AC 2012-5038: VIRTUAL MANUFACTURING LABORATORY EXPERIENCES FOR DISTANCE LEARNING COURSES IN ENGINEERING TECHNOLOGY

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Virtual Manufacturing Laboratory Experiences for Distance Learning Courses in Engineering Technology

Abstract

In manufacturing technology education, it is highly desirable for students to get a lot of hands-on experience in the laboratories in order to learn the basic principles of complex systems, motions, and operation of machines. Unfortunately, delivering such hands-on laboratory experiences to all the students has become quite challenging, as most engineering schools have distance learning programs. If it is possible to handle laboratory training with "virtual models" of the equipment in the computer, it could offer tremendous advantage for the engineering technology distance students as they could operate costly laboratory equipment on their own computer and they can learn even while making mistakes.

The paper presents an application of the virtual reality technology in order to improve the laboratory practices of engineering technology distance learning courses in the areas of industrial robotics and computer-aided manufacturing. A developed virtual reality software system, VCIMLAB has been utilized for this study. The results of the presented educational initiative, assessed through tests and feedback surveys, suggest that the virtual manufacturing laboratory is competitive in hands-on training for distance students as they can learn better the operations of robotics and manufacturing systems when realistic, interactive simulations are used instead of audio-video demonstrations. However, the implementation of this technology is still challenging due to the relatively high cost of design and development of the 3-D virtual reality simulation systems. VR is most suitable for replicating educational laboratories with highly expensive or potentially dangerous equipment.

Introduction

In the recent years, trends of the globalization have affected the higher education, resulting in an increasing flow of students seeking a new career in engineering technology. Economic pressures on the universities and the emergence of new technologies have spurred the engineering technology programs to create new systems in engineering technology education in order to afford the increased demand. The distance learning is one such a new system, which has recently become very popular in order to deliver undergraduate engineering education to the learners at various distant geographic locations.

However, given that the instructional laboratories have been an essential part of engineering technology programs, delivery of the laboratory exercises to the distant learners is a problem demanding solution. Several programs have implemented solutions for this problem including the lab kits that contain small, inexpensive laboratory equipment that each student either purchases one or given one by the university in order to do the labs at a distance location. These methods have been found very useful for delivering the labs of the courses that do not require sophisticated lab equipment. However, it has been very hard to conduct the distance laboratory experiments, which require bulky and costly equipment such as industrial robots, trainers, test instruments, manufacturing machines etc. The engineering technology programs are in the need of new technologies to adapt for distance laboratory instruction.

To date, many studies have shown that the use of computer technologies in teaching and laboratory work is feasible, and has changed the economics of engineering education.[1,2] Educational computer applications can provide instant and direct feedback on performance measurement therefore enhancing the learning outcome, especially in all forms of distance education. The computer applications have opened new possibilities in the laboratory, including simulation, automated data acquisition, remote control of instruments, and rapid data analysis and presentation. The experiences have shown that these applications also have a positive influence on the student motivation and educational effectiveness as compared with hands-on labs.

With the recent advances in computer graphics, the realistic visualization systems such as Virtual Reality (VR) have become very feasible in undergraduate engineering laboratory training. Its advantages, such as new possibilities of interaction and more realistic and pleasant learning environments are turning VR into a valuable tool in distance laboratory education. The VR systems, providing a sense of reality and an impression of 'being there', has been increasingly employed in various training and educational applications in the areas of design and manufacturing. Common applications of the VR-based education include computer-aided design (CAD), manufacturing automation, control, robotics, manufacturing assembly planning, manufacturing system visualization and simulation. [3, 4, 5]

Despite its advantages, very few applications of VR based laboratory education for distance learning have been reported in the literature. [6, 7] The common developed VR-based laboratory education systems are dedicated to education and training with the local students. They require high computer knowledge and skills for operations, which are found too sophisticated for educational purposes. The studies often overlook the importance of the VR-based laboratory education into the distance learning programs. [8]

The paper presents an application of the VR-based laboratory training in engineering technology distance learning courses in the areas of robotics and manufacturing systems. The objective of this study is to investigate the effectiveness of the VR-based laboratory training systems in distance learning programs. For implementation, an educational software package: VCIMLAB (Virtual Computer Integrated Manufacturing Laboratory) developed by the author, has been used in a senior level manufacturing course in engineering technology.

An assessment study has been performed for the laboratory components of the manufacturing and robotics-related distance course in order to measure the learning outcomes and the students' satisfaction on laboratory experiences.

