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SYNTHETIC PERSPECTIVE OPTICAL FLOW: INFLUENCE ON PILOT CONTROL TASKS

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INTRODUCTION

Computational and empirical analyses of optical flow have led to a more complete understanding of pilot control tasks. Such analyses are based on the premise that a primary stimulus for the perception of self-motion is the flow of optical texture in the visual field (Gibson, 1950; Koenderink and van Doorn, 1976). It has been further recognized that there are both local and global optical variables that might influence control behavior (Owen and Warren, 1982; Uttal, 1985). With this realization came the understanding that to study how optical flow influences control tasks, it is essential that the complex visual scene be decomposed into observable flow patterns (Regan and Beverly, 1985).

One approach used to better understand the impact of visual flow on control tasks has been to use synthetic perspective flow patterns. Such patterns are the result of apparent motion across a grid or random dot display. Unfortunately, the optical flow so generated is based on a subset of the flow information that exists in the real world. The danger is that the resulting optical motions may not generate the visual flow patterns useful for actual flight control.

We have conducted a series of studies directed at understanding the characteristics of synthetic perspective flow that support various pilot tasks. In the first of these, we examined the control of altitude over various perspective grid textures (Johnson et al., 1987). Another set of studies has been directed at studying the head tracking of targets moving in a three-dimensional coordinate system. These studies, parametric in nature, have utilized both impoverished and complex virtual worlds represented by simple perspective grids at one extreme, and computer-generated terrain at the other.

These studies are part of an applied visual research program directed at understanding the design principles required for the development of instruments displaying spatial orientation information. The experiments also highlight the need for modeling the impact of spatial displays on pilot control tasks.

ALTITUDE CONTROL

Introduction

The purpose of this experiment was to examine the characteristics of "wire frame" perspective grids as support for altitude control. Wolpert, Owen, and Warren (1983) reported that splay angle information was one of the most important indicants of altitude change. In their study, they used ground surface textures consisting of equally spaced lines either parallel to the direction of travel (meridian texture), orthogonal to the direction of travel (latitudinal texture), or both (square texture).

There are two limitations of Wolpert's work that have relevance to the current study. The first is that discrete-trial, passive-response methodology was used. This is in contrast with a setting where a person is required to continuously monitor a perspective scene, and where his or her responses result in feedback control of perspective dimensions of the stimulus.

The second limitation derives from the fact that subjects could have monitored the location at which any meridian texture line intersected the bottom edge of the screen. As a result, a subject could tell if altitude had changed by merely observing the movement and intersection without monitoring the splay angle at all.

Methods

Subjects were flown at a constant velocity, at three different altitudes, over each of the three grid types mentioned above. The display was generated by an Evans and Sutherland PS-2 graphics system. The "aircraft" was buffeted by both lateral and vertical winds. Each of the disturbances was defined by its own sum of 13 sine waves. The five subjects were required to maintain a constant height above the grid by means of a joy stick. The primary performance metric was adjusted root mean square error (ARMSE) from the assigned altitude.

The important point here is that because of the lateral noise imposed on the craft position, the meridian lines moved left and right irrespective of the actual change in altitude. As a result, subjects could not determine altitude change by only the movement of the meridian lines. Changes in altitude would have to be determined by changes in density (lower density corresponds to a lower altitude) and splay angles (the greater the angle the lower the altitude) of the grid structure.

Results and Discussion

Based on the work previously cited, it was expected that ARMSE sould be lowest for the meridian surface and highest for the latitude surface. This was not the case (fig. 1).

Because of the unexpected larger ARMSE values obtained when flying over the meridian surface texture, it was decided to look more critically at a single subject's performance. A detailed power frequency analysis was performed and showed that the meridian grid resulted in (1) less stick power associated with the vertical disturbance than any of the other grid textures; and (2) the most power in the stick movement associated with the lateral input signal (fig. 2).

These analyses indicate that the subject (1) was less reactive to the information specifying true changes in altitude when flying over the meridian texture; and (2) tended to confuse lateral with vertical motion in displays where only splay information was available.

