Engineering Notes

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Stereopsis as a Visual Cue in Flight Simulation

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Introduction

STEREOPSIS is one of several visual cues to depth. Stereopsis is different from most cues, however, in that it is physiological rather than psychological, a fact that often makes this cue more convincing than others. Since the goal of the flight simulation is to make the pilot feel, think, and react as if what he is seeing is real, adding stereopsis to the visual system is a natural step of these simulators as they become increasingly realistic. This Note describes how stereopsis can be incorporated into the out-the-window visual system of flight simulators. It gives the results of testing into the effectiveness of stereopsis as a visual cue. Based on these results, it suggests further research and possible future applications for stereopsis in-flight simulation.

Creating Stereopsis in Simulators

There are several methods that may be used to create stereopsis in flight simulators. All methods require computing a separate view for each eye. This is done by using two channels of the simulator's computer image generator (CIG) hardware in parallel. The two viewpoints are offset in position (X, Y, Z) to account for eye separation and may possibly be offset in rotation (heading, pitch, roll), to account for display configuration. In less complex scenes, the frame computation time may be divided in half with left and right views being computed by the same channel in alternate fields.

There are several methods of displaying stereo images. They may be grouped into two general categories: time-parallel methods and time-multiplexed methods. Time-parallel methods present the stereo pair to both eyes simultaneously. Independent direct presentation is a time-parallel method that has been implemented using helmet mounted displays in which the images are presented immediately in front of each eye with separate, nonoverlapping displays. A time-parallel method with possible future application to flight simulation uses two projectors with a polarizer placed over the lens of one projector and a complementary polarizer placed in the lens of the other projector. The pilot wears a viewing apparatus with polarizers that correspond to those placed over the projectors, thus allowing each eye to see only one of the projected images.

Time-multiplexed methods use a single display for both images with the images being displayed sequentially in time. Left and right images are alternately displayed, and each eye is allowed to view the display only while the image intended for that eye is being displayed. Lead lanthanum zirconate titrate (PLZT) glasses, liquid crystal shutters (LCS), and, more recently, ferroelectric liquid-crystal shutters (FLCS) are used to insure that each eye sees the proper image.

Testing Results

The addition of stereopsis promises to add another level of realism to the flight simulator. At this time, the principal question concerning stereopsis in-flight simulation is this: Is the added complexity required to produce stereoscopic imagery worth the cost? In experiments performed by the author with an Evans & Sutherland ESIG-1000 CIG, static test images were produced on a video monitor using the time-multiplexed LCS method with image resolution of 0.7 arc min/pixel. Based on the stereopsis cue alone, participants were able to distinguish which of a pair of simulated objects was closer with, on average, as little as 2.3 arc min of difference in horizontal disparity.[1] From this stereoacuity measurement, the threshold of stereopsis (i.e., the maximum distance at which stereopsis is a useful cue) may be calculated in a straightforward manner by considering the geometry shown in Fig. 1a:

$$T = 0.5E/\tan(0.5A) \tag{1}$$

where E is the interocular distance and A is stereoacuity. Using the nominal interocular distance of 2.5 in., stereoacuity of 2.3 arc min implies a threshold of stereopsis of over 300 ft. This is well within the range of many flight tasks such as aerial refueling, formation flight, and low-level helicopter flight.

Figure 1b shows the criterion for distinguishability of object depth as a function of stereoacuity. Of course, the nearer the objects, the better one's ability to distinguish depth becomes. For example, using the 2.3 min stereoacuity, an object at 100 ft is barely distinguishable from an item at 75 ft. While at 30 ft away, a depth differential of 3 ft can be discerned solely on the basis of stereopsis.

Experiments at Honeywell, Inc., using stereoscopic video displays concluded, among other things, that the depth discrimination in stereoscopic displays should be error free if the difference in disparity is greater than 2.2 arc min,[2] almost the same result as that of the author. These results indicate stereoacuity of worse than 6 arc s, which is typical under ideal conditions. It is speculated that increased resolution will improve the stereoacuity, but a brief follow up study at Honeywell, Inc., tends to discount this theory. Nevertheless, as stated before, the level of stereoacuity achieved on video displays does make this a valid cue to distances useful to flight simulation.

