SIMUSURVEY: A COMPUTER-BASED SIMULATOR FOR SURVEY TRAINING

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ABSTRACT: *This paper presents the development of a computer-based simulator for survey training, referred to as SimuSurvey. Because modern survey instruments are usually expensive, difficult to maintain, and sensitive to weather conditions, surveying course instructors often find it difficult to supply sufficient high-quality instruments for the class. Also, the instructors often suffer the need to repeat similar instructions about instrument operations to individual students; and, lack a good means of recording each student's learning progress. SimuSurvey was designed to address these issues - for use in survey training in a computer-generated virtual environment at a low cost. The functions currently provided by SimuSurvey include: (1) the visualization of a survey instrument and measurement poles involved in an assigned survey task; (2) the simulation of the control interface of a real surveying instrument; (3) the recording of each student's performed operations; and (4) design of learning activities for students to practice surveying tasks in a simulated environment. The focus of this paper is on the design and implementation of SimuSurvey. An example is provided to demonstrate the applicability and effectiveness of SimuSurvey to survey training.*

KEYWORDS: *simulator, survey training, engineering education, virtual reality, augmented reality.*

1 INTRODUCTION

The surveying course is an important core course for most vocational schools and universities in the field of civil engineering and architecture in Taiwan. A typical surveying course includes both indoor instruction, which covers surveying related theories, and outdoor fieldwork, which provides students with opportunities to familiarize themselves with the proper use of surveying instruments (Noéh 1999). As information technology has advances significantly and students' learning styles evolve, adjustment of the survey training method is needed if more effective training is to be achieved (Muench 2006, Ghilani 2000, Noéh 1999).

In the state-of-practice for survey training, survey instruments are expensive, difficult to maintain, and sensitive to weather conditions. Surveying course instructors often find it challenging to make high-quality instruments available to the class. Furthermore, Wang (2005) indicates on-the-job like methods only give novices a limited opportunity to experience real working conditions. In order to solve this problem, computer modeling technologies are sought after to meet the stringent challenges in equipment operation training. Training in a virtual environment can be valuable where training in real life situations would be impractical because a real field scenario may be dangerous, logistically difficult, unduly expensive or too difficult to control.

With the advancement of computer graphics technologies, recent investigators have developed various computer-based simulators. Simlog (2004) developed a desktop VR-based personal tower crane simulator for training. Wang et al. (2004) conceptually designed an augmented reality based operator training system to offer an augmented workspace by inserting images of virtual entities into the existing real working environment. Lehner (1996) presented a distributed virtual environment developed for caterpillars where participants communicated and collaborated in designing caterpillar products. Considering the established needs for operator training in the construction industry and the speed of internet data transmission, Bernold et al. (2002) developed an internet-based backhoe operator trainer that offers a remotely located novice backhoe operator the opportunity to manipulate a laboratory excavator via a joystick. Keskinen et al. (2000) presented a man-in-loop simulator to be used in operator training for accurate boom maneuvers of a hydraulic elevating platform. Other studies, such as Chau (2007), Kang and Miranda (2006), Hsieh et al. (2005), Chen et al. (2004), and Penumadu et al. (2000), also demonstrate the benefit of computer-aided instruction tools in engineering education.

Based on the successful experiences learned from the aforementioned investigators, a computer-based simulator, *SimuSurvey,* has been developed in this work for the purpose of facilitating survey training in a computer-generated virtual environment. A simulator is a device used specifically in training to reproduce the conditions of the working situation, enabling tasks to be learned and practiced safely and economically. Because *SimuSurvey* was designed mainly for educational purposes, its functional design must meet the requirements of teaching and learning in survey training.

Five subsystems were designed into *SimuSurvey* to support training activities. They are: (1) the level simulator; (2) the theodolite simulator; (3) the accessory simulator; (4) the total station simulator; and (5) the tangible controller. This high-fidelity simulation environment aims to enrich students' learning experiences and enhance learning results.

Following, the user interface design for *SimuSurvey* is briefly introduced. The system design and implementation of *SimuSurvey* are then discussed. Finally, an example is presented to demonstrate how *SimuSurvey* can be effectively applied to assist teaching and learning in survey training.

