EVALUATION OF INTERACTION DEVICES FOR NDI TRAINING IN VR: GAMEPAD VS. JOYSTICK

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Recent advances have led to the development of a virtual simulator to be used for non-destructive inspection (NDI) training of aviation maintenance technicians. The simulator is distinctive in that it has been developed to simulate a general type of NDI job aiding tool (video borescope), as opposed to only simulating a precise model and make. By generating a simulator based on a generic model of the video borescope, the development process must face a common hurdle: determining the best interaction device for the task at hand. In the real world, video borescopes come in a variety of shapes and sizes, as do their interaction devices. In this case, the team must decide upon the best interaction device to be used while ensuring the retention of inspection information from training and facilitating interaction ease of use, all while not permanently engraining the skills that will be needed to control the actual devices when actually used. In short, the interaction device chosen for this simulator should facilitate the trainee's ability to learn NDI techniques without hardwiring simulator control techniques which can vary greatly in the real world. In an effort to determine the most applicable interaction device for this generic training simulator, a study was conducted using expert inspectors and two common interaction devices: a gamepad and a joystick. Performance measures were collected and subjective measures, by way of post-test questionnaires, were considered as well. This paper details the evaluation of a gamepad and a joystick as interaction devices when used with a virtual video borescope simulator for inspection training. Following the findings identified in the study, recommendations are provided for the implementation of such devices.

INTRODUCTION

Aircraft inspection is a critical component of the aviation maintenance industry. Undetected defects in the aircraft could result in serious repercussions leading to loss of life and aircraft. Preventative maintenance in the form of scheduled inspection is routinely performed on the aircraft to ensure that they are airworthy. One important component of this maintenance process is non-destructive inspection (NDI). NDI is defined as the examination of an object or material with technology that does not affect its future usefulness. Because it allows inspection without interfering with a product's final use, NDI provides an excellent balance between quality control and cost-effectiveness.

A major proportion of NDI in the aircraft maintenance industry is performed by a trained aircraft inspector, who uses a variety of tools such as eddy current detectors, ultrasonic stress testers and video borescopes to detect and classify defects. Proper training on these devices is essential to ensure that the inspector is familiar with the correct procedures to be adopted while using the equipment. In the past, on-the-job training (OJT) was the primary tool used to train novice inspectors in the inspection procedures. However, this form of training is time consuming and places an undue burden on both the expert and the trainee (Latorella et al. 1992). With an increasingly younger workforce joining the workplace directly from the aircraft maintenance schools, it is essential that they are trained in the practical aspects of inspection maintenance to avoid a cumbersome transition from the classroom to the industry.

Previous research has demonstrated that virtual training simulators can be used to train the novice students in the inspection process (Vora et al. 2002, Sadasivan et al. 2005). Consistent with the use of technology to aid aviation safety, this paper details the development of a virtual borescope as a job aiding tool in the aircraft maintenance industry. Unlike previous environments which consisted of texture-mapped models without depth cues, 3D models of the engine components were used for this study. As a precursor to development of a control interface for the virtual borescope, this paper details the evaluation of different input devices for use in the control interface.

PREVIOUS RESEARCH

Background

The borescope is similar in design to the commonly used medical tools such as the endoscope or the bronchoscope. Both instruments are used to check for diseases in the human body through visual inspection. The skills and the hand-eye coordination needed to manipulate the articulating tip in both these devices are similar in nature. However, the major difference is that, unlike the engine components inspected by the borescope which are rigid bodies with no deformations, the endoscope is used in the human body, where soft tissue deformations occur due to intersections of the endoscope tip with the wall of the intestinal cavity.

The aim of developing the virtual borescope is to enable the training of novice inspectors in the methodology and practices to be adopted in engine inspection. Previous studies used to test the graphical realism of the borescope showed that the visual aspects of the environment were similar to that seen through the actual borescope (Vembar et al. 2005). As interaction with the engine models is a critical component of the inspection process, this study evaluate the feasibility of using commonly available input interfaces similar to that used in the actual borescope for controlling the articulating tip of the borescope.

