TSINGHUA SCIENCE AND TECHNOLOGY
ISSN 1007-0214 42/67 pp261-265
Volume 13, Number S1, October 2008

Development of Virtual Equipment for a Hydraulic Mechanics Experiment

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Abstract: Laboratory class is very important in the education of hydraulic mechanics. However, it usually requires a high expenditure on equipment purchase and maintenance. Virtual equipment that renders the equipment in a virtual world and provides an interactive interface for users can be an ideal solution to reduce costs. In this research, we focus on developing virtual equipment for a Venturi tube experiment. We employed multiple paper-prototypes to gather user feedback on the preliminary design. Following the final prototype, we then implemented the virtual equipment on computers. Interactive functions have been built into the virtual equipment. Users are able to manipulate the equipment and obtain real-time feedback as if they were using actual equipment. The results show that the development of the virtual equipment is technically feasible.

Key words: virtual reality; engineering education; user interface

Introduction

Laboratory class is critical for students learning the abstract concepts and models of hydraulic mechanics. During an experiment, students are able to operate equipment, observe the basic phenomena in flow mechanics, analyze the experimental data, and summarize the results. From this process, students obtain hands-on experience and gain knowledge of theories behind the experiment.

It has been stated in a variety of literatures that the traditional teaching method based on the textbook-chalkboard-homework-test paradigm is not enough for students, especially in the field of engineering. Students in this field require more participating, acting, reacting, and reflecting[1]. However, these skills are not taught in traditional teaching. Therefore, laboratory classes are essential to allow students to obtain these skills. Operating a hydraulics laboratory consumes a great amount of resources. The costs of purchases and maintaining contracts would be very high. We also need to dedicate a spacious room or even construct a special building. In addition, technicians are also required to maintain and examine the equipment. For these reasons, we attempted to develop virtual equipment using virtual reality (VR) technology. We expect the virtual equipment to allow students to operate experiments and receive realistic feedback which will reduce the high operational costs.

The space created using VR has a large effect on a student's learning experience[2,3]. By presenting the content of the theory, it allows the student to constantly repeat and inspect questions and answers at the same time[4-6]. This makes it easy for the student to realize the principles and applications. Students can develop skills through methods such as analyzing and comparing data. VR can allow students to concentrate more, repeatedly practice theory and increase their learning[7,8]. Furthermore, VR is also a huge innovation in engineering education[9].

Received: 2008-05-30
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To create the virtual equipment required to effectively support a student's learning is a great challenge. More specifically, the challenge is that the number and types of computer systems are growing rapidly. The functionality of these systems is being continually enhanced, making them increasingly complex[10]. Many systems no longer support just one function. This division of different systems will increase a user's training. However, using a system with a human-centered design can reduce the amount of training. A good human-centered interface design must let users follow their instincts to operate the system, even with a highly complex system. This can avoid the large of expenses usually spent on systematic training.

1 Venturi Tube Experiment

The Venturi tube experiment has an apparatus to study the Venturi effect. The Venturi effect was observed by an 18th–19th-century Italian physicist, G. B. Venturi. He found that fluid flow speeded up and experienced a pressure drop as it passed through a constriction. The Venturi effect is also an illustration of Bernoulli's principle. In hydraulic dynamics, Bernoulli's principle states that for a fluid, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's gravitational potential energy[11].This principle of the experiment is to verify Bernoulli's equation. In the Venturi effect, the fluid speeds up to meet the equation of continuity, and the pressure drops to satisfy conservation of energy.

Bernoulli's principle is the basis for explaining many engineering phenomena, such as the air flowing over the top of an airplane wing. Therefore, it is important to let a student understand this theorem clearly by conducting a related experiment. This workshop is a basic course in civil engineering at Taiwan University.

G. B. Venturi also designed a simple instrument to observe the Venturi effect, that is, the Venturi tube. This apparatus is a horizontal tube with a narrow throat in the middle as shown in Fig. 1. There is an outlet valve on the right side of the Venturi tube which controls the water flow out of the tube. Under the table there is an inlet valve and a motor. The motor allows for the water to flow into the instrument while the inlet valve controls the water flow. The exit valve is on top of the instrument, which controls the air in the pipes. A typical Venturi tube has an entry cone and an exit cone of 14° and 21°, respectively, as shown in Fig. 2[12].