2 USER INTERFACE DESIGN PROCEDURE

In this study, the concept of user-centered design was introduced for designing the *SimuSurvey* user interface. The design procedure is shown in Figure 1. Three major steps are followed: requirements analysis, design, and prototype and evaluation. In each step, the designer works closely with users to ensure the users' needs are satisfied.
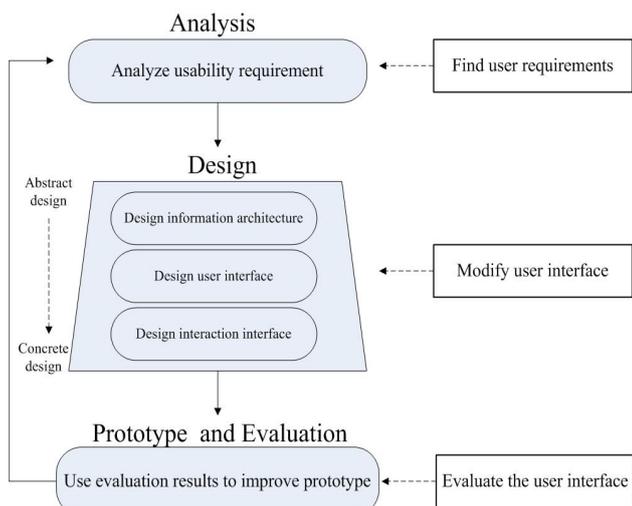

Figure 1. The user-centered design process used in *SimuSurvey*.

For the first step, analysis, we interviewed experienced instructors, college students, and instrument technicians to determine the target users' requirements. The four major requirements are summarized:

- The survey instrument and measurement poles involved in an assigned surveying task need be visualized.
- The control interface needs to be as similar as possible to that of real surveying instruments.
- Users' operation procedures should be recorded.
- The instructors should be able to, through a flexible interface, design learning activities so that students can practice the designed survey tasks in a simulated environment.

The second step, design, moves a project from understanding problems to envisioning solutions. In our study, we organized the design step into three more-or-less ordered sub-steps. First, we designed an information architecture that focuses on functionality, refraining from

specifying details about what *SimuSurvey* will look like or how users will manipulate it. The second sub-step focused on the design of the graphical user interface (GUI). In this sub-step, our main concern was how to display information in the most desired way. The interface layout, button arrangement, and color scheme used in the interface need to be carefully considered. Finally, in the third sub-step, the interaction between the users and the interface was considered.

After the interface design is complete, the third step, prototype and evaluation, is carried out to confirm that users are able to achieve their goals using the designed interface. Re-design is needed if usability problems are found in the evaluation process. To accelerate the redesign process, we used paper-based prototypes to test multiple proposed solutions with users. This type of prototype is called a low-fidelity prototype, that is, a rough sketch, and has been broadly used in GUI design. Although details of system interaction are not specified in the low-fidelity prototype, users can still evaluate the sketch in the context of a particular scenario. Potential users are able to read the scenario and use the low-fidelity prototype as an aid while considering whether or not the interface meets their requirements, and, how it can be developed to meet their information and interaction needs.

3 ARCHITECTURE OF *SIMUSURVEY*

The architecture of *SimuSurvey* is shown in Figure 2. The top level in the architecture is the user interface, which is the layer between the system and the users. The second level consists of the system functions, including visualization, virtual environment setup, learning behavior record, virtual surveying instrument control, and multi language interface. The third level is the system running environment. Since system functions of *SimuSurvey* are implemented using C# programming language (Liberty 2006) and OpenGL computer graphics library (Shreiner et al. 2005), *SimuSurvey* can run in all environments that support the .Net framework for C# and OpenGL run time libraries. The concept of C# application running in .Net framework is similar to Java applications running in Java virtual machine. The use of the bytecode (Meyer, 1997) is for reducing the dependency of an application on an operating system.
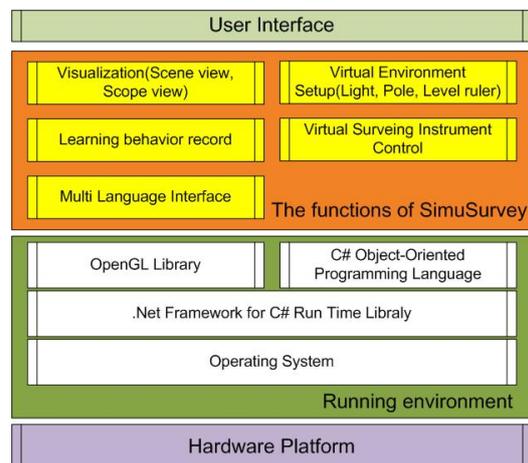

Figure 2. The architecture of *SimuSurvey*.

