

A generalized procedure to develop a virtual environment for the conducting of hydraulics laboratory experiments

C.Y. Lu, Catherine Kao, S.C. Kang, J. S. Lai and T.H. Lee
National Taiwan University, Taiwan

Abstract

In many engineering fields, laboratory experiment courses are a core aspect of engineering classes. Students can learn basic theories through manipulating the equipment and observing the phenomena in the experiments, cultivating an engineer's keen sense of observation. However, due to high costs and limited numbers of experimental equipment, students must be divided into groups having to take turns to do the experiment, causing a lot of difficulty and inconvenience in conducting this kind of laboratory course. Maneuverable virtual equipment is an ideal approach for providing a feasible alternative to using physical laboratory equipment in courses. Yet such an alternative is not without its challenges. Developing virtual equipment requires mapping experimental procedures from the physical world onto virtual environments. The system developers need to deal with constraints unique to virtual environments, such as limitations in user interfaces and computer calculation speed. It requires effective integration of the expertise between experienced teachers and the 3D system programmers. To achieve this purpose, our research has proposed a generalized procedure for developing virtual equipment and instruments for procedure-based experiments. The procedure has four main phases: (1) observation, (2) storyboard, (3) implementation, and (4) user test; or OSIT in short. To validate the OSIT, it was used to develop and implement virtual equipment for a standard hydraulic experiment, called the Force Vortex Experiment, at National Taiwan University. We found that using OSIT significantly reduced the total elapsed time of communication between instructors and 3D programmers. OSIT also delivered software that better matched users' needs.

Keywords: virtual equipment, hydraulic experiment, engineering education, user centered design

1 Research background

The importance of laboratory work to engineering education is always emphasized (Bordogna, 1998; Buch and Wolff, 2000; Phelps et al., 2008). However, due to expensive and insufficient laboratory equipment and a lack of experienced teachers, students are not able to physically attend the actual experiment and gain laboratory experience. Besides, most experimental courses in engineering classes are procedural-based and usually consist of a number of steps, making it very difficult for a new learner to get an all-encompassing overview of the experiment.

To make up for this deficiency, researchers tried to use VR technology to develop the virtual equipment for teaching and training purposes, such as the computer-based surveying tool (Lu et al., 2009; Elgamal et al., 2005; Schnabel and Thomas 2002; Gao et al., 2009). Virtual reality is the technology which allows a user to interact with an environment that is a simulation of the real world

or an imaginary world. Immersion and interaction, which are the key properties of VR (Ali et al., 2006), was widely used in engineering design to perform visualization of project designs (Shibano et al., 2001; Schnabel and Thomas, 2002).

2 Research challenges

2.1 *Challenges in the techniques of Developing Virtual Equipment*

Developing virtual equipment has two challenges (Chan et al., 2008). The first challenge is to transform the actual equipment from the physical to virtual world. The other major challenge is to transform the complicated experiment procedure in the physical world, with continuous timing, to the virtual world, which operates on discrete timing.

Many researchers attempted to solve the above-mentioned problems by going through the interactive and incremental development and user-centered design approaches (Norman and Stephen, 1986). This approach considered the demands of functions and information in a specific scene, the progressive nature of the way the virtual equipment is designed and the visual representation of the educational system. They allow the students to manipulate equipment which closely replicates the physical equipment's ability to teach engineering technique and theoretical concepts (Lu et al., 2009). To make the educational software clearer in VR, user-centered design processes were used to ensure usability for students and teachers (Gabbard et al., 1999; Stone et al., 2005). We co-operated with the Hydrotech Research Institute of National Taiwan University to develop a series of virtual equipment for a hydraulic mechanics experiment (Chan et al., 2008), which were then applied in the laboratory courses.

2.2 *More challenges in developing the virtual laboratory equipment*

After developing some virtual hydraulic experimental equipment, we found two additional challenges. The first challenge was that the development of the virtual equipment wasted too much time, reducing efficiency. The communication and negotiation between the laboratory teachers and designers, and repeated errors and corrections prolong the time taken for the development. The second challenge was the lack of a unified and effective procedure for developing the virtual systems.

3 Research goals

The goal of this research is to provide a systemized procedure for the development of virtual equipment, which can reduce the time wasted in communication between the laboratory teachers and the virtual system designers, and therefore the time taken for developing the virtual equipment. It can also promote the efficiency of design, reducing the occurrence of failures and corrections, also upgrading the effectiveness and correctness of the virtual equipment.