Borescope Inspection

In the aircraft maintenance industry, borescope inspection is a form of NDI used to test the internal parts of the engine, mainly the stator and the rotor blades, for defects. Defects in the engine can be in the form of corrosion, rust damage, debris hits along the blade edges or stress fractures. One of the most commonly used forms of the borescope is the video borescope, which consists of a long, flexible, fibre-optic cable at the tip of which is attached a CCD camera. The output of the camera is provided to the inspector on either a small hand-held screen, or on a stationary monitor screen as shown in Figure 1. It is to be noted here that although the interaction with the aircraft engine itself is in 3D, the visuals provided to the inspector are on a2D screen.

Fig 1: Two different kinds of video borescopes.

Fig 2: Close-up view of the control interface.

The tip of the borescope can be articulated with the help of a handheld control interface and buttons to control the orientation and zoom are provided on this interface. The controls vary in design from a mini-joystick (Figure 2) to a keypad. Buttons on the control interface enable the inspector to take screen captures of the images on the LCD screen or obtain a closer view of the engine components by using the magnification button.

To perform a borescope inspection of the engine, the inspector first inserts the fibre-optic cable through the fuel injection manifolds on the engine casing. Usually, a special guide tube is used to steer the tip of the borescope through the various stages of the turbines and stators and directly to the hot-section of the engine. The borescope inspection can either be performed by a single inspector who guides the borescope tip through the engine, or by two persons. In the latter case, the technician performing the inspection keeps the borescope stationary in a fixed position in which he has full view of the turbine, while the other person manually rotates the engine shaft, which in turn rotates the turbines. Based on the severity of defects and their location, the maintenance engineer decides whether it is essential to overhaul the engine and perform the necessary repairs.

3D Interaction Devices

The most common form of interaction with a computer has been through the keyboard and the mouse. Although these devices are particularly suited for tasks such as text selection, typing or pointing tasks (Card, 1978, MacKenzie, 1991), they are ill-suited for specialized tasks such as 3D object selection, manipulation and other such tasks in a virtual environment. Although 2D input devices have been used to control objects in a 3D environment (Conner, 1992), well designed interaction techniques using input devices with multiple degrees of freedom may sometimes provide superior performance to normal 2D input devices. Numerous studies have evaluated the efficiency of input devices such as the 3D spaceball and 6-DOF Flock of Birds (FOB) in interacting with object in virtual environments (MacKenzie, 1995). Although these devices afford extra levels of interaction and make it easier for the user to interact with the object, their prohibitive costs lead to their use only in specialized cases ($20 v/s $2000).

It is important here to differentiate between an interaction task and an interaction technique (Jacob, 1996). Interaction tasks are low-level primitive inputs required from the user. Examples of an interaction tasks include entering a block of text or selecting an option from a series of options. For each task, we have to select an appropriate interaction technique, which is a way of using an input device to perform an interaction task. An interaction technique represents an abstraction of some common class of interactive task. In our case, the interaction task consists of probe manipulation and selection of defects in the engine model. The input devices (Figure 3) under consideration are two of the commonly found interaction interfaces on the borescopes, namely the joystick and the mini-joystick simulated using a common off-the-shelf gamepad with directional controller used to manipulate the orientation of the tip of the probe.