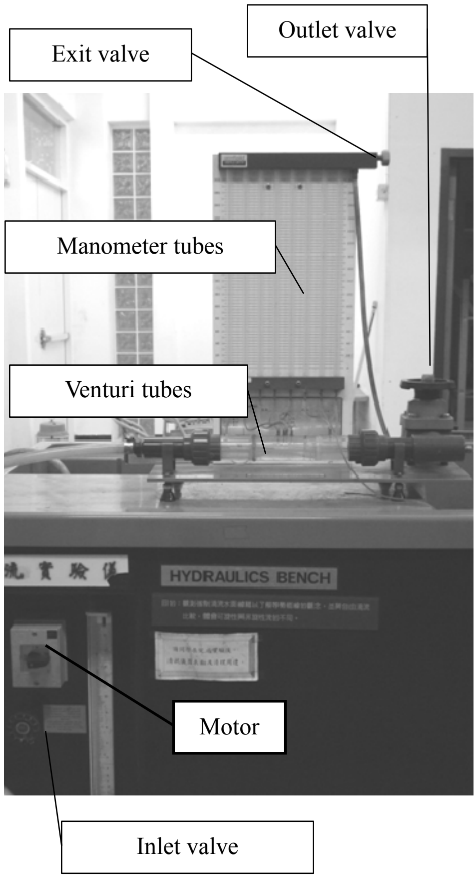


Fig. 1 Venturi tube experimental equipment

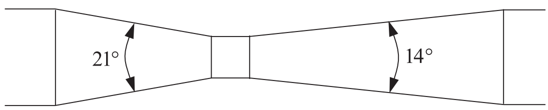


Fig. 2 Degrees of entry and exit cone

In this experiment, we measured the elevation head (h) and flow rate (Q) to compute the fluid speed and the discharge coefficient of the fluid. Students need to follow the instructions step-by-step, such as close the motor and open valves. The process ended with record eight different values from the manometer tubes.

2 Research Method

2.1 Defining the users

First, we determined who the users of the equipment will be, and defined where, when, and how they will use the Venturi virtual equipment. Here, we targeted the students and teachers of a hydraulic mechanics laboratory class. They can use the virtual equipment to enhance teaching and learning.

2.2 Requirements gathering

Our approach to gathering requirements was to conduct interviews with some of our target users. From the interviews, we ascertained their needs and obtained their suggestions for our system. After analyzing and summing up the information for our virtual equipment, we were able list out several goals to achieve. Here, our most important goal was to allow students to preview the experiment before class and to improve the teaching quality of the traditional lab-class.

2.3 Paper prototyping

We separated the processes of the Venturi experiment into several steps and drew the sections on paper. Each section can be presented by a block in the drawing. While drafting each scene, we would consider not only the users' action but also the system's response.

We carried out preliminary designs easily, quickly, and conveniently by drawing our ideas on paper. This allowed us to add or delete the content of the designs at any moment and any place. We used paper prototypes to demonstrate our preliminary design, we translated the experiment process into several scenes, and drew our designs, one scene to a page. This series of paper drawings, displayed in sequence for the purpose of our interactive virtual equipment, is called the storyboard.

2.4 User testing

To conduct user testing, we used equipment pictures and post-it notes, prepared a comfortable testing space, and set up a digital video (DV) and an observer. There is an example in Fig. 3; the background is a real picture of Venturi equipment while the rectangular post-it note below stands for the motor and the two arrows next to the exit valve represent the directions to turn it on and off. When user testing begins, we gave the testers specific tasks to achieve. The observer would then record the testers' behaviors, and the DV would capture the action during the testing. After testing, we would then ask the users to participate in an interview in order to get more suggestions. The interviews and records are helpful for us to refine our system so that we can find a more effective way to present a process to best match users' mental maps. This cycle of testing and revising was performed more than three times.

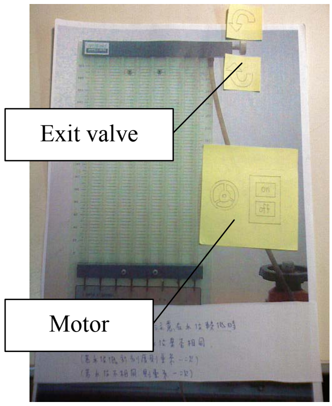


Fig. 3 User testing

2.5 Implementation

The software, 3ds Max[13], was useful for us to develop a 3-D Model. A model that closely imitates the real equipment was constructed according to real proportions. Light and material effects were also added. We then used Virtools[14] to create interactivity in the virtual equipment according our paper prototype. The details regarding these programs will be elaborated on later.

2.6 Research process

Figure 4 shows the process of our research. The first step was to define the users and the last step was our implementation. However, because implementation would never be perfect, we should feedback our results and repeated the process over and over again in order to achieve an ideal result.

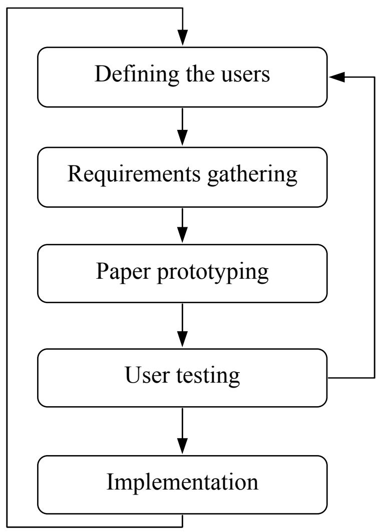


Fig. 4 Flowchart of the research process

3 Implementation

3.1 3-D modeling

We used 3ds Max for 3-D modeling of building virtual environment.

3ds Max is a full-featured 3-D-graphics application developed by Autodesk Media and Entertainment. It is one of the most widely used 3-D-animation programs for architectural and mechanical visualization. It has strong modeling functions and techniques such as extreme, polygon edit and extrude. These techniques allow a modeler to easily shape an object.

