Virtual Reality Applications in Manufacturing System

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***Abstract*—Virtual reality (VR) is a high-end human computer interface that strives to immerse the designers and users completely in a virtual interactive environment for a simulation of real world. In order to meet the requirements of market competition, VR technologies can not only reduce effectively the time and cost, but also optimize complex products in the design process. Virtual reality is a rapidly developing computer interface that strives to immerse the user completely within an experimental simulation, thereby enhancing the overall impact and providing a much more intuitive link between the computer and the human participants. Virtual reality has been applied successfully to hundreds of scenarios in diverse areas including prototyping, manufacturing, scientific visualisation, engineering, and education. This paper discusses the applications of virtual reality in the manufacturing industry.**

Keywords—Virtual Reality; Virtual Manufacturing; Simulation

I. Introduction

Nowadays, manufacturing firms needs to produce innovative products with low cost and short time delivery to market. The customisation strategy to meet the individual demands at high variety and low volume have made manufacturing processes more complex, dynamic and demanding [1]. Thus, the new demands and customer requirements for a product from conceptualisation to production are forcing the manufacturing firms to change to new technology. The new technology is virtual reality (VR). The origins of virtual reality can be traced as far back at least as "the ultimate display" [2]. The primary concept of VR is illusion. It focuses on the manifestation of the fantasy world of the mind in computer graphics. It is also a new media for information and knowledge acquisition, and representing concepts of ideas in ways not previously possible [3]. One of the applications of applying VR is virtual manufacturing (VM). Virtual manufacturing is defined as a computer system which is capable of generating information about the structure, status, and behaviour of a manufacturing system as can be observed in a real manufacturing environment [5]. VM provides a modelling and simulation environment so powerful that the fabrication/assembly of any product, including the associated manufacturing processes, can be simulated in the computer [6].

II. Virtual Reality Systems

VR is scientifically defined as an application of the computer to create an effect of interactive, three-dimensional world, in which objects have spatial form. Ivan Sutherland has introduced the key concepts of immersion in a simulated world, and of complete sensory input and output, which are the basis of current virtual reality research [2]. Although it is difficult to categorize all VR systems, most configurations fall into three main categories and each category can be ranked by the sense of immersion, or degree of presence it provides. These categories include non-immersive systems, semi-immersive projection systems and fully immersive systems as shown in Table 1 [7].

TABLE I. TYPES OF VR SYSTEMS [7].

VR System	Non-immersive VR	Semi-immersive VR	Fully-immersive VR
Input devices	Mice, keyboards, joysticks and trackballs.	Joystick, space balls and data gloves.	Gloves and voice commands.
Output devices	Standard high-resolution monitor.	Large screen monitor, large screen projector system and multiple television projection systems.	Head mounted display (HMD), CAVE.
Resolution	High	High	Low-medium
Sense of immersion	Non-low	Medium-high	High
Interaction	Low	Medium	High
Price	Lowest cost VR system	Expensive	Very expensive

III. VR Applications In Manufacturing

Manufacturing industries are the most contributors to prosperity in the industrialised countries. However, it is becoming increasingly difficult to meet customers' demands and to compete. The advances in virtual reality technology have provided the applying VR to different engineering applications such as product design, modelling, shop floor controls, process simulation, manufacturing planning, training, testing, and verification. VR holds great potential in manufacturing applications to solve problems before being employed in practical manufacturing thereby preventing costly mistakes. VR not only provides an environment for visualisation in the three-dimensional environment but also to interact with the objects to improve decision making from both qualitative and quantitative perspectives [8]. Virtual reality applications in manufacturing have been classified into three groups; design, manufacturing processes, and operation management. A brief description of every group and its relevant subgroups will be provided in the coming sections.

A. Design

Virtual reality technology has been applied into two different applications in design; design and prototyping as shown in Table 2. VR provides a virtual environment for the designers in the conceptual design stage of designing a new product; the designer could produce "3D sketch" of a product in the virtual environment. At this stage, functional experimentation of mechanical features such as hinges, assembly, etc. could be performed to evaluate the conceptual design and modifications could be made as required. Figure 1 shows virtual reality design team for Boeing Company [8]. Digital engineering denotes the integrated use of digital methods and tools throughout product design and production and is intended to improve the quality of planning and control throughout the entire product life cycle [10]. Virtual prototyping can be used before building the physical prototype to prove design alternatives, to do analysis, manufacturing planning, support management decisions, and to get feedback on a new product from prospective customers; this virtual prototyping should include as follows [7].

a) Functionality: the virtual prototype should be clearly defined and realistically simulated to address product functionality and dynamic behaviour.

b) Human interaction: the human function involved must be realistically simulated, or the human must be included in the simulation

c) Environment: an offline computer simulation of the functions can be carried out, or a combination of computer offline and real time simulation can be carried out.

