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Virtual reality as industrial Training tool for manufacturing technology: A review

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ABSTRACT

This review paper describes in general the use of VR as a training tool in manufacturing technology like design, rapid prototyping, and manufacturing with some practical examples where VR is used and its benefits in manufacturing industries which reduces a lot of cost in the design stages to the finish stages. VR is the closest man can get to reality as the names implies with the present capabilities. The technique enables engineers and designers to move around and interact with the object in real time. This review paper looks into some challenges of VR applications in manufacturing industries.

1. Introduction

Virtual reality is a technique or method by which a user visualizes, manipulates, and interacts with computers and extremely complex data which can also be utilized for industrial training [1]. It is basically a computer-based technology that gives learners a realistic, three dimensional and interactive experiences. A user using virtual reality can even interact with a computer-generated environment, without much technical training [2]. According to [3], virtual reality as "the computer aided simulation of a three dimensional model that one can interact with in order to get a better sense of the project". Another definition by [4] which is more glaring and clear said "Virtual reality is a high-end interface that involves a real-time simulation and interaction through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, taste, etc." For virtual reality it's become practically clear in its applications for creating a simulated environment and is more economical than placing the user in the real environment. Virtual reality is a kind of adoptable tool,

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that can be used in almost all fields, and its application ranges from home entertainment to high tech space craft simulation. In the present days, virtual reality is used in fields such as architecture, medicine, military, etc.

The current problem is that VR technology is not fully implemented in some industries due to the lack of expertise to man and manipulate the software for used and another problem is that VR trainees all experiences the same training routines, which are not customized to individual learning patterns. Yet every trainee learns a different way and will require their training to focus on specific aspects of the tasks [1].

The main objective of this review is to get an insight on the application of virtual reality application in industries and how to save cost and time. The most prominent uses of VR are in manufacturing industries but Nevertheless, virtual reality is slowly coming out of research laboratory and venting into the manufacturing sector.

1.1. Virtual reality in manufacturing

Nowadays, the uses of high quality graphics and animation have been on the rise in the manufacturing systems. The present two-dimensional image systems suffer from the setback of containing only a limited number of viewpoints. To offset these, three-dimensional graphic tools can be used. However, three-dimensional graphic tools require high computation and may not be available on personal computers running in real-time [5].

"Virtual Reality could be the solution, generating the three-dimensional graphic in real-time, concurrently with simulation generation, allowing users to move around and interact with the process in a natural and interactive manner" [6-8]. Manufacturing industry is particularly well positioned to take advantage of the recent emergence of affordable VR systems based on standard workstations or PCs [9]. Most of the new products today exist as computer-aided design (CAD) models from the early stages of the design cycle. Virtual Reality becomes extremely powerful when combined with CAD. It allows engineers and designers to view, manipulate, and modify complex designs. Virtual Reality is capable of presenting a realistic interface to a complex engineering model. For example, if a user wants to handle and rotate a model, he can simply reach out, grasp the object and twist his hand. Alternatively, he can also walk around the object to get a different viewpoint.

1.1.1. Virtual design and prototyping

In practice, the product is designed first and then the prototype is built. Prototyping is done, so as to check the characteristics of the products under various conditions. The product design is approved for manufacturing only if the prototype performs well. The primary disadvantage associated with physical prototypes is that, they cost too much and also consume a considerable amount of time in their development. Due to these drawbacks, many innovative products were stopped from coming into the market even before the design stage was completed.

In order to overcome the difficulties in building a physical prototype, manufacturers have begun to use Virtual Reality. Developing a 'virtual prototype' will cost only a fraction of what a physical prototype would have [10]. Virtual prototypes help in the integration of design and manufacturing personnel to ensure that engineering designs are producible. Virtual prototyping not only simulates the way things look, but also simulates the way things work. Engineers can create and modify potential designs in real-time, seeing the effects of their modifications and changes immediately. Also the user can explore the geometries, relationships, and movements of objects in three-dimensional spaces in an almost realistic way, as if the part were physically there [10].