PERSPECTIVE FLOW FIELDS AND HEAD TRACKING IN A 3-D VIRTUAL WORLD

Introduction

In the previous study, we discussed the impact of perspective flow displays on a manual control task that regulated the altitude of a simulated aircraft. In certain military rotorcraft, systems exist in which movement of a sensor system is slewed to the crewmember's head motion. Currently there is only standard flight symbology in this helmet-mounted display to indicate altitude, attitude, and heading. A small portion of the display provides information concerning the field of view and field of regard of the sensor.

Despite the fact that these systems are currently fielded, little systematic data exist concerning how a pilot uses flight/target information presented on a helmet-mounted display. Even less data are available on alternative display configurations that might make a pilot more sensitive to changes in aircraft state.

As part of a program to better understand helmet-mounted flight displays, we conducted a study to validate a laboratory simulation of the currently fielded system. A perspective flow field was used to create the virtual world that was the basis for this simulation. A detailed report of this study is in preparation.

Methods

A wire-frame perspective grid was displayed to six subjects by means of a head-mounted 1 in. Sony electronic viewfinder. Head position was monitored by means of a Polhemus head tracker. As the subjects moved their heads, they were able to "look" around the virtual world.

Six subjects were "flown" over the grid at two different altitudes and three different velocities. Positioned on the surface was a wire frame cube. The target was offset to the left or right of the direction of travel. The subject could "track" the target by means of a cross hair that was generated in the middle of the monocular display. Tracking ARMSE was determined by subtracting line of sight (LOS) to target from the visual LOS.

Results and Discussion

Figure 3 shows the mean screen errors for the different offsets, as a function of slant angle to the target. The term slant angle incorporates elevation and azimuth components. It is important to remember here that as range to the target decreases, optical (apparent) velocity increases. So, during the course of the "flight," the target was in fact accelerating, even though "aircraft" speed was constant throughout the flight. A 3×4×2 (speed × offset × altitude) repeated-measures analysis of variance was conducted on the mean ARMSE values for each subject. This analysis indicated that as optical velocity increased, there was a significant increase in screen error ($p < 0.001$). This was true irrespective of whether the increase in optical velocity was produced by changes in slant range or "vehicle" speed.

In figure 4 is shown the change in both ground error and screen error as a function of slant angle. To calculate ground error, the target and visual LOSs were first projected to the ground plane. Ground error was then given as the distance between those two intersections. As slant angle increased, ground error did not significantly change ($p > 0.46$). One interpretation of these data is that the subjects were treating the task as a true three-dimensional LOS problem. If the subjects had maintained screen error constant (as in an arcade game), ground error would have directly varied with slant range. A second interpretation is that subjects tried to maintain a constant screen error, but were unable to do so because of the accelerating optical velocity of the target.

HEAD TRACKING DURING SIMULATED AUTOMATED AND MANUAL HELICOPTER FLIGHT

Introduction

A model of head tracking in a 3-D world (represented by a perspective flow field) was developed and tested in the previous study. The purpose of the present experiment was to (1) validate the laboratory simulation, and (2) model the trade-offs that pilots make when they are required to control their craft and simultaneously head-track targets. A detailed report of this study is in preparation.

Methods

Six AH-64 Apache helicopter pilots took part in a simulation of the pilot night-vision system (PNVS). The study took place in a fixed-base mock-up of the helicopter. The visual scene was a complex, computer-generated world in which a stationary helicopter served as the target. Each pilot was initially flown "automatically" in either a rectilinear or curvilinear path past the target. This served to simulate a copilot/gunner or a pilot in an automated flight mode. The pilot was then required to duplicate the ground track in manual flight mode while simultaneously tracking the target. The spread of target ranges extended from approximately 6,000 to 400 ft. In the trials reported here, own-ship velocities never exceeded 80 mph.

Head-tracking ARMSE was calculated as in the previous study. Ground-track error was also measured. This was the difference in feet between the flightpaths in the automated versus manual flight modes. During the manual flights, pilots were informed that target tracking was the primary task, but that ground track error was being measured.

Results and Discussion

Figure 5a shows the averaged screen errors in the manual and automatic flight modes, as a function of slant angle. A repeated-measures analysis of variance revealed a significant effect of slant angle ($p < 0.005$) as well as significant slant angle by flight mode interaction ($p < 0.001$). The inference is that screen error is greater near the end of a manual flight than it is at the end of an automatic flight.

