PROGRESS ON THE SIMULATOR AND EYE-TRACKER FOR ASSESSMENT OF PVFR ROUTES AND SNI OPERATIONS FOR ROTORCRAFT

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Background: The concept of Precision Visual Flight Rules (PVFR) and Simultaneous Non-Interfering (SNI) Routes for rotorcraft is based on the hypothesis that rotorcraft with Global Positioning System (GPS) navigation capabilities can stay within narrow, defined horizontal airspace limits while operating under Visual Flight Rules (VFR). If the pilot maintains the aircraft within the confines of a PVFR route and if these routes can be designed to keep rotorcraft separated from fixed-wing traffic then PVFR routes offer rotorcraft the possibility of operating in congested airspace simultaneously with fixed-wing aircraft on a non-interfering basis, hence the term SNI operation (Hickok & McConkey, 2003).

INTRODUCTION

The objective of this research program is to investigate Precision VFR (PVFR) routes for Simultaneous Non-Interfering (SNI) operations in the National Air Space (NAS). For a variety of reasons, it is not practical nor is it safe to investigate these routes exclusively using actual in-flight rotorcraft. The research plan calls for a series of steps which will facilitate this investigation.

1. Conduct a human factors investigation of in-flight performance of pilots during a PVFR route (This phase is described in detail in Hickok & McConkey, 2003).
2. Replicate the same task and environment used in the in-flight study using a virtual simulation. Compare human factors data (visual scan patterns, performance, etc.) to determine if the simulation approximates actual flight and is therefore suitable for further investigation.
3. Assuming the simulator satisfies the requirements set out in the first phases of the program, we can then construct new PVFR routes and collect human performance data to determine their feasibility and predicted improvement over current standards.

The role of the Naval Postgraduate School is to construct the simulation environment for experimentation in the later phases of the program. NASA will construct a mobile eye-tracker for use in data collection. It must be suitable for use both in the actual rotorcraft and in the simulator.

This paper will report on progress in both of these parts of the research program.

THE SIMULATOR

The actual simulator consists of both an apparatus and related software and models. Our approach is to construct a simplified simulator that replicates only those aspects of the piloting task that are relevant to this research program. We have been conducting research on rotorcraft navigation and piloting for several years and have completed a cognitive task analysis and several prototype simulators for the overland navigation task (J. Sullivan, Darken, & McLean, 1998; J. A. Sullivan, 1998).

The Apparatus

The hardware apparatus for the SNI simulator consists of an internal environment (cockpit) to include seat, controls, and simulated gauges, and also a display to simulate the external environment.

The selected aircraft for the experiment is the Army OH-58A. The primary data for pilot performance are airborne digital data of actual position and head and eye position during flight. Tracking the position of the aircraft during simulated flight is relatively trivial. However, it is essential that the simulator replicate the displays and gauges of the OH-58A in order to be able to compare head position and eye gaze data from the airborne portion of the program to the simulator portion. We currently have a placeholder LCD panel for simulated gauges but a plan is in place to replace this with a full scale panel from OH-58A specifications. We will still use LCD panels to drive the gauges but will use a cut-out in the panel with the LCD panel showing where needed.

In Figure 1, we show the apparatus inside the projection screens. The LCD panel will be replaced shortly.

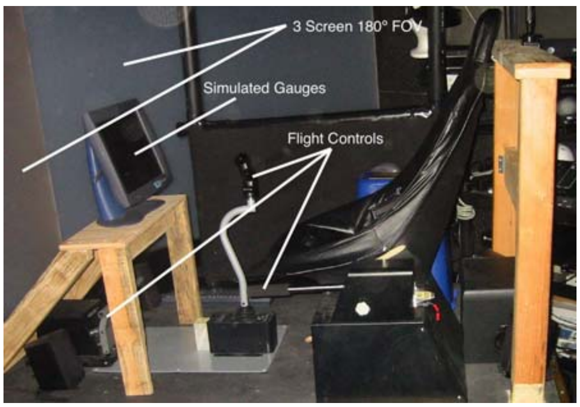

Figure 1. The SNI simulator apparatus.

To simulate the external environment, we use a 3-screen wide field-of-view display. In the virtual environment literature, this is commonly referred to as a CAVE (Cruz-Neira, Sandin, & DeFanti, 1993). Our simulator can also use a Chromakey™ "bluescreen" mixing capability that uses a head-mounted display with a camera mounted on it (Lennerton, 2003). This apparatus is likely unusable for this application, however because of incompatibilities with the eye-tracking device.

In Figure 2, we show a pilot in the simulator during use. The screen behind the pilot is a surrogate for the frame of the aircraft to limit the visual field similarly to the actual airframe.

Figure 2. The SNI simulator during use.

The Virtual Environment

The environment chosen for the experimentation plan is the region immediately surrounding Tullahoma, TN Regional Airport (THA). Satellite Technology Implementation (STI) designed the flight routes as described in Hickok & McConkey (2003). A portion of the flight route is shown in Figure 3.