Caterpillar company that produces heavy equipment such as wheel loaders and backhoe loaders use a Virtual Reality system known as the 'CAVE' developed by the University of Illinois, Chicago. Earlier, Caterpillar used three-dimensional programs, which did not allow viewing of product from all sorts of angles. The new system which they are currently using, allows product designers to go through many more iterations and revisions than before, when the physical prototypes had to be built before customers got their first look at new product designs [11]. Boeing, with the help of Virtual Reality created a virtual prototype model for its new aircraft Boeing 777. Virtual prototyping allows pilots and designers to test how well the new components work. Chrysler Corporation, the automobile manufacturers use Virtual Reality for testing the interior of a car. The user sitting in front of an actual steering wheel wears a head-mounted display to view the virtual interior of the car. With the help of a wired glove, the user can turn on a virtual radio or honk a virtual horn [12]. The above mentioned were some of the potential applications of Virtual Reality systems in design and prototyping. There are many other industries that use Virtual Reality for similar purposes.

1.1.2. Virtual assembly planning

The assembly of extremely complex products, such as aircraft and electro-mechanical products are difficult to automate, as the high demand dexterity required for assembling them, are not easily achieved by robots. Also, complex products may have many small parts and reprogramming robots for these quantities is an expensive prospect. The concept of virtual assembly planning can be used in such cases. Virtual Reality provides an excellent environment for the clear observation of assembly experts at work. As the experts work, the movements of both the user and the components can be recorded by the system. Once the user completes assembling the parts to his or her satisfaction, an assembly plan can be automatically generated from the stored usage data [12]. One major criticism in using Virtual Reality in assembly is that the virtual systems lack the sense of touch i.e., the user cannot feel the object. The sense of touch is extremely important for precise positioning of parts during the assembly process. However, research study shows that to overcome this problem, two new methods called the "collision snapping" and "proximity snapping" positioning has been developed.

Ford Motor Company uses Virtual Reality for automotive assembly. The vehicle parts are represented in a CAD system. The CAD file is then transferred to the system with Virtual Reality equipment. A user manipulates the virtual part in real-time and attempts to assemble it into a virtual vehicle. Also, the concept of networked virtual environment enables colleagues located at different sites to work together on design projects in some virtual space and perform real-time simulation of assembly and manufacturing processes [11].

2. Application of VR in manufacturing

Manufacturing industries are the most important contributors to prosperity in the industrialized countries. However, it is becoming increasingly difficult to meet customers' demands and to compete. The advances in virtual reality technology in the last decade have provided the impetus for applying VR to different engineering applications such as product design, modelling, shop floor controls, process simulation, manufacturing planning, training, testing and verification. Virtual reality allows a user to step through the computer screen into three-dimensional (3D) world. The user can look at, move around, and interact with these worlds as if they were real. The primary goal of VR are that of illusion [2]. VR holds great potential in manufacturing applications to solve problems before being employed in practical manufacturing thereby preventing costly mistakes. Virtual reality not only provides an environment for visualization in the three-dimensional environment but also to interact with the objects to improve decision making from both qualitative and quantitative perspectives [13]. The following section details the use of virtual reality in manufacturing applications, which include: design, prototyping, machining, assembly, inspection, planning, training and simulation. Virtual reality applications in manufacturing have been classified into three groups; operations management, manufacturing processes, and design [14].

2.1. VR applications in Design

Virtual reality may play very significant rule in designing a new product. VR technology has been applied into two different applications in design; design and prototyping as shown in Table 1. The benefits of the applying VR in design as shown in Table 2. VR provides a virtual environment for the designers in the conceptual design stage of designing a new product [14], 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. Once the designers are satisfied with their design, then the design could be detailed to make the necessary modifications [15]. All of the materials were used without further purification.

