual bulldozers and trucks.

CONCLUSIONS :

The application of VR in manufacturing possesses immense potential and challenges, both for research and industrial applications, as seen through the developments reported so far. It can easily be perceived as the next generation interface, as indicated by the current trend in use of multi-media and network technology. The intuitive and immersive perception that VR allows, can be expected to enhance the capabilities of many current systems used in manufacturing such as CAD, CAM, and CAPP both independently as well as concurrently.

The principal shortcomings are imposed by the need for high computation power and speed, the heavy costs involved with the same, and also because many of the relevant technologies need development before adequate benefits can be obtained. If these shortcomings are to be overcome new technological advancements in hardware are required and even a greater effort should be placed on software which is found to be lagging far behind hardware according to various reports including [Larijani, 1994].

The paper aims at providing a brief overview of recent developments in the field of Virtual Manufacturing and generates interest in this potential research area.

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