Virtual reality applications in engineering education

VR applications have great potentials for use in education at all levels. VR interfaces have the potentials to complement existing approaches in education. In virtual worlds, learners can be simultaneously provided with three-dimensional representations, multiple perspectives and frames-of-reference, simultaneous visual and auditory feedbacks. With careful design and implementation, these capabilities can be synthesized to create a profound sense of motivation and concentration conducive to mastering complex materials. [9] Training using VR systems is based on the assumption that knowledge or skills acquired in a virtual world will transfer to the real world. The VR in laboratory instruction makes use of computer models in order to simulate the behavior of the system or process under study, substituting the laboratory equipment. [10] This way it is possible to repeat an experiment many times, comparing the findings with the model-based values.

Empirical data have been collected on the relative success of VR in terms of instructional effectiveness, as well as the transfer of skill to the real world. Many studies have emphasized the success of VR technologies for education and training. [11] For instance, researchers have shown that people can indeed learn to perform certain tasks such as console operations from virtual environments and knowledge and skills acquired in a VR simulation have been shown to transfer to performance in the real world.

There are many relevant examples. As described in [11], the multi-national companies use such technology. For example, Motorola runs a three-day training courses on the operation of their robotic assembly lines using VR environments for their teaching associates based around the world. VR based education have also been adopted by some engineering institutes, for example, Geo-technical, Rock and Water Resource Digital Library (GROW) a part of National Civil Engineering Digital Library (NCERL) project. It has been developed in the department of Civil Engineering and Engineering Mechanics of University of Arizona. [12]

Generally, we can expect that the use of VR and all other means of educational software in laboratory training maximize the interaction with the student and enhancing various phases of the educational process. The automation of the experimental bench, through introduction of a combination of the above systems, improves the quality of education, offering important advantages such as:

1. The students devote their time to fruitful discussion and useful observations, having the possibility to analyze directly the measurements, repeat some of them, compare with theoretical or simulation results etc.
2. The students concentrate on understanding fundamental concepts and not performing tedious wiring and measurements.
3. The students can be introduced to interrelated disciplines, such as from electrical machines to power electronics, automation and control, data acquisition etc.
4. Drilling can be enabled at any time without supplementary effort by the educational staff.
5. Minimization of failures due to wrong settings and wiring.
6. Minimization of the effort needed by the laboratory support staff.
7. New possibilities on continuous education, distance-learning, collaboration with industries, and training of industrial personnel.

The virtual laboratory - VCIMLAB

The VCIMLAB is an educational software system, which been designed and developed for supporting the engineering laboratory training in computer aided manufacturing (CAM), industrial automation, industrial robotics and related areas. The VCIMLAB uses the desktop, non-immersive VR technology as a basis for simulating the manufacturing laboratory instruments and provides a three dimensional, interactive environment for students to work with them. The virtual laboratory mainly consists of 3D simulation models of industrial robot arms, computer numerical control (CNC) machines and automated assembly systems.
Through the real time interfaces of the VCIMLAB, the students can operate the virtual simulation models of the manufacturing equipment and corresponding system software.
The VCIMLAB provides several distinguished combinations of laboratory models for a step-by-step approach of learning, starting from the easiest, going through the hardest combination. These distinguished simulation environments are named as 'rooms'. Each room contains a basic training unit, such that the students focus on a specific group of hardware. The VCIMLAB provides total four rooms. The difficulty level increases from 1 to 4 which is the hardest. As an initial step of operation of VCIMLAB, the level of difficulty is defined by the selection of VCIMLAB room (See Fig 1).

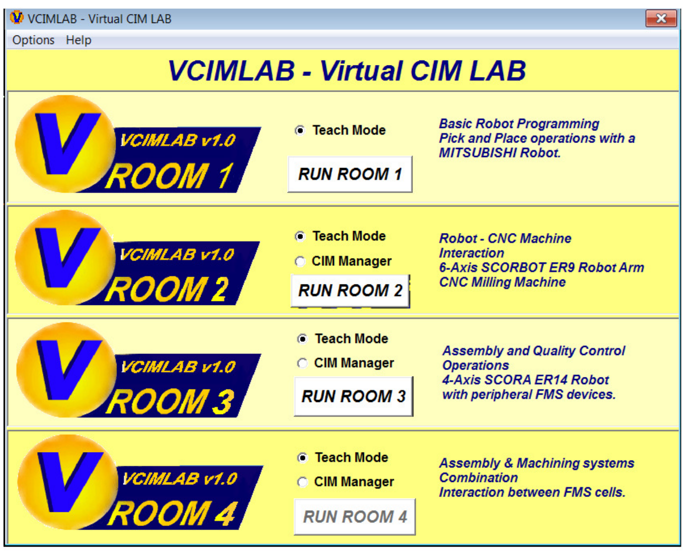

Figure 1: VCIMLAB – Main Screen; Selection of difficulty level (Rooms)