More significant are results of a study that measured flight performance in a simulator that has a stereoscopic helmet mounted display. It was found that stereo imagery provides a significant performance advantage in formation flight despite the fact that the resolution used was 3 arc min and the presence of accommodation-convergence conflicts.[3] This study used collimated imagery, which has been found to relax accommodation-convergence restrictions of directly viewed CRTs.[4] Collimated displays are widely used in simulators,

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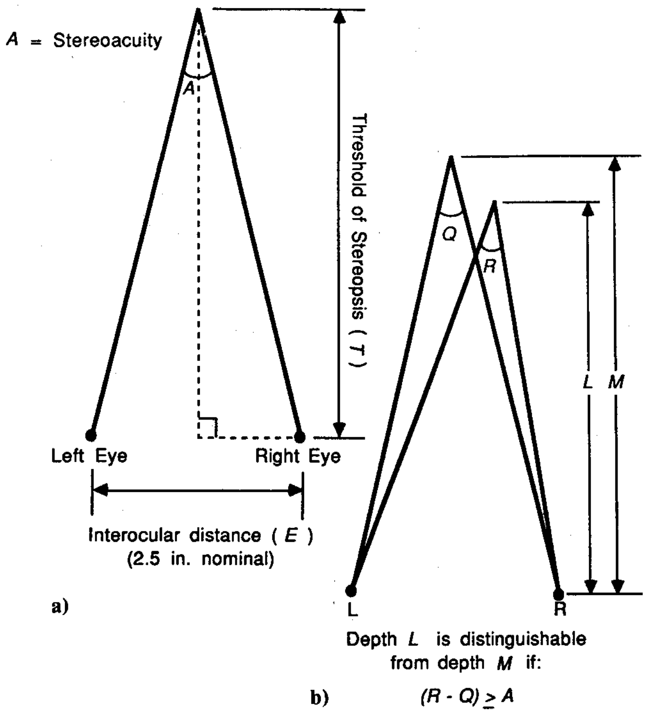

Fig. 1 Threshold of stereopsis and distinguishable depth.

and this fact bodes well for the widespread compatibility of stereopsis with flight simulators.

Future Research and Applications

The true value of stereopsis to flight simulation will require much further research. A state-of-the-art stereoscopic flight simulator is currently being built for the Army Research Institute. This system, called the Simulator Complexity Test Bed, features a helmet mounted display system with high-resolution area-of-interest insets. The CIG is stereo capable and software reconfigurable, meaning that the system can be configured to produce stereo views, or the same hardware can be configured to trade stereopsis for greater resolution and scene density or additional monoscopic channels. This will allow the evaluation of stereopsis without having to commit to running in stereo all of the time.

The future for stereoscopic flight simulators appears promising. Clearly, the tasks most likely to benefit from stereopsis are those in which objects are viewed at relatively close distances and/or where there is a scarcity of other depth cues. Such tasks as aerial refueling and formation flight require the pilot to acquire and maintain a precise position in close proximity to another aircraft without the benefit of the constant motion parallax present in other maneuvers. Low-speed nap-of-earth flight and landings require accurate distance perception to close range objects. Space operations, such as docking and manipulator arm operation, exemplify an application where all available cues are needed to successfully perform these slow, precise, and short range maneuvers with accuracy of fractions of an inch.

Conclusion

Advances in CIG and display technology now make it feasible to create stereoscopic out-the-window imagery for flight simulation. The results of testing to date indicate that, in simulators, stereopsis is a valid cue at distances of up to 300 ft and that stereopsis will enhance pilot performance in many training tasks. The true value of stereopsis to flight simulation will require studies using pilots in state-of-the-art stereoscopic simulators. Such systems are now being developed.

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Comparison of One- and Two-Interface Methods for Tunnel Wall Interference Calculation

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Introduction

THE procedures of recently developed adaptive wall wind tunnels require a variety of flow variables to be measured near or on tunnel wall boundaries. These variables can be utilized to determine wall interference. Several wall interference calculation methods are available based on different kinds of boundary measurements. The NASA Ames Research Center 2-ft tunnel[1] has the capability to obtain these boundary measurements. Specifically, the pressure coefficient interference $c_{pi}(x,0)$ at the centerline of the tunnel can be determined based on the measurement of axial and vertical velocity components $u_t(x, \pm y_1)$ and $v_t(x, \pm y_1)$ on one interface named as method 1, or based on the measurement of vertical velocity components $v_t(x, \pm y_1)$ and $v_t(x, \pm y_2)$ alone on two interfaces named as method 2. The coordinates y_1 and y_2 describe the location of interfaces in the tunnel (see Fig. 1).

For small disturbances in a subsonic flowfield, $c_{pi}(x,0)$ is related to the axial interference velocity component $u_i(x,0)$ as follows

$$c_{pi}(x,0) = -2 \cdot u_i(x,0) \tag{1}$$

The interference velocity component $u_i(x,0)$ according to method 1 is given by Lo[2] and Dahm[3] in the following form

$$u_i(x,0) = \frac{\beta y_1}{2\pi} \int_{-\infty}^{\infty} \frac{u_t(\xi,y_1) + u_t(\xi,-y_1)}{(\xi - x)^2 + (\beta y_1)^2} \, \mathrm{d}\xi + \frac{1}{2\pi\beta} \int_{-\infty}^{\infty} \frac{v_t(\xi,y_1) - v_t(\xi,-y_1)}{(\xi - x)^2 + (\beta y_1)^2} \cdot (\xi - x) \, \mathrm{d}\xi \tag{2}$$

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