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P.183: Motion Parallax Enhances Depth in a Perspective Air-Traffic Display

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Abstract

In this paper we investigate the utility of motion parallax induced by head movement in the context of a perspective rendering of three-dimensional air traffic configurations. Discrimination of altitude differences is improved by the addition of motion parallax (compared to a static display), but does not afford the large changes of viewpoint possible with manually-controlled rotations.

1. Introduction

Display of air traffic information in a three-dimensional format has a number of advantages over traditional plan-view displays, particularly with respect to the depiction of altitude information. Air traffic configurations are inherently three-dimensional, with a fourth dimension (time) being important for assessment of future conflicts between aircraft. Traditional traffic displays have evolved from radar scopes, in which signals from a rotating antenna that scans in azimuth are displayed in plan view, using azimuth/range polar coordinates. In this type of display, altitude information is conveyed by a text “tag” associated with each aircraft. While complete in an informational sense, this representation does not produce the same mental representation in a human operator as that produced by a perspective projection “picture” of the traffic; this has been demonstrated by showing that controllers adopt different strategies for solving the same problem, depending on how the problem is depicted. Using a three-dimensional perspective display, a larger proportion of problems are solved by altitude changes than when the same traffic pattern is represented in the traditional plan view [1].

A perspective view of traffic is provided by an experimental display currently under investigation in the Flight Deck Display Research Laboratory at NASA's Ames Research Center [2]. This display allows the operator to change the viewpoint in various ways using a graphical user interface. In particular, the entire displayed volume may be rotated by depressing the right mouse button and “dragging” the mouse: vertical mouse motions rotate the display about a horizontal axis parallel to the display surface (pitch), while horizontal mouse motions rotate the depicted airspace about its vertical axis. Other transformations are accomplished using a graphical control panel. Using these controls, an operator can generally obtain a view which allows effortless perception of the spatial relationships between the aircraft of interest. This process, however, occupies one of the operator's hands and can require multiple interactions with the interface. Our goal is to incorporate additional depth cues into the display which allow faster and more accurate perception of the spatial relations between the aircraft, in the most natural way possible.

In this paper we examine the benefits provided by the addition of motion parallax driven by head movements. The sensation of depth arising from motion is a form of the *kinetic depth effect* (KDE) [3], but whereas the KDE is typically illustrated by the motion of a rigid object viewed by a stationary observer, in the present case we are concerned with the visual motion of a stationary object induced by observer motion. From a mathematical standpoint, the two situations are equivalent, depending only on the relative motion between observer and object; efficient computational algorithms for solving the resulting *structure from motion* problem have been devised [4].

Although the potential for motion parallax as a potent cue to depth was recognized early in the development of computer graphics [5], even today it has not seen widespread application, perhaps because of the need to incorporate some sort of head-tracking device. (This may change with the recent demonstration of an inexpensive head-tracker constructed from the Nintendo Wii remote control unit [6].) While most previous exploitation of motion parallax has been in the context of virtual reality displays [7-8], other investigators have also explored the perception of depth generated in non-immersive environments [9-12].

2. Methods

The experiment was performed on a 3.06Ghz Xeon computer running the Windows XP operating system with 2GB RAM, equipped with an ATI All-In-Wonder X800 graphics card with 256MB video memory. The display used was a Samsung SyncMaster 770 LCD panel, with a screen resolution of 1280x1024 pixels. The video board produced imagery with 24 bits per pixel, and refresh rate of 60Hz.