We developed the Virtual Forced Vortex Experiment using a systematic procedure that we proposed. We aimed to show that the results would verify that our systemized procedures are effective and correct.

4 Proposed OSIT procedure

In response to the aforementioned challenges, which were time wasting and the lack of a systemized development procedure, we proposed a generalized procedure for developing virtual equipment and instruments for procedure-based experiments. This procedure has 4 main phases: (1) observation, (2) storyboard, (3) implementation and (4) user test; or OSIT in short.

4.1 Overview of OSIT procedure

Figure 1 is a flow chart of the OSIT procedure. The real world and virtual world are interconnected by the OSIT procedure presented between two dotted lines. The first phase is the *Observation phase*. Team members observe the real experiment and create a 3D model of the equipment. The dual direction workflow between observation and storyboard represents interaction between both phases in the real world. All observation data of the real world is input to *Storyboard phase* and transformed into *storyboard script*. Storyboard script is the specification and guidance for designers to transform the real world to virtual world through the single direction workflow. In the *Implementation phase* the designer will develop a user interface and logic programming to create the virtual equipment. Finally, the user operates the virtual equipment in the real world to verify the effectiveness of the virtual system.

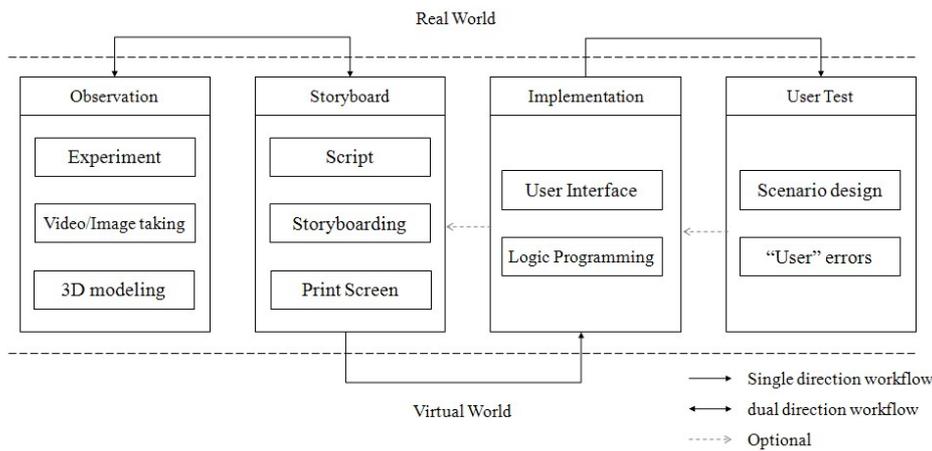


Figure 1. OSIT procedure flow chart.

In the OSIT procedure, the participants are separated into four groups: (1) Professors, (2) Teaching Assistants, (3) Designers and (4) Students. In Table 1, we provide clear roles and assignments for each member in each phase of the OSIT procedure.

Table 1. Roles and Assignments in the OSIT procedure.

Phase	Participants			
	Professor	Teaching Assistant	Designer	Students
Observation	theory and contents of laboratory course	operating process of experiment	3D Modeling of equipment	
Storyboard	physical phenomena of experiment	concept of user interfaces	concept of interactive techniques	
Implementation			develop virtual equipment	
User Test		observe user test		test virtual equipment

Professor: Provide the theory and content of the experiment courses and analyze the theories in the *Observation phase*. Provide accurate phenomena that reflect the theory in the *Storyboard phase*.

Teaching Assistant: Observe procedures and actions at each step and collect the experiences in the *Observation phase*. Map out the storyboard script; provide the interactive interface requirements in *Storyboard phase*, and observe the user test procedure in *User test phase*.

Designers: Do 3D modeling in *Observation phase*, and provide a method of interaction in the virtual equipment's design during the *Storyboard phase*. Proceed with design of interactive interface and virtual equipment in *Implementation phase*.

User test: Operate the virtual equipment to verify the effectiveness of the OSIT procedure.

In the following subsections we explain in detail the four phases: Observation, Storyboard, Implementation and User test.

4.2 *Observation phase*

The team observes the real equipment and the operating procedures in each stage and measures the dimensions in detail. All reactions and phenomena that would occur in the real equipment should be carefully recorded by camera or video camera. The outcome of the observation phase provides the source material for analyzing and drafting the storyboard script in the *Storyboard phase*.