4 SYSTEM DESIGN AND IMPLEMENTATION

In developing *SimuSurvey*, we first need to model and visualize the survey instruments on computer. Then, a scene visualization module is needed to allow instructors to create a training scene in the virtual environment. In addition, we need functions for setting up the designed learning activities in the virtual environment, and for recording users' operational behaviors. The following subsections discuss the design and implementation of these functions and modules in *SimuSurvey*.

4.1 *Virtual instrument modeling and control*

Virtual Instrument is an instrument model constructed in a virtual environment. This model aims to offer the trainees a learning tool that has behaviors similar to that of a real survey instrument. In this research, the virtual instrument is modeled by a simplified geometric form of a real survey instrument. The geometry consists of rectangular cubes, cylinders, and cones, using the *SolidCube*, *SolidCylinder* and *SolidCone* subroutines of the OpenGL graphics library.

Figure 3 shows the modeling, in *SimuSurvey*, of a theodolite, currently the most important and accurate instrument for angle measurement (Fialoszky 1990). As shown in Figure 3(a), the theodolite is placed on top of a tripod with two coordinate frames, one is the global coordinate frame and the other is the local coordinate frame 0, located at the center of the tripod base. The theodolite consists of three parts: the top, central, and bottom parts.

Figure 3(b) shows the top part of the theodolite. It consists of a housing, standards, telescope, vertical circle and an eye piece focus. Two coordinate frames are designed to simulate the behavior of the telescope, as shown in Figure 3(c). Coordinate frame 5 is located at the geometric center of the theodolite. The variable Z_{0-5} represents the distance along the Z direction between the coordinate frame 0 and coordinate frame 5 and is used to model the height of the virtual instrument. The variable θ_5 of frame 5 is used to control the rotation of the telescope, while the variable θ_6 of frame 6 is used to simulate the focal distance control.

Figure 3(d) shows the tripod model used to provide a stable and rigid support with rough horizontal alignment for a survey instrument in the virtual environment. It consists of three legs and a head. Three coordinate frames are designed to simulate the behavior of the tripod, as shown in Figure 3(e). The variable θ_9 of frame 9 is used to simulate the expanding angle of one of the tripod legs. The variable X_{9-12} represents the distance along the X direction between coordinate frame 9 and coordinate frame 12 and is used to simulate the extension length of one of the tripod legs. Coordinate frame 3 is located at the center of the tripod head for linking with the theodolite.

Figure 3(f) shows the bottom part, central part, and a section of the top part of the theodolite. The bottom part is used to connect the tripod to the rest of the theodolite. The central part of the theodolite consists of the horizontal circle and an element on top for supporting the rotation axis of the telescope and for facilitating rotation of the central part about the vertical axis. As shown in Figure

3(g), the variable θ_2 of frame 2 is used to represent the initial angle of the horizontal circle, while the variable θ_4 of frame 2 is used to simulate the rotation angle of the horizontal circle. Table 1 summarizes the variables used for modeling the virtual theodolite on a tripod.

In addition, as shown in Figure 4, a control panel has also been designed as a user interface for manipulating the virtual instrument.

Table 1. The variables for modeling the virtual theodolite on a tripod.

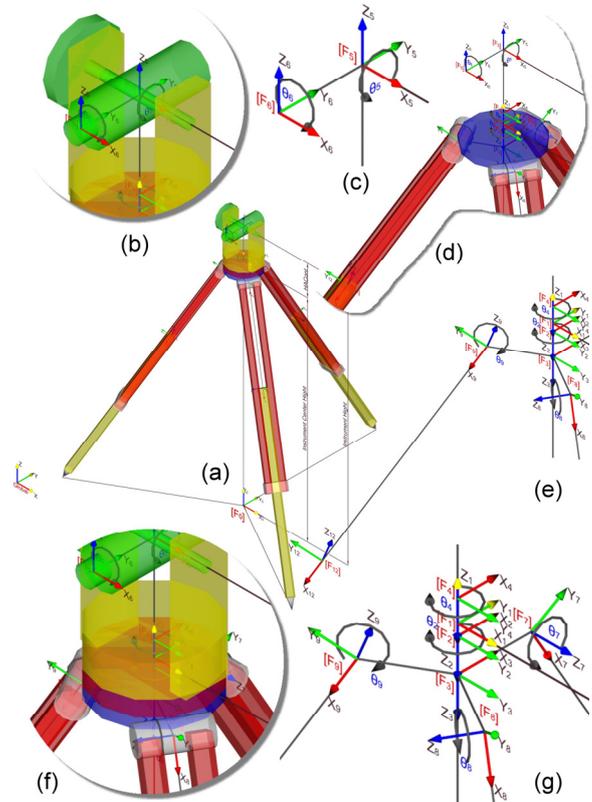| Variable	Representation
θ_2	The initial angle of the horizontal circle
θ_4	The rotation angle of the horizontal circle
θ_5	The vertical rotation angle of the telescope
θ_6	The control for focal distance
$\theta_7, \theta_8, \theta_9$	The expansion angles of tripod legs
$X_{7-10}, X_{8-11}, X_{9-12},$	The extension lengths of tripod legs
Z_{0-5}	The instrument height of the theodolite

Figure 3. Modeling of a virtual instrument in *SimuSurvey*.
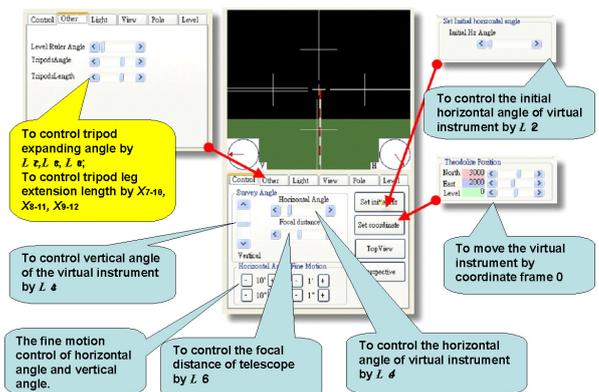

Figure 4. The interface for controlling the virtual instrument.

4.2 Scene visualization

The main purpose of the Scene Visualization module is to provide users with a simulation environment for practicing surveying tasks. The Scene Visualization module provides a view controller to allow users to select the top view, front view, right view, and perspective view during operation. Since the surveying tasks can be easily shown in different views, this module can also assist instructors in demonstrating examples and explaining surveying concepts more clearly.

The visualization interface of *SimuSurvey* allows users to practice two important surveying skills: aiming toward a target and reading through the telescopic eyepiece. Users are allowed to zoom in and out on the scope view, as shown in Figure 5(a), by adjusting the telescope focus value on the virtual instrument. In order to better visualize the horizontal and vertical alignment angles of the virtual instrument, we draw two circles, named V-circle and H-circle, as shown in Figure 5(a), for displaying the values of the vertical and horizontal angles respectively. Figure 5(b) shows the View control interface of *SimuSurvey* that allows users to shift between top, front, right and perspective views, as shown in Figure 5(c), 5(d), 5(e), and 5(f), respectively.
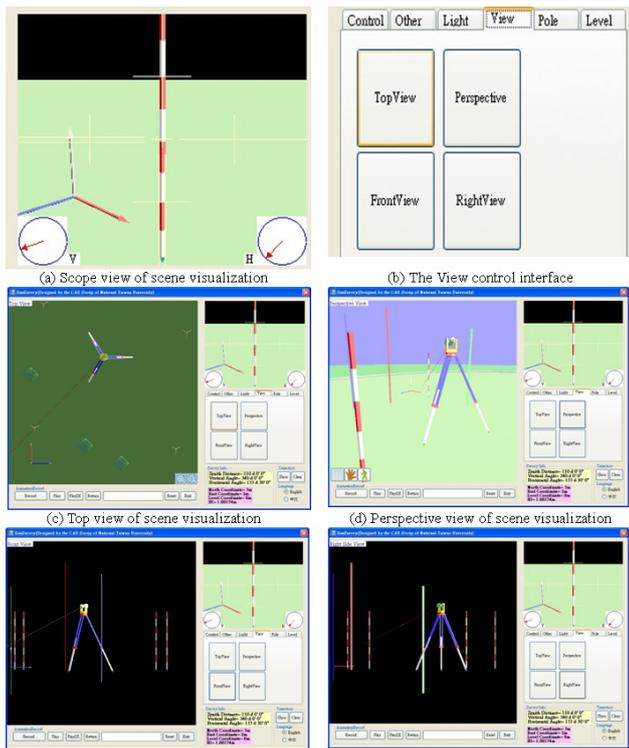

(a) Scope view of scene visualization   (b) The View control interface

(c) Top view of scene visualization   (d) Perspective view of scene visualization

Figure 5. Scene visualization of *SimuSurvey*.

4.3 Virtual environment setup

The function of Virtual Environment Setup is to provide an interface for instructors to design learning activities for students to practice survey tasks in a simulated environment. Figure 6(a) and 6(b) show a virtual surveying training environment before and after the setup of measurement poles and level rulers.

SimuSurvey provides three functions for setting up the virtual environment. The first function is designed for controlling the lighting in the virtual environment. This function simulates real lighting by allowing for change of the position and color of the lights in the virtual environment. The second function is designed for setting up the measurement poles, the reference targets commonly used in surveying practice, as shown in Figure 6(c). The third function, as shown in Figure 6(d), is designed for setting up the position of the level ruler, a vertical ruler used for measuring the distance from the ground.

With *SimuSurvey,* instructors are able to set up various practice scenes for students using a standard personal computer setup. The preparation time was found to be much less than that needed in setting up a practice environment in the field. Students can also benefit from the use of *SimuSurvey* because they can practice more examples for better understanding of the concepts and operational procedures.
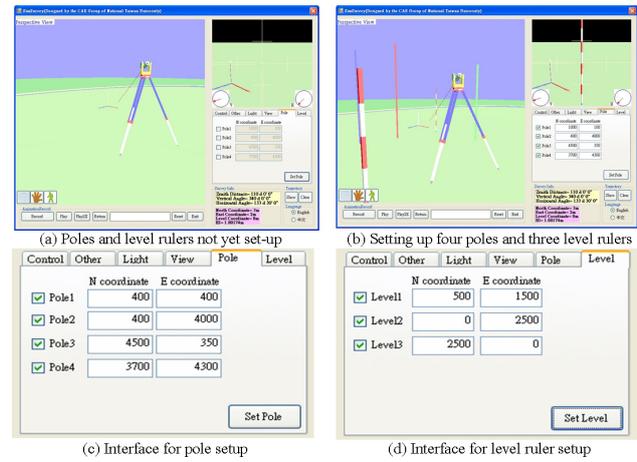

(a) Poles and level rulers not yet set-up   (b) Setting up four poles and three level rulers

(c) Interface for pole setup   (d) Interface for level ruler setup

Figure 6. Setting up poles and level rules in the virtual environment.

4.4 Learning behavior recorder

In most training for surveyors, the trainees learn the skills to operate the equipment by following the steps: (1) observe the trainer's demonstration of standard operation procedure; (2) imitate that operation procedure step by step; and (3) repeat the whole procedure without assistance from the instructor. One of the most important tasks for an instructor is to follow the learning progress for each and every student in the class. However, in Taiwan most vocational schools today, an instructor needs to simultaneously train as many as 40 students. It is very cumbersome for them to monitor the students' learning progress.

In most cases, the instructor assigns trainees a surveying task, and then examines whether or not they have successfully completed this task. However, this method only allows the instructor to check whether the final state of the instrument meets the standard. Should the surveying result be incorrect, instructors have few clues to find when and where the task went wrong. Therefore, we implemented, in *SimuSurvey*, a function that records the history of the user's performed operations.

Figure 7(a) shows the interface of the Learning Behavior Recorder. This interface allows users to record and playback operations performed on the virtual instrument. Instead of recording the animation frame by frame, we parameterize the operations and store them on the hard disk.

In this way, the required storage space is significantly reduced. While users replay the operation, *SimuSurvey* will read the time history of the parameters, as shown in Figure 7(b), decode them and generate the animation in real time. This function allows the instructor to review the details of each trainee's operations and locate where they went wrong. Students can also use this function to review standard procedures, and practice them for reinforcement.
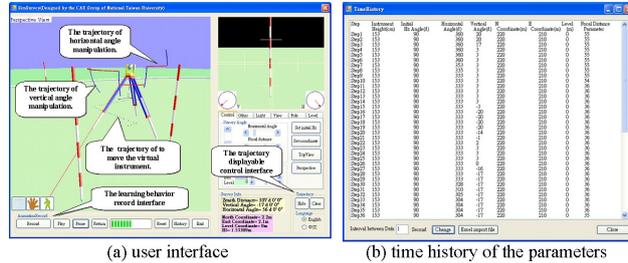

(a) user interface   (b) time history of the parameters

Figure 7. Learning Behavior Record in *SimuSurvey*.

5 APPLICATION EXAMPLE

To verify the feasibility of the system, we developed an application example that supports teaching activity during surveyor training. In this example we measure azimuth, the direction of a line as given by an angle measured clockwise from the north end of meridian (Kavanagh and Bird 1996). However, the real survey fieldwork, the north direction cannot be obtained directly. Surveyor has to calculate the north direction from known coordinates. Based on the authors' teaching experience, the azimuth concept and the procedure of obtaining north direction are not easy to explain to a novice surveyor. By introducing the interactive environment provided in *SimuSurvey*, instructors can more effectively demonstrate the azimuth concept.