In the Room 1, the VCIMLAB provides the users a basic scenario for learning the operating principles of an industrial robot arm. This is a beginning stage to familiarize the students with how to control and program an industrial robot arm safely for various pick & place operations and to prepare them for more advanced levels of operations.
A snapshot of the VCIMLAB Room 1 is shown in the Figure 2. The Room 1 involves only one industrial robot arm, a 5-Degree of Freedom standard industrial robot model with rotary tables for performing a variety of robotic pick & place operations. The students are free to use the virtual robot teach pendant, robot control and programming software, provided as simulation

software interfaces for performing the robotic tasks in virtual environment. A typical laboratory experience assigned to each student in Room 1 is as follows;

The student is given a robotic manipulation task of moving parts/blocks from any specified locations to specified destination points. For performing this task, the student moves the virtual model of robot arm to the desired points, which the robot arm passes through during its motion, and store the necessary positions into the virtual robot's memory by using the virtual teach pendant. At the end, when all the necessary points of robot motion are stored, the students write robot programs or also known as scripts by the simulation of the ATS (Advanced Terminal Software) interface in the virtual environment. The robot motions, programmed to carry out the desired tasks are then executed in VR environment by using a virtual control software interface.

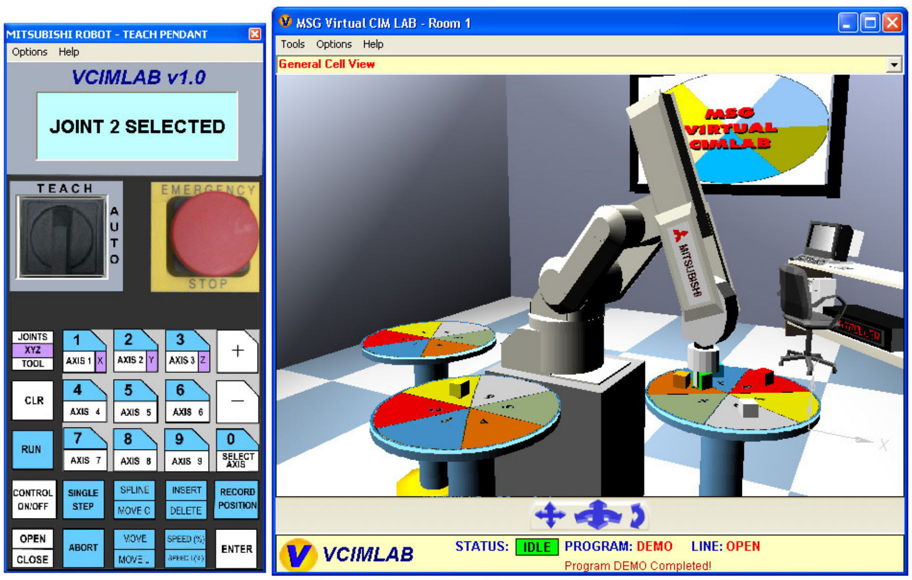

Figure 2: Room 1 – Basic Robot Training

In the Rooms 2, 3 and 4, the VCIMLAB provides conventional robot cells in which typical robot - CNC interactions; several assembly and quality control operations are studied.

The Virtual CIM Laboratory Room 2, includes an industrial robot arm with a linear slide base and a CNC Milling machine. The robot in VCIMLAB Room 2 is operated exactly in the same way as the robot in Room 1. The difficulty here is a CNC machine is added to the system, which complicates the operations of the robot. Additionally, an interface for performing the CNC machine configurations, design of operations, writing NC programs, machine control is also added to provide training on the CNC machine systems. A snapshot of the Room 2 is shown in Figure 3.

As a further step of the basic robot training performed, in Room 2 the students are expected to program the given robot is to load the CNC machine with a raw part, program the sequence of the operations between robot and machine. By this way, the students learn how to operate a complete cell to produce a part with the given specifications, how to program the robot for CNC operations without collisions in a correct sequence.

