A COMPARISON OF THREE HMD SYMBOLOGIES FOR ATTITUDE MAINTENANCE IN A SIMULATED GENERIC ROTOR AIRCRAFT

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ABSTRACT

The present research examined the relative effectiveness and mental workload associated with the use of Anvis, Collar, and Theta symbologies for an attitude maintenance task. Subjects performed an attitude maintenance task and an auditory probe task in single- and dual-task conditions. Both the Collar (roll) and Theta (pitch) showed an advantage over the Anvis for minimizing deviations in attitude. Moreover, as indexed by the auditory probe task, the mental workload associated with performing the attitude maintenance task was generally less with the Collar and the Theta than with the Anvis. We suggest that the relative superiority of the Collar and the Theta can be attributed to the fact that these symbologies convey a strong sense of objectness.

INTRODUCTION

In the search and rescue (SAR) helicopter community there is a saying that "you cannot rescue what you cannot see". A less extreme version of this statement is the fact that it is much more difficult to complete a SAR mission when visibility is degraded: degraded visibility results in decreased situational awareness, a concomitant increase in pilot workload, and a risk that the SAR mission may need to be aborted.

To assist SAR pilots in dealing with degraded visibility, the Canadian Department of National Defence, in collaboration with University and Industrial partners, has launched an initiative to develop an Enhanced Synthetic Visual System (ESVS) in which images from three sources are projected onto a fully immersive head mounted display (HMD). (1) Images generated from a synthetic terrain database yoked to a GPS system. (2) Images from an online advanced sensor which is designed to pick up "culture", novel objects, and to provide additional detail to the terrain database when necessary. (3) Images of symbology representing primary flight and power data for the helicopter.

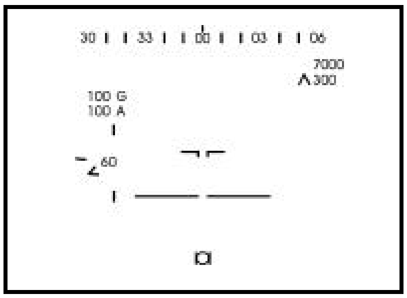
The present research was designed to evaluate the effectiveness of Anvis (Wytsma & LeBlanc, 1997), Collar (Thompson, 1996) and Theta (Geiselman & Osgood, 1993) attitude symbologies for use in an ESVS and in other possible HMD applications. As discussed below, the Anvis is a relatively standard, but impoverished 2D representation of attitude. In contrast, the Collar and Theta each convey a strong sense of 3D objectness. Insofar as objectness may facilitate the perception and interpretation of information in complex visual displays (Wickens & Long, 1995), it was hypothesised that the Collar and Theta would be more effective representations of attitude than the Anvis. To test this hypothesis, an attitude maintenance task was used in which subjects were required to minimise deviations in pitch and roll. In addition, an objective measure of mental workload was included.

Symbology Sets

The Anvis, Collar, and Theta attitude symbologies were embedded within a common set of flight and power information including heading tape, ground and air speed, torque (bottom left), slipball, altitude and VSI (top right). To confirm that subjects used the attitude symbologies to facilitate performance, a no-attitude symbology condition (none) was included in the present study. The "none" condition included all of the common symbologies, but no specific horizon and aircraft positioning information.

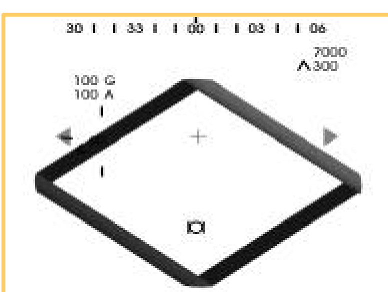
The Anvis attitude symbology consists of a moving horizon line and a stationary aircraft symbol.[1] As shown in Figure 1, there is nothing intrinsic to the Anvis symbology to suggest that the lines form "objects".

Figure 2: Anvis



The Collar (Figure 2) was implemented as a semi-transparent 3D object: the 3D appearance of the Collar was achieved through the presence of shading and "Y"/arrow junctions. Following the specifications described by Thompson (1996), the Collar spanned 30^0 (w) x 20^0 (h) object with sides of 1^0. These visual angles are such that when gaze is directed centrally, changes in the Collar's positioning should be perceived pre-attentively (Enns, & Resnick, 1991). The Collar may be especially useful for HMD applications because the centre of the screen (i.e., the inside of the Collar) is uncluttered. In addition, research by Thompson has shown that the Collar is effective for tracking, a task that is of relevance to SAR and a variety of other helicopter-based missions.

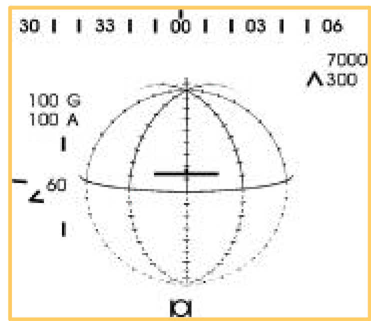
Figure 2: Collar



[1] *All three of the attitude symbologies were implemented using this inside-out frame of reference*.

The Theta (Figure 3) was implemented as a semi-transparent 3D ball. The upper lines of the Theta were solid and the lower lines dashed. The longitudinal lines represent 45^0 increments. The centre line bisecting the ball represents the horizon whereas the inverted"T" represents the aircraft. Geiselman and Osgood (1993) have shown that the Theta is very effective for maintaining attitude.

Figure 3: Theta



METHODS

Participants

Twelve students recruited from the aerospace engineering program at Carleton University participated in this study. All of the participants were non-pilots.

Facility

The study was conducted on a stationary flight simulator at Canadian Marconi Company, Kanata, Canada. The simulator was equipped with a pphysical flight deck structure, including cockpit housing and aircraft seating, low fidelity flight control systems (cyclic, collective, rudder pedals) and an immersive HMD providing a binocular field of view with 79^0 x 40^0 FOV at VGA resolution. Flight dynamics were modelled with HELISIM using performance data for a Bell 412 helicopter. A simulated turbulence algorithm was affected about the pitch and roll axes of the flight model. The simulated turbulence was confined to the pitch and roll axes in order to minimize the pedal adjustment required when in forward flight. