Use of Non-Immersive Virtual Reality in Mechanical Engineering Laboratory

Dr.R.Mahalinga Iyer and Mr.C.Frieiberg
School of Engineering Systems
Queensland University of Technology
2, George Street
Brisbane Q4001
AUSTRALIA
m.iyer@qut.edu.au

Abstract

Virtual Reality (VR) differs from computer animation in two distinct ways. Firstly, VR allows users to randomly interact with the computer generated world. Secondly, the objects within this synthetic environment are three dimensional. There are three functional groups within Virtual Reality. They are: immersive, non-immersive and augmented or hybrid systems. In non-immersive VR, the user interacts with the synthetic environment without the assistance of specialized environment or equipment such as the CAVE or gloves etc. The manipulation of the environment is done by a mouse or a joy-stick. This paper is confined to non-immersive virtual reality systems.
Traditional Mechanical Engineering laboratory experiments (or any other engineering laboratory experiments) are done within a limited time. In many cases, the students will not know how to operate a piece of equipment. The training required for such purpose is prohibitive both in time and finance, to any Engineering School. It would be extremely beneficial, if the students can prepare themselves, prior to attending the laboratory session, to have some prior knowledge on how to use the equipment and collect data. The Virtual Reality system, if implemented properly, will provide such an opportunity for the student to practice the laboratory exercises before commencing the physical experiment. This paper will review some of the existing systems; describe the use of a commercial VR system to train the students to program a Mitsubishi robot and the development of an in house system to enhance the experience in using a Hounsfield tensometer for testing the strength of materials. The paper will also discuss the preliminary evaluation of the usefulness of the VR-Robot system.

1. Introduction

The accreditation engineering courses criteria summary document of Engineers Australia (EA) under the curriculum section [1] emphasizes the importance of practical 'hands on' experiences. The criteria includes the following performance indicators to be satisfied by engineering curriculum of any engineering program:

- Embedded experiential learning activities, appropriate to the technical domains within the designated field of practice, and directed at developing

- An appreciation of the scientific method, the need for rigour and a sound theoretical basis;
- A commitment to safe and sustainable practices;
- Skills in the selection and characterization of engineering systems, devices, components and materials;
- Skills in the selection and application of appropriate engineering resources tools and techniques;
- Skills in the development and application of models;
- Skills in the design and conduct of experiments and measurements;
- Proficiency in appropriate laboratory procedures; the use of test rigs, instrumentation and test equipment;
- Skills in documenting results, analyzing credibility of outcomes, critical reflection, developing robust conclusions, reporting outcomes.

It is evident that laboratory exercises play a vital role in any engineering curriculum. Through laboratory exercises, students observe 'real' phenomena that reflect theoretical concepts they have learnt. These exercises not only reinforce understanding of theoretical concepts but also indicate to them the limitations of the theories. Ideally, students should have access to conduct the experiments and to repeat them if they wish to learn more about the experiments. However at present the laboratory exercises are controlled to such an extent that the students have very little 'hands on' experience in performing the experiments. This is further aggravated due to financial pressures on the universities. A typical laboratory session may last about three hours with very little prior preparation. The only pre-lab preparation is through handouts on the experiments and parts of equipment manuals. The static content of the experiment sheets or parts of manuals do not convey the dynamic process that occurs in the laboratory. An informal survey [2] done at the then School of Mechanical Manufacturing & Medical Engineering (now called Engineering Systems) of the Queensland University of Technology in 2003, clearly indicated that the students are opposed to reducing the laboratory exercises and would prefer to have more 'hands on' exercises. Chen et.al. [3] conducted a survey related to pre-lab assignments and found that:

- Most of the students agree that the pre-lab activities are necessary
- Majority (85%) of the students believe the traditional pre-lab activities and readings are ineffective.
- Any pre-lab activity should focus on finding out how to operate the instruments and conduct the experiment.

It is clear that some form of interactive pre-lab activity that promotes the understanding of how to operate the various instruments and equipment will increase the 'hands on' experiences as well as the understanding of the laboratory exercises. The financial strain on universities and the diverse activities of the academic staff prevents the introduction of physical based laboratory exercises that are freely accessible to the students with minimal supervision. New innovative ways need to be found to prepare the students for doing the experiments. The rapid changing computer technology and the availability of a variety of software make it possible to devise an experience for the students that will enhance the laboratory exercises. Virtual Reality is a platform that can greatly improve the traditional engineering laboratory. Virtual Reality can be defined as an immersive, interactive, viewer centered multi-sensory three dimensional synthetic environments. There is general confusion in assuming computer animation as VR. The difference between VR and computer animation is in the type of interaction by the user with the computer generated world and the nature of the objects in VR. In VR, the user can randomly interact with the synthetic world which is composed of three dimensional objects. There are three functional groups within Virtual Reality. They are immersive, non-immersive and augmented or hybrid systems. In non-immersive VR, the user interacts with the synthetic environment without the assistance of specialized environment or equipment such as the CAVE or gloves etc. The manipulation of the environment is done by a mouse or a joy-stick. Present day undergraduate students are familiar with the computer games' environment which uses synthetic environment. Thus, the students are expected to easily adapt to the use of VR in their study. This paper will review some of the existing systems; describe the use of a commercial VR system to train the students to program a Mitsubishi robot and the development of an in house system to enhance the experience in using a Hounsfield tensometer for testing the strength of materials. The paper will also discuss the preliminary evaluation of the usefulness of the VR-Robot system.

Literature Review

Virtual Reality has been successfully used in pilot training in the aviation industry, medical training and military training. Only recently, has VR been making its way into general engineering education. Several examples have been reported in the literature recently with many different interpretations in the use of VR in engineering education. Some of the different ways to use VR (and its interpretations) and related technologies in engineering education are:

- Non-immersive VR tools for enhancing interactive learning
- Immersive VR tools for enhancing interactive learning
- Web based remotely controlled experimentation
- Web based pre-lab preparation
- Simulation based pre-lab preparation or experimentation.

This paper focuses on only the non-immersive type VR and its application in pre-lab experimentation. Jack and Karlesky [4] reported on setting up a virtual manufacturing laboratory The students will perform a pre-lab preparation on robot programming and once satisfied and checked are allowed to run the robot remotely from a web browser. In this set up, the user starts a simulation and is given the opportunity to provide input as required. Once simulated the user can submit the program to the physical robot and test it. The actions of the robot can be viewed remotely through video cameras that can be controlled by the user. It appears that only a simulation is performed with no feedback to the user on any potential mistakes or dangers. It is also not clear whether the students will not be able to download their program directly to the physical robot without going through the pre-lab session on virtual robot. Machine operations and manufacturing using VRML was reported by Tan, Yew and Gramoll [5]. One of the examples they described was the development of a virtual lathe with push button and slider controls for the students to understand machine operations. Students can manipulate the buttons and sliders to run the machine and observe the machining operation. Some checking is done for collision, but not comprehensive to be the same as the physical lathe. They have reported some more work need to be done to be more authentic. Budu [6] described an interactive virtual geotechnical laboratory. The package is created as a courseware that is suitable for web based instructions and/or delivery by a CD-ROM. This has the elements of pre-lab assignment that is close to what the student need to do in the lab. Drag and drop features are included for the students to systematically prepare the instrument for one of the three tests: direct shear, triaxial and consolidation. Another feature of this courseware is the pre-requisite knowledge, post experiment testing. The results from these are recorded individually. This allows the instructor to know how well the student had done the laboratory as a whole. In the pre-lab session the students are also guided in the preparation of the apparatus for testing on the virtual machine as well as conducting a virtual test before performing the physical test. This is a good example of the use of VR for enhancing the laboratory experience of students. A CD-ROM based laboratory courseware for torsion experiment was described by Chevalier et.al. [7]. The development of one experiment was reported and suggested that this should be used as a template for other experiments. However, the courseware is used as a multimedia presentation of the laboratory and not used as a pre-lab assignment for the actual physical lab. Whether the students followed the multimedia courseware with the physical experiment is not clear from the description. However, the results of the evaluation questionnaire indicate that the multimedia presentation helped in preparing the students for the physical lab. How VR can address competency gaps and can be used in process design was discussed in two papers by Whitman et.al. [8, 9]. They have modeled a real life manufacturing cell to teach activity and process modeling. The learning is through simulation except that the material flow through the cell is animated for easy understanding. Furthermore, the VR simulation model is also used as one of the means to address competency gaps in manufacturing engineering graduates. They neither have nor reported any link between the VR models and the real physical systems. The students after going through the simulations do not experience the physical system. A pre-lab tutorial system for strength of materials laboratory in which the students will go through the setting up the apparatus and perform the test virtually before conducting the physical experiment was reported by Chen et.al. [3]. The student evaluation of the system indicated that more than 95% of the students felt that the pre-lab assignment with VR is more effective than traditional paper based pre-lab assignment. This is another good example of the use of VR with manipulation of the instruments and setting up the experiment in the virtual world is identical to the physical experiment.

Use of VR_Robot : Commercial software

It has been recognized that with the current generation of students, the incorporation of VR in the curriculum will enhance the learning experience. School of Engineering Systems (formerly School of Mechanical Manufacturing & Medical Engineering) of Queensland University of Technology (QUT) over the past few years is attempting to integrate VR in the mechanical engineering degree curriculum. This is directed at two directions: the possibility of using commercial software and developing the required system in-house. To enhance the learning experience through hands on activities, the School purchased a Denford™ CIM (Computer Integrated Manufacturing) system consisting of a CNC mill, CNC lathe, a Mitsubishi Movemaster RVM1 robot on a linear slide and a vision system. As part of the package a set of VR worlds for the purpose of training the students in the use and programming of the robot and the CIM system was also purchased. There are two sets of VR worlds: A set of five worlds solely for programming the robot and understand the controls of the robot and the other set consisting of four VR worlds for programming the combined CIM system. The envisaged use of the VR worlds is that the students, using the robot VR worlds, will understand the various functions of the teach pendent to program the robot safely before using the physical robot. Figure 1 shows the physical robot and the VR robot with the pendent. It can be clearly seen that the virtual world is close to the physical world and the students can easily identify the controls in the physical world once they have used the VR robot.

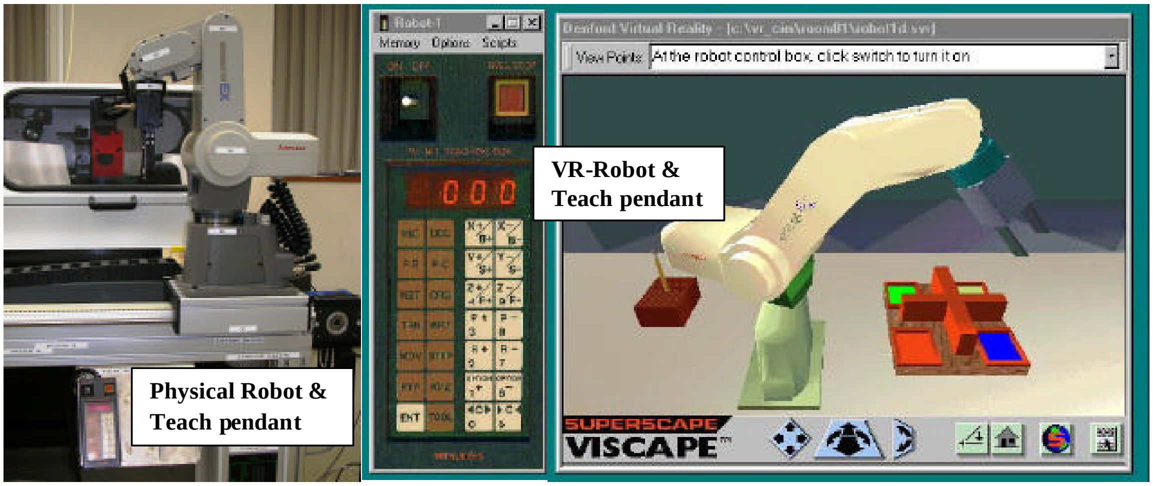

Figure 1: Physical robot and the VR robots with teach pendants

The VR robot has been in use for the past three years. It was observed that the students had little difficulty in using the physical robot after using the VR robot. However, there were several difficulties were noted in the operation of the VR robot. The source code was not provided making it difficult to make any modifications as required. There were some access security issues which made it necessary to give full access rights to the students, which the school is not keen to do. The software was written for Windows95™ and was quite adapted to Windows 98™. But when used in Windows 2000™ or Windows XP™ environment, the program tended to crash occasionally. This often frustrated the students. Another feature that hindered the learning is the availability of intelligent objects. These are pre-programmed actions activated by pressing the left button on a nominated area. As a result, instead of learning the various functions of robot movement and programming, students were playing with the intelligent objects. The instructor of the class had to be vigilant and ask the students to learn the controls rather than playing. As a consequence, Tus, it was decided to develop a pre-lab VR experiment in house for one of the laboratory experiment as a trial.

Development of a VR Hounsfield ™ Tensometer