Head position was measured using a Polhemus Fastrak six degree-of-freedom tracking device (Polhemus, Colchester VT, www.polhemus.com). The sensor was held in place on the subject's forehead by slipping it under the headband of a cap. (The sensor was placed on the front of the head to avoid calibration of the eye-to-sensor offset.) Because the offset between the sensor position and the positions of the eyes was small, rotations of the sensor were ignored and only the sensor position was used to determine the projection parameters used by the graphics system. The Fastrak communicated with the host computer via the computer's serial port, at a baud rate of 115200. Subjects were presented with a series of images depicting configurations of aircraft, represented within a cylindrical volume of airspace centered on the "own-ship" (figure 1). A 3D model of a jet was used as an iconic representation of each aircraft. Viewing parameters were set such that the radius of the cylinder represents a distance of 60 nautical miles, and the cylinder's height represented a 12000 foot altitude difference. In each judgment, a 3D configuration of planes appeared about the own-ship and a message appeared at the left side of the screen instructing the subject to select (by left-clicking) the aircraft at the same altitude as the own-ship. For each trial, the own-ship was placed at at an altitude of 20000 feet. A single additional aircraft was placed at the same altitude, and four distractor aircraft were introduced, differing in altitude from the own-ship by a parameter d, with two distractors at altitude 20000+d, and two at 20000-d. The target and distractor aircraft were assigned random lateral position, but were constrained to avoid collision-courses (which would have triggered collision alert features in the display software). For each testing condition, each subject performed 30 judgments: ten judgments each at altitude differences d of 1000, 3000, and 5000 feet. On each trial, the subject was asked to use the mouse pointer to select the aircraft at the same altitude as the own-ship. In addition to the spatial configuration of the icons themselves, additional pictorial cues to the three-dimensional structure were provided by drop-down lines from each aircraft icon to the textured ground plane, and low-contrast shadows rendered on the ground plane.

Eight conditions were tested, comprising a 2x2x2 fully crossed design with the following factors: head-tracking/parallax enabled (yes/no); subject allowed to rotate display using mouse (yes/no); and initial rotation of the airspace about the horizontal axis (0/25 degrees).

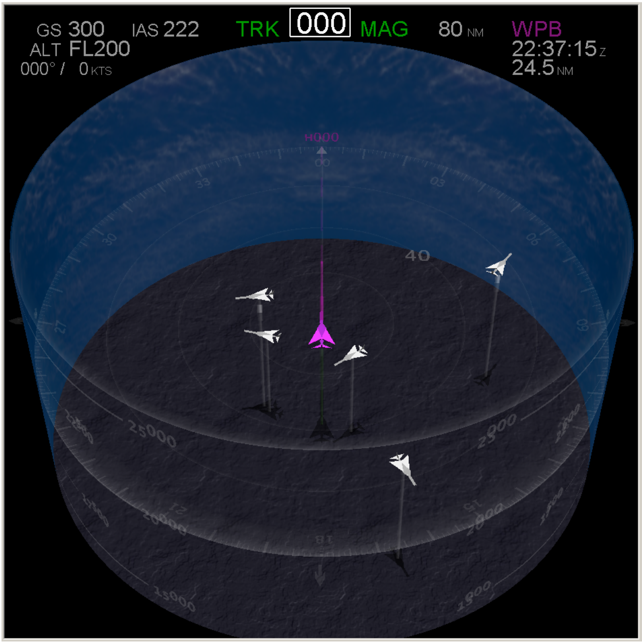

Figure 1: Typical traffic display used in the experiment.

3. Results

For the simple altitude matching task we tested, best performance was obtained when the subject was allowed to rotate the displayed airspace into a profile view (using the mouse); from this viewpoint, it was trivial to determine the single target aircraft at the same altitude as the own-ship. The average response time (across all parallax and initial viewpoint conditions) was 3.74 seconds (SEM = 0.11 seconds), and no errors were made.

Longer response times were obtained when the subject was forced to make the judgment in the initial view direction, using only pictorial and parallax cues. The average response time was 7.50 seconds (SEM = 0.63 seconds) for an initial view direction of 25 degrees, and 8.58 seconds (SEM = 0.62 seconds) for an initial view direction of 0 degrees (plan view). In both cases, significant numbers of errors were made (see figures 2 and 3). Performance was generally better for the oblique view, although this result was not statistically significant for the small number of trials.