Fig. 1. Virtual reality design team in Boeing Company [9]

TABLE II. MANUFACTURING DESIGN APPLICATIONS [11, 12].

Application	Definition	Example
Product design	Virtual design is the use of VR technology to provide the designer with a virtual environment to evaluate the design, evaluate alternate designs, effectively interact with the product model and conduct ergonomic studies using full human body tracking.	A virtual workshop for mechanical design was developed at Massachusetts Institute of Technology. The goal of the project was to develop a simulated workshop for designers to do conceptual design work while having to take into account manufacturing processes. The simulated workshop consists of a band saw, a drill press, a milling machine, a radial arm saw and a table saw.
Prototyping	Virtual prototyping means the process of using virtual prototypes instead of or in combination with physical prototypes, for innovating, testing and evaluating of specific characteristics of a candidate design.	University of Illinois, Chicago, and Purdue University have designed and implemented a prototype of a VR based computer aided design system. The focus of this work is to allow a simplified method of designing complex mechanical parts through the use of VR techniques.

B. Manufacturing Processes

This has been classified into three different areas; machining, assembly, and inspection. Virtual machining involves cutting processes such as turning, milling, drilling, and grinding, etc. Machining using virtual reality mainly deals with cutting processes such as turning, milling, drilling, and grinding, etc. Figure 2 shows an engineer uses VR to simulate the use of a hexapod machine tool [13]. The user can mount a work-piece on the milling machine, choose a tool and perform direct machining operations, such as axial movements or predefined sequences [14].

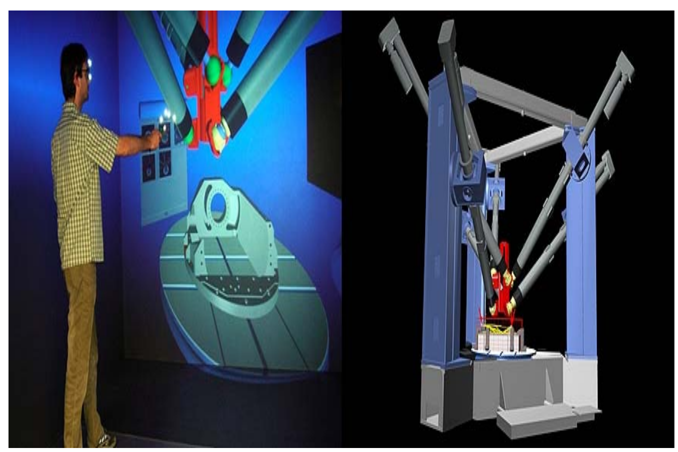

Fig. 2. Virtual machine tool [13]

Virtual assembly is a key component of virtual manufacturing and is defined as the use of computer tools to make or to assist with assembly-related engineering decisions through analysis, predictive models, visualisation, and presentation of data without realization of the product or support processes. Virtual reality can be used for assembly/disassembly operations. In assembly line, virtual manufacturing is mainly used to investigate the assembly processes, the mechanical and physical characteristics based on modelling and simulation [15]. In 2006, Toyota has used a virtual person so called Ergo Man to help reduce the physical loads on assembly workers building the next-generation Camry at its manufacturing plant in Melbourne. It was used as part of an innovative 3D virtual assembly operation that digitally replicated the entire assembly production process [16]. Another VR application in assembly is Ford Motor Company which has partnered with Siemens to build virtual assembly plant technology [17]. The application, called IntoSite, uses Google Earth infrastructure to allow users to navigate through 3D versions of actual Ford assembly plants, right down to individual workstations. IntoSite is currently about a year into its pilot phase, which is taking place at the Michigan Assembly Plant in Wayne, Michigan. Allowing engineers to fiddle around with parts and processes virtually makes for a more efficient company. No matter how automated and virtual the auto manufacturing process becomes, vehicles are ultimately made by humans. The better the communication between those humans, the better product they're able to create. Fortunately, IntoSite doesn't just allow engineers to virtually travel to assembly plants all over the world, it will also better connect them to their global colleagues. Through this unified communications approach, questions can be answered by co-workers across the globe instantly, data can be shared in real time, and even travel costs could potentially be reduced. Figure 3 shows Ford Motor Company is piloting new software from Siemens, using Google Earth infrastructure that facilitates virtual navigation within its assembly plants.