METHODOLOGY

The virtual borescope simulation was run both on the desktop and a laptop. The desktop consisted of a 2.6Ghz Pentium 4 processor, coupled with 1GB RAM and

Fig 3: Interaction devices tested: joystick and gamepad

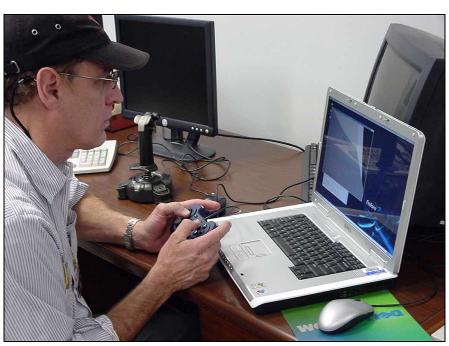

Fig 4: Interaction using gamepad

Table 1: Controls for camera position and orientation

Interface	Position controls	Orientation
Joystick	Front Button-zoom in & Back Button -zoom out	Joystick
Gamepad	Button 1-zoom in & Button 2-zoom out	Mini joystick

GeForce5700Ultra video card. The laptop consisted of a Pentium M 1.6GHz processor with 512 MB RAM and a GeForce 6800 video card. The simulators were run at interactive frame rates (>30Hz) on all the machines. Figure 4 shows the participant using the gamepad to control the virtual borescope.

The virtual borescope simulator was implemented under Linux. The engine blades were modelled in Maya from the hot-section engine components of a PT-6 engine and exported as .OBJ files. Textures were applied to the model to denote the path to be followed in the task performed by the participants. We used OpenSceneGraph (OSG) for rendering the engine blades on the screen. The participant was presented a camera-view of the engine on the computer screen. The position and orientation of the camera was controlled by specific keys in the input device, as outlined in Table 1. Unlike the actual borescope where the tip has limited motion, the camera in the virtual borescope had no constraints and could rotate a full 360° about either axis. A timer was implemented to record the user clicks as a way of measuring the time taken to move from one target to the next. Figure 5 shows the screenshot of the scene presented to the participants, with the arrows

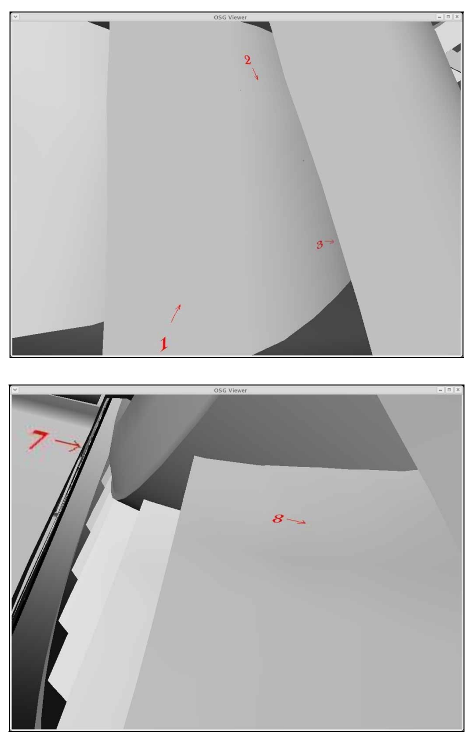

Fig 5: Screenshot of the test scenario of the virtual borescope

pointing the direction to the next number in the sequence.

Participants

A total of seven subjects (all male) participated in this study. The participants were either industry veterans with extensive borescope inspection experience (7 years – 20 years) or were instructors in the aircraft maintenance training school, who had prior experience with using the borescope for engine inspection. All the participants were provided the same interfaces, but the order of the input interfaces was changed in an attempt to counter balance the order effects.

Procedure

Before the start of the experiment, the participants were asked to complete a consent form and a demographic questionnaire, which collected data about their experience with borescope inspection and use of training simulators. The experiment consisted of two steps: familiarization phase and testing phase.

In the familiarization phase, the participants were provided training on the borescope inspection procedure and interaction with the environment using the interface device. On successful completion of this step, the participants were provided with a simple task scenario in which they were asked to follow a numbered path on the blades from points 1 through 10. To prevent searching among the targets, all the participants were familiarized with the path at the beginning of the experiment. Figure 6 shows the view of the virtual environment as seen by the participant on the screen.