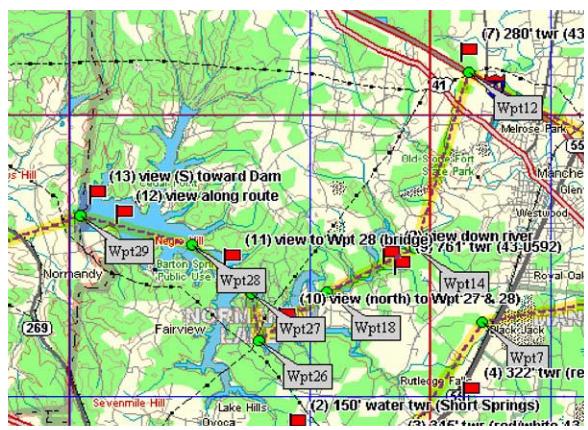

Figure 3. A portion of the flight route (from Hickok & McConkey (2003).

After the region was selected, we collected publicly available digital data of the area and began to construct the virtual model for use in the simulator. We have used Digital Terrain Elevation Data (DTED) and aerial imagery to compose the model shown in Figure 4. We have approximated the locations of three of the waypoints also identified in Figure 3.

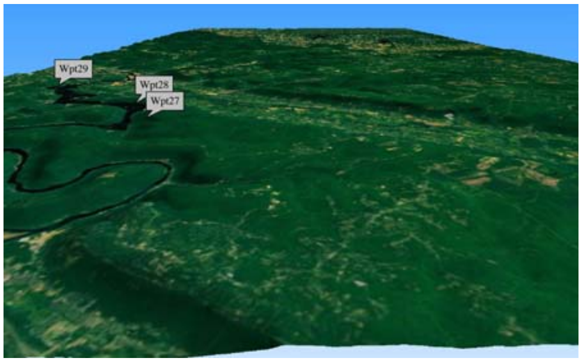

Figure 4. The virtual model.

The model is a work in progress. We have not yet implemented low-level features that will be needed for the PVFR route. The STI team will inform us of these features and their locations. We will then take photographs as needed and place these objects on the virtual model. The model is then imported into the simulation environment so that the virtual helicopter can fly through virtual Tullahoma.

EYE-TRACKING

The objective of the eye tracking portion of the project is to capture head pose and eye gaze position during flight, either simulated or actual. Actual flight is obviously the more difficult of the two due to size and power constraints. The data must be captured and time stamped for later evaluation.

Ames Portable Eye-Tracker

The purpose of this technology development project is to develop a lightweight, comfortable head-mounted eye tracking device suitable for extended use in operational environments. The basic design is patterned on a prototype developed at the Rochester Institute of Technology, and is based on a raquetball eye shield. A portion of the plastic lens is cut away and replaced with an adjustable “hot mirror” which allows the subject a clear straight-ahead view, but reflects an infrared image of the eye to a small camera mounted on the side of the frame. A second forward-looking camera records the “subject's eye” view of the scene, which is used to locate the subject's head within the experimental environment. Images from the cameras are tiled into a single video signal using a “quad processor”, and then are recorded for later analysis. The head mount may be directly connected to the recording unit (“tethered” operation), or connected using a 2.4 GHz wireless link. Before recording, time code is added to the signal; the initial time for the time code generator can be derived from a GPS receiver, and GPS position information (sampled once per second) may also be recorded.

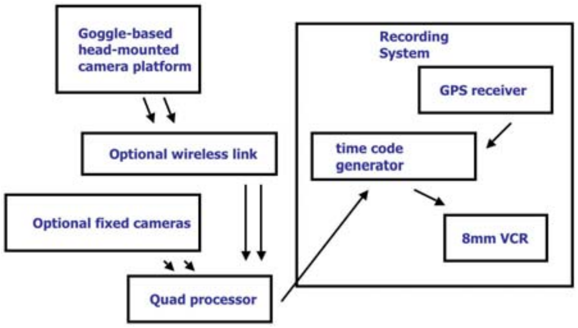

Figure 5. Schematic diagram of the eye-tracking device.

Head Pose Estimation

While the head-mounted camera unit described above has the highest potential gaze-tracking accuracy, there may be situations in which it is impossible to use a head mount. Therefore, we are also exploring technologies to recover gaze using images from a remote, fixed camera. In such images, the subject's eye may only subtend a few pixels, and in this case there is insufficient data to determine eye gaze. However, in normal behavior, the eye rarely deviates more than 5 or 10 degrees from primary position (straight ahead in the head), and so the pose (orientation) of the head can be used to obtain a crude estimate of gaze.