Designers start 3D modelling in the observation phase and complete it before the storyboard phase. Designers use the data of real equipment to create the 3D model.

4.3 *Storyboard phase*

Teaching assistants use data and information from the actual experiment to draft the preliminary storyboard script in four categories: (1) Real experimental process, (2) User's action in virtual world, (3) Screen response to user's action and (4) Logic (decision to pass or not). Designers create snapshots of the 3D model for each real experimental process. All participants then discuss each storyboard category based on the preliminary storyboard script and snapshots. Finally, a complete storyboard script is created.

Real experimental process: Teaching Assistants simplify the real procedures and divide them into sequential processes so that students can manipulate the virtual experiment step by step.

User's virtual actions: Students need to execute the operations in the virtual interface. The operations include manipulating the components, installing the accessories and measuring. Through the user's action in the virtual world, he or she can practice every process in real world.

Screen response to user's action: When the user executes the process, the screen will display how the real equipment should react, such as by changing the height or moving a component. It will also present the physical phenomena, such as the rotation of water and paddle or water spray, as it would appear in the real world.

Logic: If the user had completed and fulfilled what was required in the process, the logic will be "1" and enter the next procedure. Otherwise, the logic will be "0" and user will be required to repeat the same process.

After the storyboard script is finalized, designers then implement the outcome of the storyboard.

4.4 *Implementation phase*

After the storyboard script is finalized, designers will proceed to develop the virtual equipment, design the interactive interface and develop the logic of the virtual equipment.

The storyboard script describes every process. A well-designed experimental procedure can help the beginners get familiar with the experiment quickly (Koretsky et al., 2008). The storyboard puts all the scenarios in a sequential format and analyzes the contents of every process, describing the physical representation that should appear in the screen, and discussing the interactive effects. It can provide the designer of the storyboard and the designer of the virtual equipment a direct communication channel and immediately reflect the problems in the development of the virtual equipment (Pablo et al., 2008). The experience will be fed back to the storyboard phase as a reference for future improvement.

4.5 User test phase

When the virtual equipment is completed, eight randomly selected testers shall proceed with a scenario test. The goal of the user test is to check the completeness and effectiveness of the virtual experiment. The user’s operating experience and the feedback of errors can be a reference for the modification of the virtual equipment.

5 Implementation

In accordance with the OSIT procedure, we continue with the design and development of interactive virtual equipment for the Forced Vortex Experiment (FVE). Following is the progress of our research:

In the OSIT matrix as listed in Table 2, we can clearly see the role and job assignment of each participant in different phases. The team proceeds with the OSIT procedure for the FVE as follows:

Table 2. OSIT matrix in developing the forced vortex equipment

Phase	Participants			
	Professor	Teaching Assistant	Designer	Students
Observation	Prof. T. H. Lee provides the theory and purpose of the experiment.	Observes the construction and operation of FVE. Takes photos and videos of the equipment and the operation procedures.	Develops the 3D model. Discusses the accuracy of the 3D model of the FVE with Teaching Assistants.	
Storyboard	Advices and instructs on the physical phenomena of the fluid, and discusses the Storyboard Script.	Drafts the preliminary Storyboard Script (S.S.) Discusses and revises the S.S with the Professor and Designers until satisfactory results are achieved.	Advices on the virtualization of the physical phenomena of the fluid. Provides a snapshot for review.	
Implementation	Accepts the final virtual FVE upon satisfactory inspection.	Accepts the final Virtual FVE upon satisfactory inspection.	Develops the virtual FVE in accordance with the final Storyboard Script.	
User Test		Observes the user test procedure.		Uses the Virtual FVE.

5.1 Observation phase

Professor T.H. Lee provided the experimental theories, goals and the physical phenomena of the fluid in Forced Vortex Experiment. The Teaching Assistants observed and operated the vortex experiment in the laboratory. They also recorded the key points of the experiment, measured dimensions, took photographs and videos of the equipment and the operation procedures, and drafted the storyboard script. Designers developed the 3D model with the 3ds MAX in accordance with the observed information and suggestions made by the Teaching Assistants. Through observing the video tape, the designer noticed that every accessory had its own function and ensured it was separated as independent component, in case a related interactive effect was needed later on in the process.