Here we use an example to demonstrate an azimuth measurement problem, as showing in figure 9(a). Imagine two points, point A and point B. The North-East (NE) coordinate of point A is $A(N_A, E_A) = (3000, 400)$. The NE coordinate of point B is $B(N_B, E_B) = (400, 3000)$.

We used *SimuSurvey* to demonstrate how to find the azimuth (φ_{AB}) and reverse-azimuth (φ_{BA}). First, we will change the scene window to the top view using the View Control Interface. And next, set two poles in the virtual environment, one is at coordinate $A(N_A, E_A)=(3000, 400)$, and the other is at coordinate $B(N_B, E_B)=(400, 3000)$. After setting the poles, we move the virtual instrument to coordinate A(3000, 400) and set the initial direction of the horizontal circle target at the north direction. Next, we clockwise turn the horizontal circle target toward coordinate B(400, 3000). Now the user can read the horizontal angle as 135°00'00" from the surveying information windows, as showing in figure 8(b). Because the initial direction of the horizontal circle is targeted to the north direction, the azimuth (φ_{AB}) from A to B is equal to horizontal angle.

To demonstrate finding the reverse-azimuth, we move the virtual instrument from coordinate A to coordinate B, and clockwise turn the horizontal circle target toward coordinate A. The azimuth (φ_{BA}) form B to A is 315°00'00"

shown in the survey information window, as shown in figure 8(b). The reverse-azimuth (φ_{AB}) from A to B is equal to azimuth (φ_{BA}) from B to A, 315°00'00". The reverse-azimuth (φ_{AB}) that is to reverse and azimuth (φ_{AB}) add 180° to the original direction. Their relationship can be expressed as:

Reverse-azimuth (φ_{AB}) = Azimuth (φ_{AB}) + 180°   (1)

This application example of *SimuSurvey* was tested in the surveying class at Daan Vocational High School, a well-known surveyor training institute in Taiwan. After the class, the students were asked to fill out a questionnaire, to assess their learning motivation and to take a quiz to measure whether or not they had correctly learned the concept. The results of questionnaire reveal that 91% of the students agree (including strongly agree and agree) that the virtual instrument can be of benefit to their learning. The scores of the quiz indicated that 66% of the students could answer the questions about azimuth correctly. From the authors' experiences, the results are superior to those of traditional teaching methods.
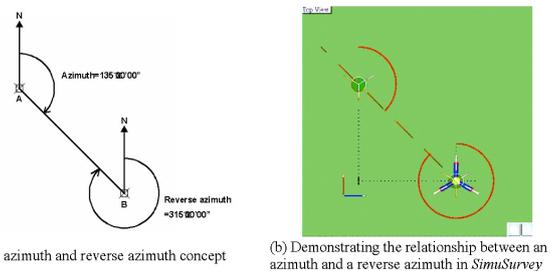

(a) The azimuth and reverse azimuth concept   (b) Demonstrating the relationship between an azimuth and a reverse azimuth in *SimuSurvey*

Figure 8. The azimuth and reverse-azimuth example.

6 CONCLUSIONS

In this paper, the development and application of SimuSurvey, a computer-based simulator for surveying training, have been presented. The user-interface and functional components of SimuSurvey have been carefully designed to meet the needs of teaching and learning in surveying training. Therefore, both the instructors and students can benefit greatly from the designed functions of SimuSurvey. The functions provided by SimuSurvey allow the instructors not only to demonstrate the concepts and operational procedures of a survey instrument more effectively than traditional methods but also to flexibly design learning activities for the students to practice, so they can learn efficiently in a convenient environment. Moreover, SimuSurvey can record the history of each student's operations allowing instructors to analyze and identify the common learning problems of the students. In addition, the implementation of SimuSurvey allows it to be run in all environments that support the .Net framework for C# and OpenGL run time libraries.

In the application example provided in the paper, we have demonstrated how to use SimuSurvey for teaching the concept of azimuth, one of the most difficult concepts for novice surveyors. We have also tested SimuSurvey in the Survey course teaching at Daan Vocational High School in Taipei. The preliminary results indicate that both the students' motivation to learn and their technical results are significantly better than those using the traditional

teaching approach. More thorough investigation on the effectiveness of applying SimuSurvey in surveyor training is currently underway and the results will be reported in a future paper.

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