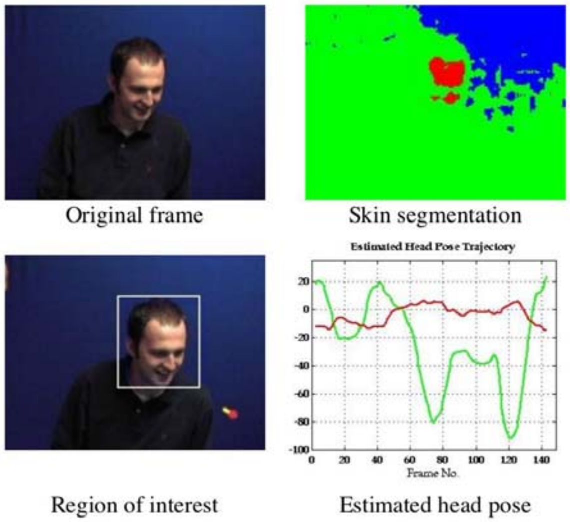

Figure 6. Head pose estimation.

The problem of head-based gaze tracking can be divided into a few distinct components:

1. We must find the head in the image
2. Once we have located the head we must estimate the pose.

When color is available, it is often possible to easily find the face using a color based segmentation (see Figure 6). For monochrome images we have also explored a template-matching algorithm. To estimate the pose parameters, we have investigated methods for directly mapping the image to parameter values. To do this, we start with a training set of images with known pose values; a principal components analysis is then used to extract the “eigenfaces”, a set of images which captures the variation between the images in the training set. By restricting analysis to the first few eigenfaces, a large reduction in dimensionality is achieved. Finally, we solve for a polynomial function of the eigenface coefficients that comes closest to predicting the pose parameters in the training set. We have achieved accuracy of a degree or two using a synthetic training set. Current work is in progress to develop a training set based on real images, where the pose parameters used for training are taken from a 3-D model of the test subject's head.

This is not the primary approach we envision for the SNI program at UTSI but it is a suitable technology that may be useful either in the aircraft or the simulator. We will know if this is needed after preliminary testing concludes shortly.

Head-Based Gaze Tracking

Once we have determined the gaze direction (be it of the eye or head), we still need to determine the location or object in the environment that is the target of gaze. To do this automatically, it is necessary to develop a model of the environment. Figure 7 shows an example taken from the interior of a control tower simulator, but the principles are the same for a cockpit or any other environment. We begin by constructing a model of the environment; in this case we used architectural drawings and on-site measurements to construct the model. Next, we determine the position of the virtual camera for which the rendered model is aligned with the video data. Once that has been accomplished, we grab the image texture from the video and “paste” it onto the surfaces of the model. We can then re-render the model from novel viewpoints, including the “subject's eye” view. After the position of the subject's head has been determined, the estimated head pose can be used to cast a gaze vector; the intersection of this gaze vector with a model surface yields the point of regard in the scene.

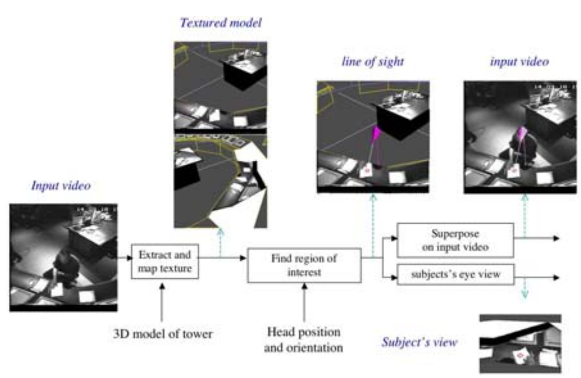

Figure 7. Head-based gaze tracking

The procedures for automatic determination of the camera position will also be used for video based head-tracking with the portable eye-tracker.

The first prototype device for the experiment has been designed and is currently undergoing testing at NASA Ames. On July 2nd the first outdoor test was made, and the need for some additional optical baffling was discovered. Construction of the second goggle is nearly complete. A different battery has been selected for the power source and the power supply regulator issues have been solved. Most of the remaining outstanding issues will not be clearly defined until the July integration trip to UTSI.

SCHEDULE

Key schedule milestones are shown below:

- Test Readiness Demonstration: 09-30-03
- Data Collection Complete: 10-31-03
- Simulator Complete: 12-31-03
- Simulator Test Plan Draft: 03-01-04

REFERENCES

Cruz-Neira, C., Sandin, D., & DeFanti, T. (1993). Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. *Computer Graphics*, 135-142.

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Sullivan, J., Darken, R., & McLean, T. (1998, June 2-3, 1998). *Terrain Navigation Training for Helicopter Pilots Using a Virtual Environment.* Paper presented at the Third Annual Symposium on Situational Awareness in the Tactical Air Environment, Piney Point, MD.

Sullivan, J. A. (1998). *Helicopter Terrain Navigation Training Using a Wide Field of View Desktop Virtual Environment.* Unpublished Masters thesis, Naval Postgraduate School, Monterey, CA.

SUPPORTING DOCUMENTATION

Documents and technical direction related to this test include:

1. FAA Aeronautical Information Manual (AIM).
2. FAA Order 7110.65N; Air Traffic Control