3ds Max also benefits from a broad range of tools for key frame and procedural animation that can be used to animate almost any parameter in the scene. 3ds Max can create rich and complex design visualizations.

By following the paper prototype to build the virtual equipment on computer, we created our virtual equipment with 3ds Max using realistic proportions and material texture to make it more realistic. The equipment is modeled after real equipment in the Hydro-tech Research Institute's laboratory. Figure 5 is a demo of our results.

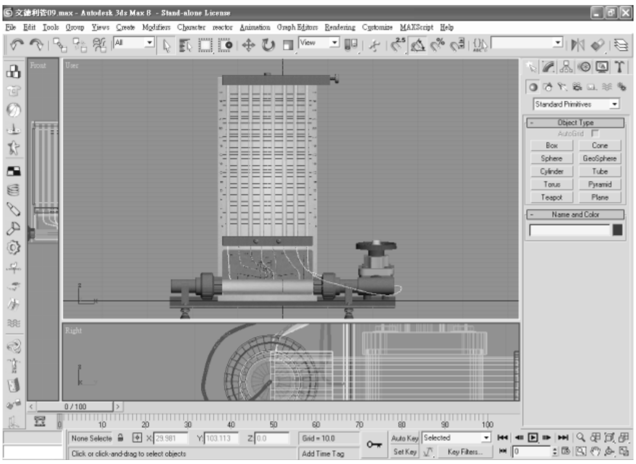
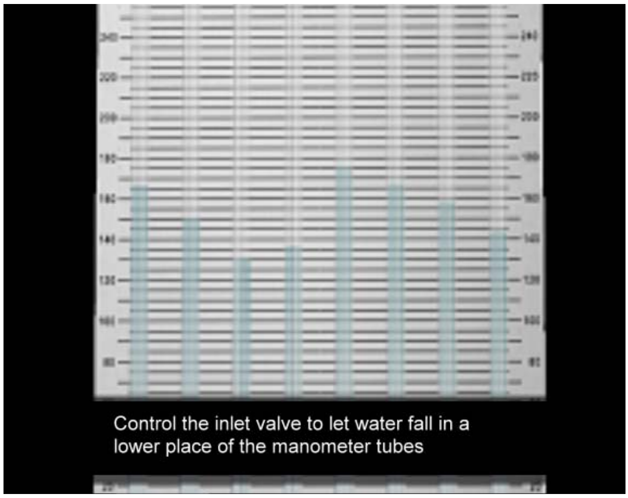


Fig. 5 Virtual equipment in 3ds Max

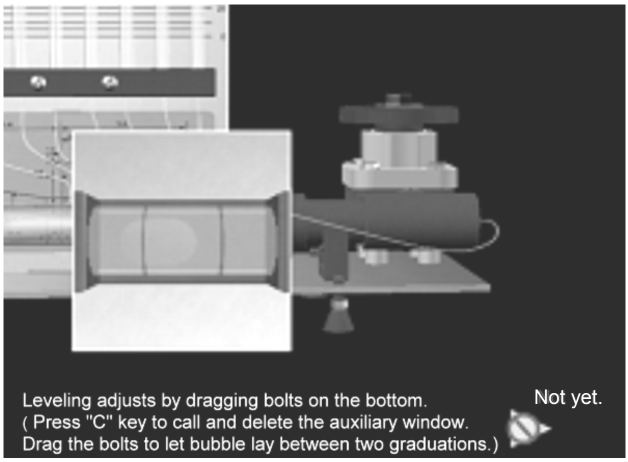
3.2 Building interactive environment

Virtools is an exceptional system for constructing an interactive and real-time virtual reality environment on personal computers, game consoles, and the Internet. Virtools supports a wide variety of 3-D formats. 3-D content capture plug-ins support most commonly used digital compact cassette (DCC) software formats such as 3ds Max and Maya for importing and exporting 3-D XML files, making real-time 3-D technology easily available.

After importing the 3-D models into Virtools, we used it to build a virtual reality world on the Internet. In this world, users can interact with the virtual equipment such as with the real experiment. In Fig. 6(a), tips appear below the window to let the users know how to manipulate the virtual equipment. The users should perform the experiment step-by-step. If the users do not complete the systems requests, they cannot proceed to the next step and the system will return an error message. For example, in Fig. 6(b), the system asks the user to level the equipment, and if the user does not complete the request, an error message appears in bottom-right of the system window.



(a) Control tips



(b) Error message

Fig. 6 Interactive interface of the virtual equipment

4 Conclusions

This paper presents the applications of virtual reality in equipment design and implementation. The virtual model and virtual environment that closely simulates the real equipment and the real lab are demonstrated. The model is constructed with realistic proportions. Light and material effects can be added to make a more realistic model. In the virtual world, we designed a fixed process that leads the users to operate the virtual equipment in the correct way. If they do not follow the instructions of the system, the experiment would not proceed. Since tips and aid-windows are provided, users can operate the system without too much assistance. The method and the user interface we used are an effective way of virtual reality design. Possible future applications of virtual reality equipment are extensive, and the next step would be to apply the system in real teaching.

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