The basic development of the VR Hounsfield tensometer was undertaken by the second author as a final year project. At the outset, based on the experience with the VR robot, a set of requirements were drawn for the development:

- VR experiment must complement the real laboratory
- The system must be a non-immersive VR
- The equipment and the controls must be reproduced faithfully in VR
- VR experiment must reproduce the actions required to conduct the physical laboratory and not as a simple simulation.
- The system must be easily accessible to all students, preferably web based.
- The system must be developed in a modular fashion for ease of modification.

- The system must have enough intelligence to provide feedback to the students when something is done wrongly or correctly.
- The system must be easy to use and guide the students to perform all key test procedures with well defined controls.

The Faculty of Built Environment and Engineering has a synthetic laboratory consisting of VR authoring tools, modeling software. Thus, it was decided to use the existing VR authoring tool, Cosmo-worlds. Solidworks™ 3-D solids modeling software is already in use with the design classes and was selected for creating the models. The process of developing the sample virtual laboratory experiment is quite complex. Proper planning is essential for the development of a robust system. A considerable amount of time was spent identifying the features of the Hounsfield machine that were required to be modeled within the virtual laboratory. The physical experimental apparatus is shown in figure 2. An understanding of the physical laboratory is also essential, so that the created VR model provided an accurate representation of the function of the Hounsfield machine. Due to the large number of files required for the creation of the VR laboratory, a systematic naming convention, directory structures and modification diaries were conceived and implemented to enable work to be organised and completed effectively. All the critical features and components were modeled with full detail. Non-critical components were modeled in less detail to ensure that the file size of the finished product was not unacceptably large.

Figure 2: Hounsfield Tensile Testing Machine and some details

The various stages in the development of the VR experiment is also shown in figure 3. The 3-D solid models were imported into Cosmo-worlds and their appearances edited to make them look similar to the physical apparatus. For the Hounsfield Tensile Testing Virtual Laboratory Experiment the degree of environmental modeling was insignificant. A number of different lighting schemes were investigated before a simple headlight system was deemed sufficient as the functionality rather then aesthetics is the main concern. The key to user interactivity in Cosmo-Worlds are the animations that are present within the virtual laboratory. The interactivity present within the virtual laboratory is generally made up of a number of animations that are triggered depending on the type of user intervention