At first glance this makes a great deal of intuitive sense. During manual flight, the pilot is not only head-tracking a target, but also manually flying the helicopter. However, inspection of figure 5b reveals another explanation of the increased screen error. As can be seen, optical velocities during the manual flight mode are significantly greater than during automated flight. Additionally, a multivariate regression revealed a significant positive correlation ($p < 0.0001$) between optical velocity and screen error, when the effect of slant angle is statistically removed. This analysis is consistent with the interpretation that optical velocity is a major source of head-tracking error.

An interesting question that arises from these data is why optical velocities are greater during manual flight. Presumably, given that the pilot is under control of the craft, he or she could have biased the flightpath to decrease optical velocity, and, hence, screen error.

Figure 5c provides some understanding of the complex trade-offs that the pilots were making. This figure shows that as slant angle increased (and slant range decreased), the magnitude of the ground error decreased significantly ($p < 0.005$), then gradually increased. As with the second experiment, the data reported here are consistent with the interpretation that the pilots were treating the task as a true 3-D problem. Otherwise, there would have been no reason why they would not have simply held screen error constant and allowed ground error to vary. Also, although they flew a flightpath that increased the problem of head tracking (by increasing optical velocity), their manual flightpath resulted in, if not a constant, at least a minimal ground error. This, of course, is the name of the game for a combat pilot.

GENERAL DISCUSSION

Pilot control tasks include both manual flight control and the control of head-slaved sensor systems. Three studies were presented to highlight the nature of the design considerations that are important in the development of displays that convey spatial orientation information. Factors emphasized included the need to characterize both optical/visual flow fields and the control dynamics of manual and head-slaved systems.

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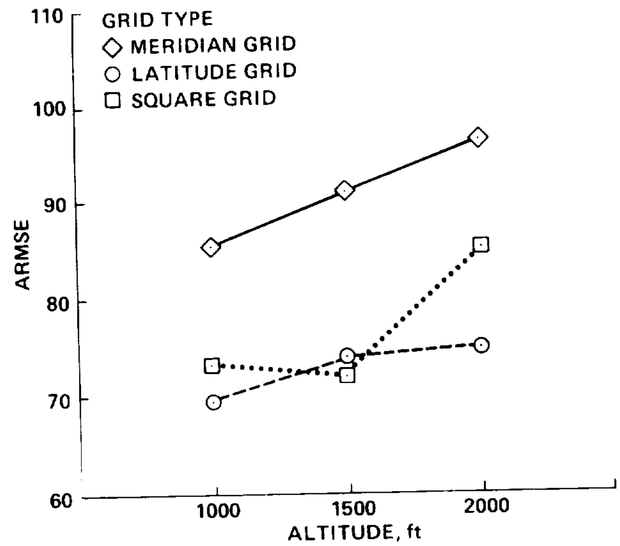

Figure 1.– Mean median ARMSE as a function of grtid type and altitude (ARMSE measures based on 10-sec intervals.

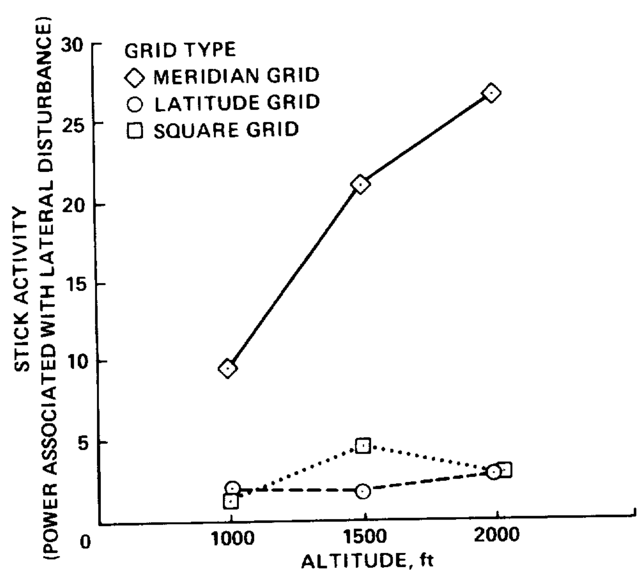

Figure 2.– Control-stick activity associated with lateral disturbance as a function of grid type and altitude (subject 5).