Table 1
Design application in manufacturing

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 alternative 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. [9].
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 virtual reality 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 virtual reality techniques [10].

2.2. Applications of VR in operation management

Operations management has been classified into three categories; planning, simulation and training. The benefits of applying VR technology to these categories are Due to the necessity of a smarter factory planning; Virtual reality is a useful method to improve the understanding of the plans and to support interdisciplinary discussions. Figure1 shows fully immersive VR environment, which has been used as a tool for future factory design. This environment has been developed to provide a visual, three-dimensional space in which to explore the effect of various product mixes, inspection schedules, and worker experience on productivity [16]. Virtual reality-based training is the world’s most advanced 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 [17]. Some of the simulation products provide some form of visualization for depicting model output.

Table 2
Summary for virtual reality benefits in manufacturing applications

Area	Benefit
Design	To allow the whole design team to work together in the virtual environments. To improve visualization of the product by allowing the user to co-exist in the same environment with the product model. To improved interaction with design in terms of more intuitive model manipulation and functional experimentation.
Prototyping	To reduce significantly the amount of hardware prototypes during conception, design, and evaluation of new products. To provide a virtual environment for innovating, testing and evaluating of specific characteristics of a candidate design.
Operation management planning	To improve the understanding of the plans and to support interdisciplinary discussions. To allow the users to interact and change the model during runtime. To enable unskilled users to understand and participate in the planning process. To support the technological as well as the economical modeling of diverse production planning scenarios.
Simulation	To convince the use the simulation tools. To verify and validate a simulation model. To enable the user to understand the results. To provide a virtual environment for communication of results. To achieve the credibility for the simulation [21]
Training	To duplicates an entire manufacturing process to a virtual environment to give trainers their own factory to learn in. To provide a user with an environment to explore the outcomes of their decisions without risk themselves or equipment. To allow the employees to practice existing and new tasks in safe.
Manufacturing processes machining	To evaluate the feasibility of a part design and the selection of processing equipment. To allow the user to study the factors affecting the quality, machining time and costs based on modeling and simulation
Assembly	To reduce design cycle time, re-design efforts, and design prototypes [16] To predict the quality of an assembly, product cycle and costs. To address assembly and disassembly verification.
Inspection	To model and simulate the inspection process, and the physical and mechanical properties of the inspection equipment. To provide an environment for studying the inspection methodologies, collision detection, inspection plan, factors affecting the accuracy of the inspection process, etc [20].

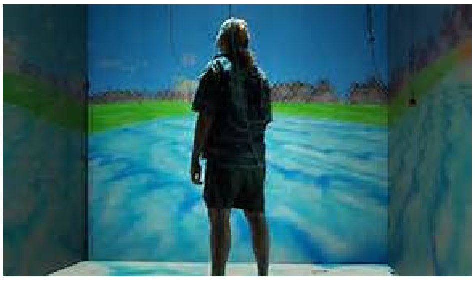

Fig. 1. Fully immersive VR environments

2.3. VR applications in manufacturing processes

Manufacturing processes has been classified into three different areas: machining, assembly, and inspection. The following breakdown will give more light on the use of VR in manufacturing processes [14].

2.3.1. Machining

Virtual machining mainly deals with cutting processes such as turning, milling, drilling, and grinding, etc. The VM technology is used to study the factors affecting the quality, machining time of the material removal process as well as the relative motion between the tool and the work piece [14]. Figure 2 show an engineer uses a Virtual reality "semi-immersive environment" to simulate the use of a hexapod machine tool. [18]. University of Bath in Bath has developed an interactive virtual shop floor containing a three axis numerical control milling machine and a five axis robot for painting. 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 [19].