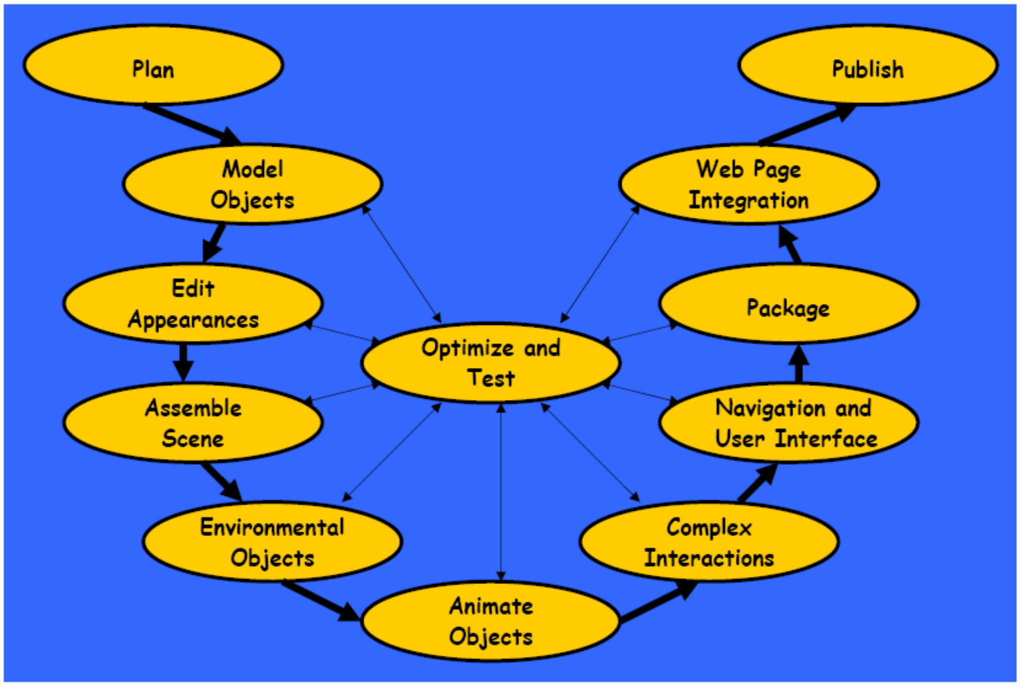

Figure 3: Flow chart representing the development of the VR experiment [10]

In order for the VR experiment to faithfully represent the physical experiment, some complex interactions must be programmed using JavaScript. This is currently not completed. A number of custom views were developed to enable efficient user navigation around the virtual laboratory. Various viewpoints were established to guide the user's attention to the most important aspects of the Hounsfield machine such as the control panel and the two grips that hold the specimen in place for the experiment. Throughout the entire development process a concerted effort was made to test and optimise virtual laboratory revisions. The individual models were initially tested to ensure compatibility with the available browser plug-ins. File packaging, even though a complex task, is fully automated. Once the file is packaged, it can be published for general use. Depending on the medium one wishes to use, the publishing of the package generated above is simply a case of the correct organisation of the created files. A small instructional leaflet was composed to allow first time users to view and interact with the virtual laboratory. Selection of plug-in is crucial to the usability of the VR system. After several attempts, Blaxxun Interactive was chosen as the plug-in for its versatility. This plug-in places all commands under the control of the left and right mouse buttons of the user's mouse, so that there is no need to search for the appropriate control button within the browser. This is a very useful feature and enhances the process of interacting with the virtual environment.

Figure 4 gives the overall view of the components that comprise the Hounsfield Tensile Testing Virtual Laboratory and the instrument panel. Figure 5 shows the tensile test specimen in place and the test in progress.