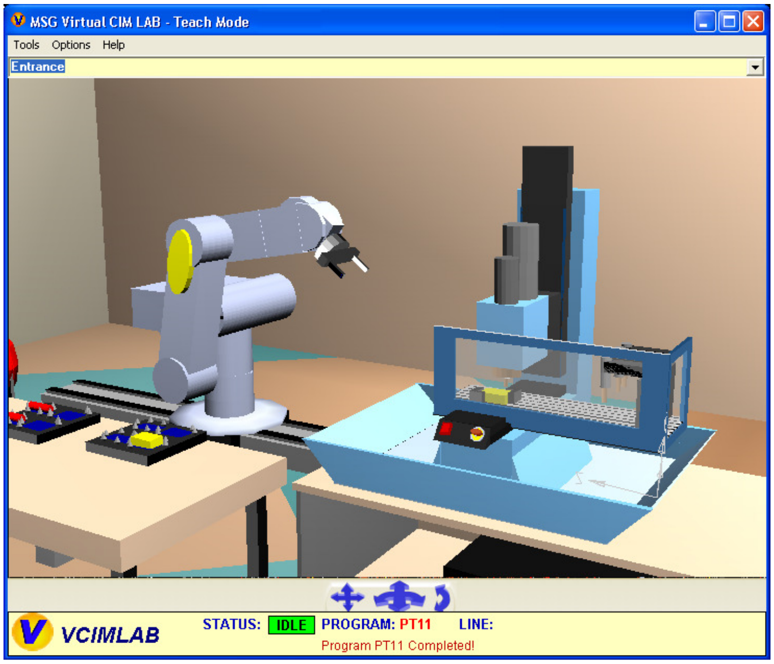

Figure 3: Industrial Robot Arm – CNC Machine Interaction

In the virtual laboratory Room 3, an assembly and quality control cell with a SCARA robot is provided. In this level, the students are expected to performing several assembly and quality operations by programming the given robot and the peripheral equipment such as: a Laser Scan Micrometer, Glue Dispenser, Screwdriver tool etc. (See Fig. 4).

The VCIMLAB Room 4 is a further step of training in cellular manufacturing operations. It consists of the combination of the equipment presented in Rooms 2 and 3. The knowledge and experience gathered in the previous levels of the training is applied in Room 4 to establish a parallelism in manufacturing system components. In addition to the operations performed in Rooms 2 & 3, Room 4 serves with the capability of combining two robotic cells to perform a variety of full manufacturing processes. One example is that, the block parts can be machined in the CNC cell, and be transferred to the assembly cell for further dispensing and assembly operations.

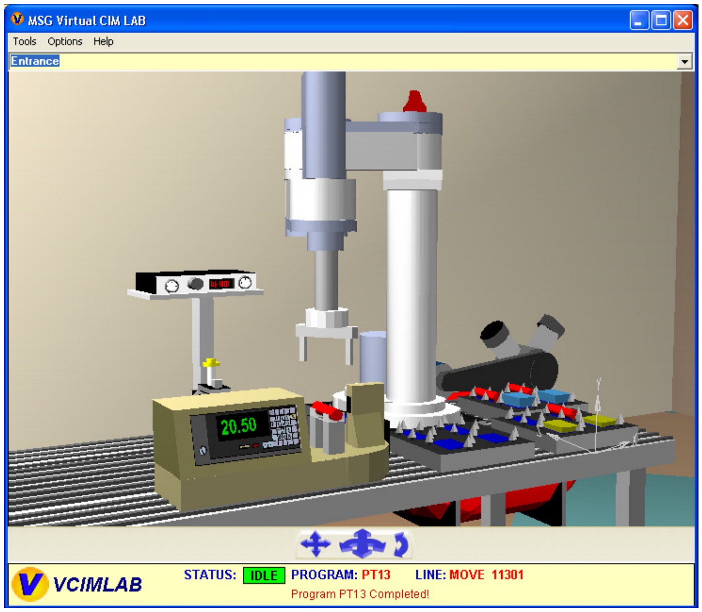

Figure 4: Assembly and Quality Control Cell with SCARA Robot

The Virtual CIM Manager is a VCIMLAB module (See Fig. 5), which provides the centralized control of the production activities in the VR based laboratory for performing the manufacturing orders defined by the user. The module simulates the Computer Integrated Manufacturing (CIM) operations as defined by the users. The VCIMLAB - Virtual CIM Manager enables students to use and study components and subsystems individually as well as the entire integrated CIM system.