2.3.2. Assembly

Virtual assembly is a key component of virtual manufacturing and is defined as: "the use of computer tools to make or "assist with" assembly-related engineering decisions through analysis, predictive models, visualization, and presentation of data without realization of the product or support processes" [20]. In assembly work [15,16], VM is mainly used to investigate the assembly processes, the mechanical and physical characteristics of the equipment and tooling, the interrelation among different parts and factors affecting the quality based on modelling and simulation. Virtual reality can be used for assembly/disassembly operations. For example, can a human worker assemble a part or a component? And then can the part be disassembled for service and maintenance at latter stages? Other questions need to be addressed, too: is it "difficult" or "easy" to assemble/ disassemble a part? How long does it take? How stressful is it in terms of ergonomics? Is there enough room for tools? [21].

2.3.3. Inspection

Virtual inspection makes use of the VM technology to model and simulate the inspection process, and the physical and mechanical properties of the inspection equipment. This aims at studying the inspection methodologies, collision detection [22], inspection plan, factors affecting the accuracy of the inspection process, etc. [23].

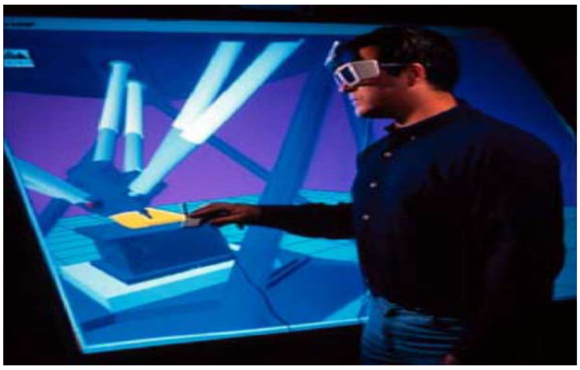

Fig. 2. Virtual reality machine tools

3. Results and discussion

Virtual reality has contributed immensely to manufacturing in different aspects. The above lamentation gives us an insight on how virtual reality could be used to bridge the gap between various departments involved in the development of a product, thus saving valuable time and also money spent on travel, this can only be accomplished by using a shared environment which is an extension of teleconferencing.

Similarly, VR played an important role in design and prototyping process, whereas building it physically consumes more time and is also expensive. Virtual manufacturing when combined with simulation tools can reduce design and production cost, as well ensure product quality, and reduce the time required to go from product concept to product, while being highly responsive to continually changing market and world condition.

Despite all the benefit of virtual reality applications in manufacturing Ragusa et al [24] pointed out some research issues that needed to be tackle and resolved before virtual reality can be fully operational. Some of the research issues are:

Limitations of CAD: The current CAD technologies do not fully support concurrent user operations in either a stand-alone or network mode, and the variable perspective are not yet possible.

Network communications: Present network technologies and capabilities would only marginally support the throughput requirements of distributed CAD and VR concurrent design environments.

Limitations of VR technology: Virtual reality technology does not have the potential to handle the networked, interactive needs of a distributed real-time design system. In addition, a basic premise, yet to be validated, is to determine if visualization techniques significantly clarify shared information and improve decision making by multiple team members working in an interactive environment.

Human and organizational behaviour: If virtual reality based manufacturing has to be implemented, then understanding the human and organizational issue must be addressed. The use of technology regardless of its promise, does not guarantee that humans working in virtual environment will perform better than those using present systems.

Cost efficiency: Cost –benefit has to be an important part of the determination of any industrial use of virtual reality.

4. Conclusion

In this review paper, some of the potential application areas of virtual reality have been discussed with some practical examples where it is used. Virtual reality, when properly implemented can offer many advantages to manufacturing industries be it large or small. It could enable manufacturers save a lot by reducing unnecessary cost and also reduce lead-time while product quality remained improved.

Virtual reality still remains a challenge due to its limitations, only few industries implemented it uses. According to Larson-Mogal [25] "Virtual reality is not something that an average user will have this year or next year", that means a lot of work has to be done on both the technology and the software before it usability.

We concluded that despite it numerous challenges and limitation they lay optimism in its manufacturing applications that still remain as powerfully and not yet fully exploited.

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