Fig. 3. Virtual assembly in Ford Motor Company [17]

Virtual manufacturing technology is used to model and simulate the inspection process, and the physical and mechanical properties of the inspection equipment. This virtual inspection provides an environment for studying the inspection methodologies, collision detection, inspection plan, and the factors affecting the accuracy of the inspection process [18].

C. Operation Management

Virtual reality in operation management is classified into three categories; planning, simulation and training. In planning, VR can lead to an optimal planning of a manufacturing system by giving a visual environment to the all person involved in the planning process to monitor the factors that can lead to inadequate results and delay the start of product. Visual comparison of possible solutions based on human experiences and facts lead to a rapid start of production and robust manufacturing processes [19]. VR in simulation helps to verify the model logic and real-world behaviour of the model [20] and it supports the simulation tools to understand the results and the dynamic behaviour of the model. VR also convinces the people who do not believe, know the simulation tools and understand the capabilities of simulation [21]. Virtual reality-based training is the world's most advance method of teaching manufacturing skills and processes to employees. Using cutting-edge VR technology, training takes place in a realistic, simulated version of the actual facility, complete with the actions, sights, and sounds of the plant floor [22]. Factory and plant layouts are increasingly being planned digitally with 3D CAD tools. In order to improve the sustainability of planning as a whole, the three-dimensional data must also be used in downstream planning processes. Generating and simultaneously updating two-dimensional layouts to represent simulated processes schematically is ineffective, redundant and error-prone. Depending on the context of their use, interactive 3D visualizations and animations in lieu of 2D representations can additionally deliver various advantages and improvements, e.g. analyses of potential collisions of work-pieces and equipment during production, clear presentations of complex systems and animations of manual equipment. Review3D was used to develop a tool for simulation-based planning of resource-efficient factories, which links into a company's specific digital production planning interfaces, where automatic and manual simplification procedures were considered for planning data with a very high level of detail to generate interactive 3D visualizations, called Virtual Factory [23]. Figure 4 below shows the virtual factory [24]. In keeping with the virtual factory's sustainability requirement, such models can naturally be used for more than just the actual planning process, e.g. for marketing, training or operational planning. Researchers also implement the virtual reality for training workers to perform manual lifting without causing harm to their lower back. Researchers also used virtual reality and augmented reality to reduce the risk of collision. They simulate the process in real time whereby the virtual displayed product moves on belt conveyor and any forthcoming collision can be monitored early in advance [25]. A study conducted by [26] used singular and combined visual feedback techniques to train user in performing manual lifting task in order to reduce the back pain problem. Virtual reality platform based on a dynamic multi-agent programming language was designed to show that simulating a multi-agent system in a virtual environment with dynamic properties can be used for interactive prototyping. The researchers developed a specialized virtual reality platform, named AReVi, for interactive prototyping. The main point of interactive prototyping concerns the use of dynamic modeling capabilities in a virtual environment designed as a multi-agent system [27].

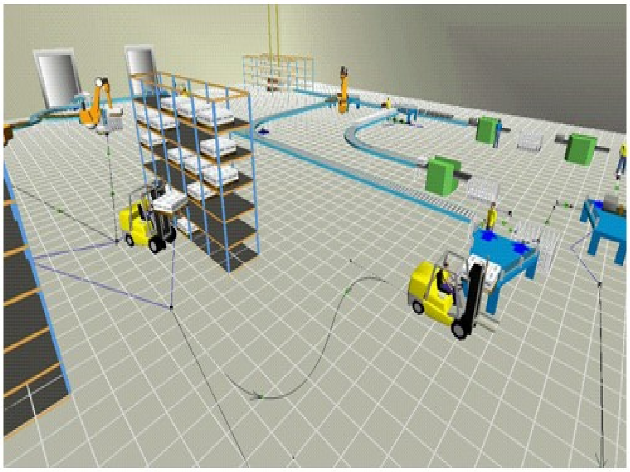

Fig. 4. The virtual factory [24]

IV. CONCLUSIONS

New advances in computerized modelling, visualization, simulation, and product data management are making virtual reality (VR) a viable alternative to traditional product realization and manufacturing. VR can be a powerful tool for testing and evaluating new products and ideas. Its applications in manufacturing enable companies to reduce design and production costs, ensure product quality and slash the time needed to go from product concept to production. VR technology has been applied to solve clients' real-world problems, and has increased profitability, reduced time to market, and increased worker safety. Manufacturing design and processes can be defined, modelled and verified before they can be actually implemented. VR offers the engineer's new ways to not only visualize their problems, but also to interact with environment to solve the problems effectively and efficiently. It is important to realize that VR is not merely for visualisation purposes, instead, offers improved methods of interaction and visualisation, where it can be applied in real engineering problems.

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