5.2 Storyboard phase

The Teaching Assistants divided the real experimental procedures into many sequential processes, such as setting up and adjusting the equipment, installing the accessories and feeding the water. All the processes were filled in the first column, entitled ‘Real experimental processes’, in the storyboard script. For each process in the first column, the corresponding action that the user should perform on the virtual equipment was filled in at the second column, entitled ‘User’s action in virtual world’. The contents of the third column, ‘Screen response to user actions’, and the fourth column, ‘Logic – pass/fail’ were decided accordingly and an initial draft of the preliminary storyboard script completed.

Teaching assistants, professors, and designers discussed the contents of the preliminary storyboard script with the aid of the snapshots of the preliminary 3D model provided by the designer. After many discussions and much brainstorming they finalized the storyboard script for the FVE virtual equipment.

In the beginning we drafted a storyboard script with 8 processes. However, after some discussion we found many problems, such as: (1) the level screws in the window did not link to the main equipment, (2) a ruler should be shown on the screen for measurement, (3) the switch of the pump

should be an on-off push button instead of a knob to twist, (4) the water spray should occur when the depth gauges touch water level, and (5) to enable student to realize the correctness, a comparison between measured figure and computer should be presented. After repeated discussion the storyboard script was increased to 10 processes, and a finalized storyboard script was decided on.

5.3 Implementation phase

The designer proceeded to design the virtual Forced Vortex Experiment (FVE) based on the final storyboard script. The designer started by modifying the 3D model as required in storyboard phase at first and then imported the 3D model into Quest3D. Later on, the designer followed the 10 processes in the storyboard script to design the virtual experimental processes and created the operational interfaces, establishing the interactive system. Every process presented in the virtual interactive environment looked exactly like real equipment and allowed imitating real world operations.

By adopting the systemized OSIT procedures, many scenarios can be found and listed at the first two phases, *Observation* and *Storyboard*. A system designer, who lacks hydraulic experimental knowledge, can get acquainted with the structure and content of the experiment, precisely and correctly divide every process of the whole experiment and clearly understand the functions and pictures that should be presented at every process. Therefore, at the *Implementation phase* there is less necessity to get a hydraulic expert involved.

Figure 2 and Figure 3 are snapshots of the Forced Vortex Experiment developed in our research.



Figure 2. Whole scene of FEV

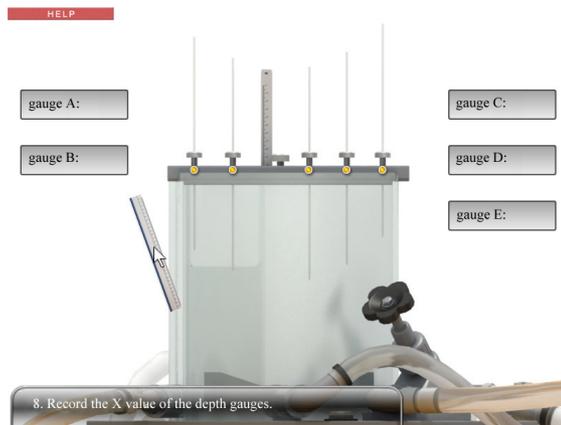


Figure 3. Cylinder of FEV

6 Perspective work

At present our research has completed the construction of the virtual FVE equipment and the interactive experiment software. Our final goal is to put the system onto a website. Teachers and students can manipulate the Forced Vortex Experiment instantly via the website.

We plan to conduct user tests of the virtual vortex experimental equipment as part of our continuing research. We wish to confirm the completeness and effectiveness of the virtual equipment via this testing. We wish to realize whether students can relate to the experimental processes via the instruction of experimental procedures through the interactive scenarios, thereby acquiring a learning effect equal to that offered by a real laboratory. More importantly, we wish to investigate whether there is a need to modify the categories in the storyboard script or add more columns, in order to promote the function of the storyboard script in providing correct message to designers. And it could also be a reference material for others to make a storyboard script.

7 Conclusion

The major contribution of this research is a systemized procedure for the development of virtual experiment equipment for education purposes. The procedure proposed in this study has been named the OSIT procedure. This procedure clearly separates the whole development procedure into four phases: Observation, Storyboard, Implementation, and User test. The roles of all developers, including the professors, teaching assistants, system designers and students have also been clearly defined. In this research, we applied the OSIT procedure to a real case: developing virtual equipment for the Forced Vortex Experiment (FVE), a basic experiment in the hydraulics laboratory. We found that the OSIT can enhance the communications between the project participants so the quality of the product was improved and project duration was reduced. In the future, we believe that the OSIT procedure and our experiences can be reused to develop other types of virtual equipment, especially for those experiments involving complicated procedures.

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