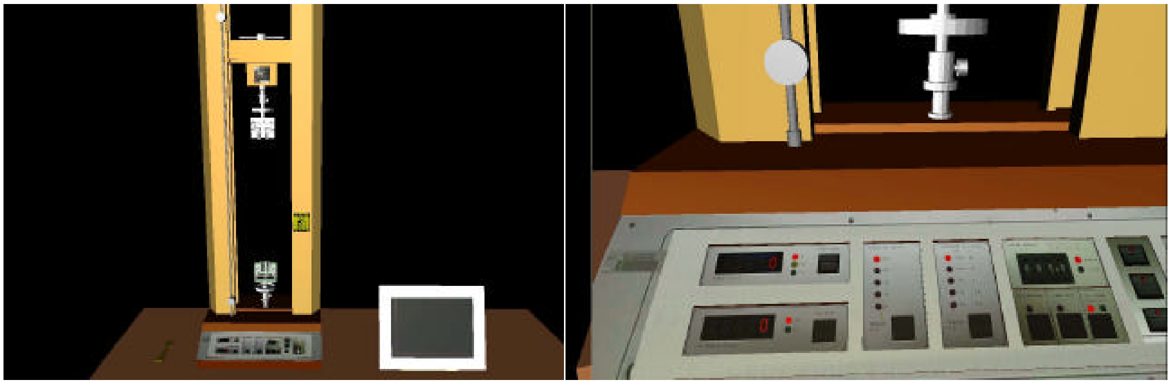

Figure 4: Overall view and the instrument panel of the Tensile Testing VR apparatus

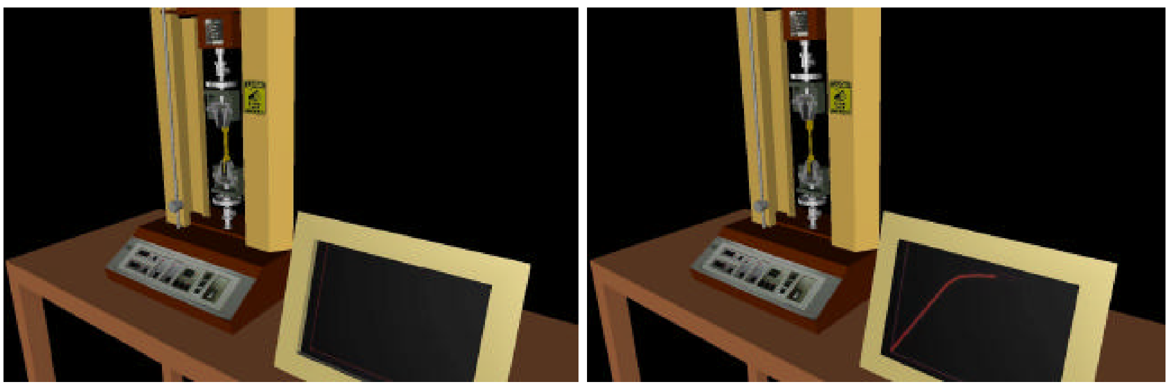

Figure 5: Specimen in the jaws and the test in progress

Current Status and Future Work

The VR experiment has undergone some preliminary evaluation by the authors and not yet released for students use. There are a number of issues that need to be addressed before the system can be released.

- At present, there is only one ductile specimen is available in the VR world. It is desirable to have three or four different specimens of different behaviour.
- Currently there is not enough intelligence in the animations to instruct the student when he/she has done something incorrectly.
- The fineness of animation required to show the actual extension of the specimen with necking (where appropriate) has not been incorporated.
- Even though a short manual was written for the use of the VR experiment, there are no built in instructions or help facility,
- For evaluation purposes, it would be desirable to keep a record of how individual students have performed in the VR experiment.

Conclusion

There is enough evidence in the literature that indicates that a pre-lab assignment is necessary for the students to fully understand the laboratory experiment. The traditional paper based information does not convey the dynamic nature of the experiment and therefore require a more dynamic instrument is required. Simple simulations, which do not truly reflect the behavior of the experimental apparatus, are not useful. The current status of computer technology and the internet provides a way to create a VR experiment. Commercial software is not generally adaptable to the local requirements of the engineering curriculum as shown by the VR-robot. The development of a VR tensile testing experiment is currently under development at the Queensland University of Technology and, with some enhancements, should be ready for release in 2006.

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