When the target was acquired at the centre of the screen, the participants pressed the left mouse button to provide a timestamp of target acquisition. These were stored in a file, which was used for later analysis. After completion of the task, the participants filled out a subjective questionnaire based partly on the Presence questionnaire (Witmer and Singer, 1998), concerning the input device they had just used in the task. This procedure of familiarization and testing was repeated for the next input interface and the subjective questionnaire administered at the end of the test phase.

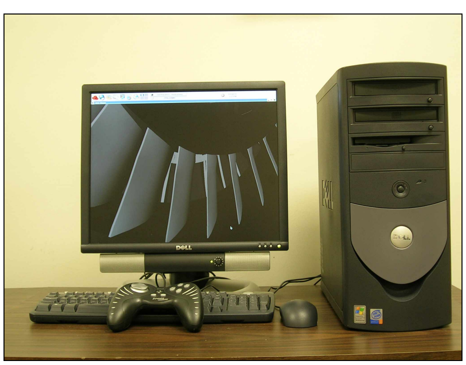

Fig 6: View of the simulator as seen by the user

Data collection and subjective questionnaire

During the testing phase of the experiment, we recorded the time taken by the participants to move from one target to the other as well as the total time taken to complete the task. On completion of each phase of testing, the participants were asked to complete a subjective questionnaire. The responses to the questionnaires were on a 5 point Likert scale, with 1 being strongly disagree, 5 being strongly agree, and 3 being neutral. A majority of the questions in the questionnaire dealt with the perceived ease of use of the input device for navigation within the virtual environment as well as the interaction capabilities or short-comings of either of the input devices. The results of the data collected are presented in the next section.

RESULTS

Figure 7 shows the mean times taken to complete the tasks by the participants computed from the data collected. The mean time taken by the participants using the gamepad was 242.09 seconds, while the mean time to complete the task using the joystick was 316.2 seconds which seems to indicate that the gamepad was a more efficient interface for the task. A t-test was used to analyze the time taken to complete the task using the keyboard and the gamepad with joystick. There was no significant difference in time ($p>0.05$).

We used the Wilcoxon rank sum test to analyze the combination of the data obtained from the questionnaires of both the input interfaces. The participants responses were significantly different ($p<0.05$) in twelve of the fifteen questions. The gamepad was preferred over the joystick in the following parameters:

1. Responsiveness to actions initiated. 2. The mechanism which controlled movement through the environment seemed natural. 3. Ability to anticipate what would happen next in response to actions 4. Involvement in the simulated borescope experience. 5. Distraction from the control mechanism. 6. Quick adjustment to the virtual environment experience. 7. Proficiency in moving and interacting with the virtual environment at the end of the experience. 8. Effortless

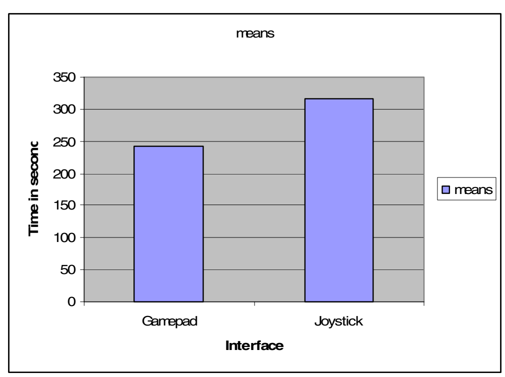

Fig 7: Mean time taken to complete the task while using gamepad and joystick

manipulation of the interface for defect selection. 9. Ability of the interface to aid in following a path. 10. Interference of control devices with performing the task. 11. Concentration on the task rather than on the mechanisms used to perform the task. 12. Preference of the interface for training of borescope inspection.

CONCLUSIONS

The results of this study will help us in further developments of the virtual borescope. Evaluation of independent devices for the probe feed and the articulation control are under consideration. A common complaint of the participants was the lack of limits to the camera motion. Future plans for the borescope simulator include the addition of defect textures and better camera controls to realistically simulate the motion of the articulating tip of the borescope.

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