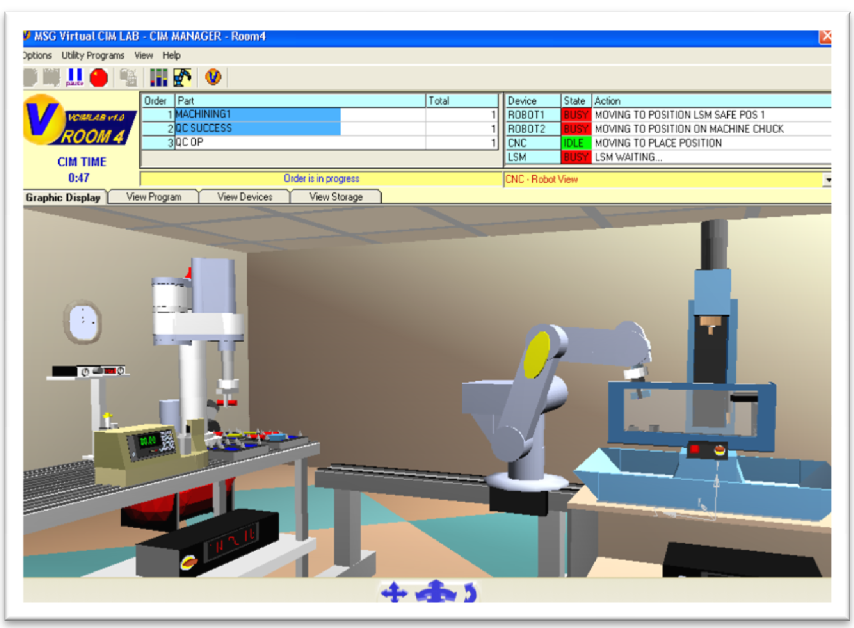

Figure 5: Virtual CIM Manager

The implementation of VCIMLAB in a distance learning course

In order to measure the effectiveness of the VCIMLAB laboratory training system in the distance laboratory education, a pilot study has been performed on a senior level manufacturing course in the Miami University, Department of Engineering Technology.

The Miami University, Department of Engineering Technology currently runs a number of distance learning programs. The students across the state take distance engineering technology courses from the main campus remotely via the Interactive Video Distance Learning (IVDL) system. The ENT 407 – Modern Manufacturing Systems is such a credit course delivered in hybrid format. Most of the course contents, lectures and assignments are delivered online using the course web site. Several lectures are delivered using the Interactive Video Conferencing System (IVDL). The course covers a broad range of topics in manufacturing including the manufacturing processes, modern manufacturing technologies, application of computers in industry, non-manufacturing environments such as Group Technology, Lean Manufacturing, CAD, and Concurrent Engineering. Due to the restrictions of its distance delivery format, no laboratory exercises had been previously developed for this course. The implementation of the virtual laboratory exercises with VCIMLAB is the first practical implementation at this institution.

The objectives of this implementation are: 1) to explore to which extent the considered virtual laboratory modalities can be efficiently implemented in practice and used by distance students to obtain practical training as a supplement to a theoretical course module, and 2) to explore the relative importance of VR-based interactive laboratory exercise in comparison with traditional audio-video demonstrations. The experimental protocol used and the results obtained are presented and discussed in this section.

For evaluation purposes, all the distance students taking this course have been randomly put into two groups. A group of students have been asked to download and watch the video demonstrations and tutorials prepared for teaching the operating principles of industrial robot manipulators. This group (Group 1) has seen total of four 1-hour length videos focusing on various aspects of industrial robot control, programming and flexible manufacturing systems.

The other group (Group 2) of distance students has not been given these educational videos. Instead of that, the students in this group have been asked to download and install the VCIMLAB software on their computers. Tutorial and educational support material was provided to these students describing: 1) the robot used in the experiment (its mechanical and kinematic characteristics, and its control and programming features) and 2) the exact procedure and steps needed to program a robot manipulation task using the pendant.

In the virtual rooms of the VCIMLAB, the students were asked to manually manipulate the robot arms to complete various given tasks. Once they get familiar with the robot manipulations, they were given programming assignments for carrying out several robot manipulations, and automated material handling tasks in the virtual environment. Those students, who complete these tasks were then asked to use the VCIMLAB CIM Manager module to prepare hierarchical cell controller programs and arrange for the process plans and schedules to produce parts. By the end of each session, students of all three groups completed their training by sending the completed robot programs to the instructor.