As can be seen in figure 3, the elimination of the parallax cue did not cause a marked degradation of performance; indeed, for the smallest altitude difference some subjects showed improved performance. In this case, subjects were forced to rely on the static pictorial cues in the display: in the oblique view, the vertical "drop-down" lines were the most informative, as their length was directly proportional to altitude. Thus, subjects could follow a strategy of inspecting all of the drop-down lines, and selecting the one with the median length. While this strategy might have been used also in the conditions where parallax information was available, subjects attempted to use the parallax cue when possible. When the parallax cue was used to perform the judgment, the average response time was 10.39 seconds (SEM = 0.30), while in the absence of the parallax cue the average response time was 5.69 seconds (SEM = 0.30).

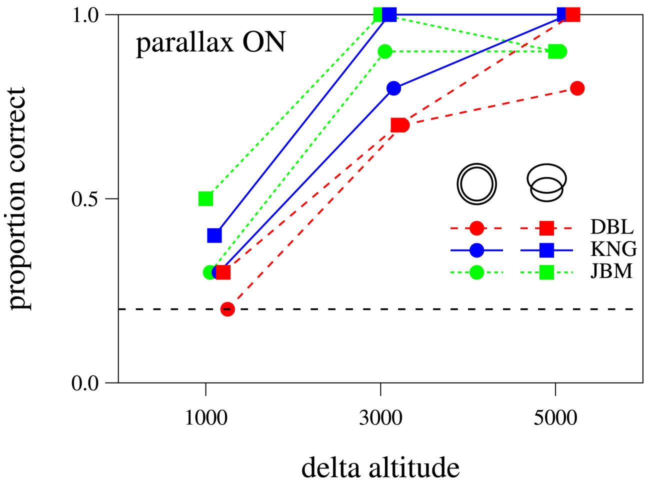

Figure 2: Proportion correct in altitude determination task with head-slaved parallax enabled. Initial view was either top-down (circles) or oblique, as in figure 1 (squares). The dashed line at the value of 0.2 represents the chance level in the five-alternative task.

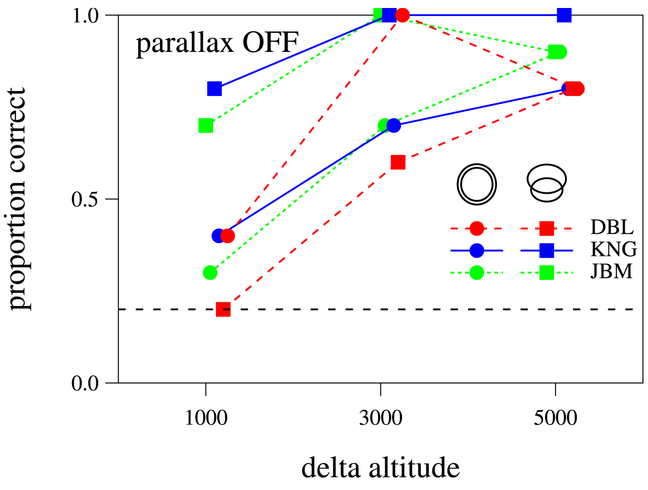

Figure 3: Proportion correct in altitude determination task using a static display.

4. Discussion

The configuration tested in the experiments described here failed to provide a compelling demonstration of the utility of the parallax cue. Qualitative statements from the test subjects also indicated that the degree of perceptual immersion in the three-dimensional construct was less than total. One reason why this may have been the case is that the virtual space which was depicted lay entirely behind the display surface (as if the display were the front surface of a fish-tank). This was done so that a situation could never arise in which an object needed to be rendered outside of the display area, but had the unfortunate side-effect of producing a significant mismatch between the parallax-defined depth and the depth implied by binocular disparity and accomodation (both of which implied that all of the objects were located in the plane of the display surface). We therefore plan to investigate in future work configurations in which the depth of the virtual objects is centered at the depth of the display surface, to minimize the conflict. The provision of correct binocular disparity cues is also expected to enhance the utility of the parallax cue.

Although the altitude discrimination judgment is both slower and less accurate when head-motion-driven parallax is the only cue available, it nevertheless has the advantage of allowing hands-free manipulation of the view. The advantages offered by view rotations larger than those generated by real head movements with respect to a virtual object suggest that exaggerated viewpoint shifts controlled by head movement might be valuable.

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