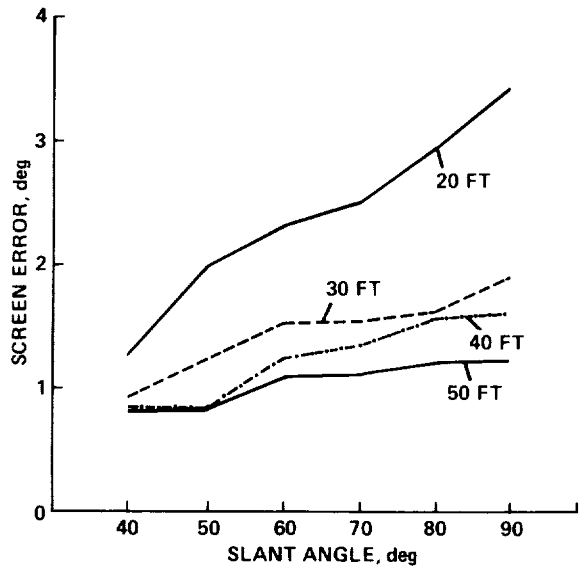

Figure 3.– Head tracking/virtual world, screen error versus offset.

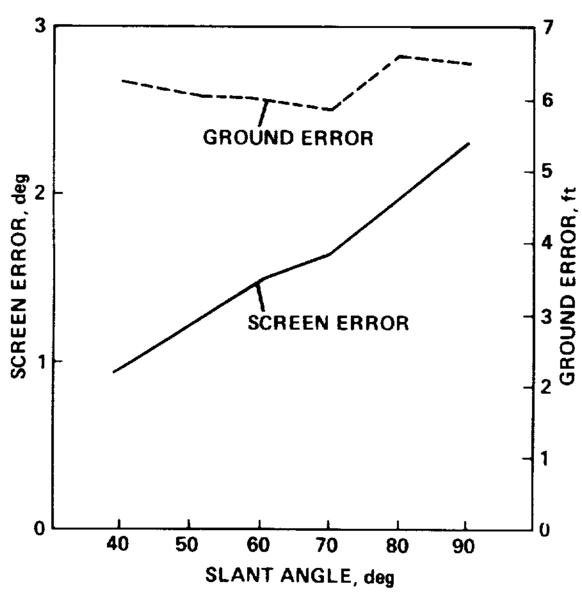

Figure 4.– Head tracking/virtual world (all conditions).

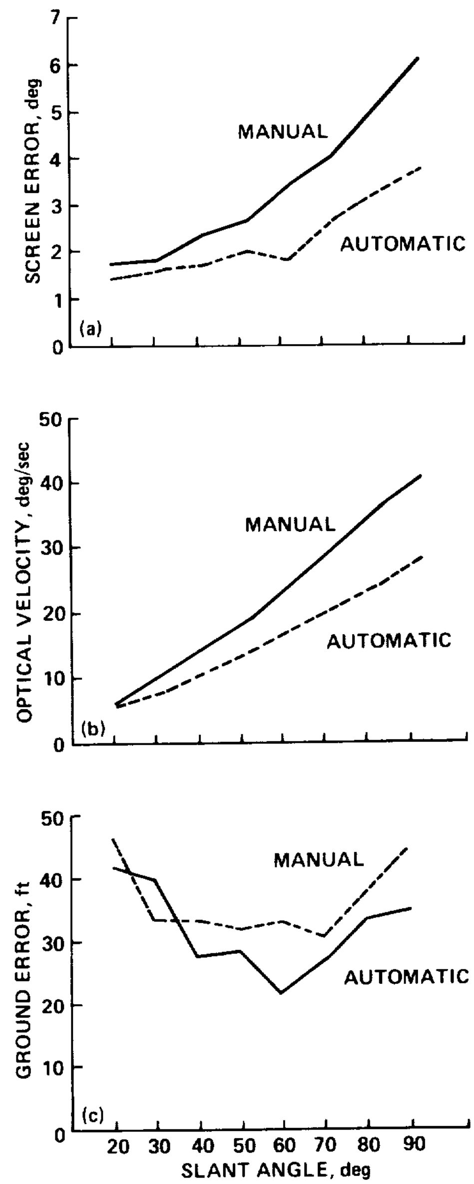

Figure 5.– Manual versus automatic flight, all conditions. (a) Screen error. (b) Optical velocity. (c) Ground error.