A set of experiments have been designed and implemented for assessing the effectiveness of the VR system on distance learning. The experiments basically consist of: tests to evaluate the learning outcomes, and opinion surveys to obtain the feedback of the students about their overall experience in the virtual laboratory. In order to evaluate the learning outcome on the virtual laboratory experiences, all the students in both groups have been given a dedicated written test in order to measure their understanding of the robot experiments. The test includes a series of technical questions regarding the programming and control of industrial robot arms. As a result of the evaluation, it has been significant that the performance of the group of students who have been trained with the interactive VR system was significantly higher than those who have observed the same concepts from the video demonstrations.

In addition to the test, all the students have been asked to fill out an opinion survey about their overall experience with the method of the laboratory experience delivered in this course (Virtual Laboratory/Video Demonstration). Total of 40 students were surveyed. The survey results have shown that the students, who had VR for the laboratory sessions have had much more fun than the other group, and they have been much more certain about what they have learned in this course. Table 1 presents a summary of the survey results on select questions regarding the laboratory experience of the students.

Table 1: Summary of the opinion survey results

RUBRICS	**Virtual Reality Laboratory**		**Video Demonstration**	
	(1=Strongly disagree, 2=Disagree, 3=No opinion, 4=Agree, 5=Strongly agree)			
	MEAN	**SD**	**MEAN**	**SD**
The lab sessions were motivating for me to learn more about Industrial Robotics and CIM systems.	**4.75**	**0.54**	**2**	**0.58**
The teaching method in lab sessions helped me visualize and understand the manufacturing processes.	**4.5**	**0.66**	**2.5**	**0.73**
I got familiar with hands on practice of real industrial robots with the lessons I learnt in this lab experience.	**4**	**0.987**	**1.5**	**0.96**
This method helped me learn the basics of industrial robot control and programming.	**4.5**	**0.675**	**2.75**	**0.71**
I would like to have lab sessions like this to help me learn.	**4.75**	**0.55**	**2.5**	**0.59**
Overall, I have had fun in these labs.	**4.5**	**0.88**	**2.25**	**0.82**

An interesting conclusion can be drawn in relation to the comparative assessment between the group, which used the virtual reality laboratory and the group, which used the Video demonstrations, with the obtained results being particularly in favor of the “virtual reality” group. In other words, one finds that a realistic virtual environment, even with a complete absence of real (visual etc.) feedback from the considered experimental system, can provide adequate learning elements, compensating for the lack of direct physical presence on the real experimental site.
This finding seems to be valid for laboratory training course on robotic manipulation. However, a large-scale study is still needed to investigate these issues more profoundly.

Conclusions

An implementation of a developed VR-based laboratory work-support system into the distance learning has been presented in this paper. The developed VR-based software VCIMLAB system has been utilized for investigating the effectiveness of the virtual laboratories on the laboratory training on the industrial robotics and flexible manufacturing systems. A pilot study has been performed in a distance learning manufacturing course at the Miami University, Department of Engineering Technology. From a technological perspective, this research work focuses on the adaptation of concepts and techniques developed in the field VR, and on exploring their integration in distance laboratory education. From a pedagogical perspective, the goal is to assess the performance of virtual laboratory systems, in terms of the “quality” of training provided to distance students.

As a result of our experience with the VR-based laboratory training in distance education, we significantly figured that the VR is a highly flexible and cost effective mode of delivering robotics laboratory experience to a range of distance learning students, who do not have constant access to the university’s laboratory facilities due to geographic restrictions. The VR-based system creates an interactive scene with a sense of ‘being there’, so that the students can feel free to develop solutions to 'what if?' scenarios in real time with the simulations of the manufacturing equipment. Instead of watching the things happening in the virtual world, they can have the feeling of actually doing the things. In this sense, the VR provides a significant advantage over the audio-video demonstrations of the manufacturing equipment and processes. The experience gained through VR-based laboratory education system showed us that the performance of the distance students, who practice the with the virtual laboratory for learning the theoretical concepts is significantly higher than those who were trained with the video demonstrations.

Most significantly, the students can get things wrong safely without damaging machinery or work, this allows them to learn from their mistakes and develop their skills and understanding of the process. In general, the VR - gives the system trainers or teachers the opportunity to introduce their students to highly complicated and expensive devices and systems in a cost-effective way. . VR is most suitable for replicating educational laboratories with highly expensive or potentially dangerous equipment. Although, the design and development of 3-D virtual reality systems cost relatively high, often not yet affordable by small educational institutions, the use of VR can still be a suitable alternative to conventional expensive educational laboratories.

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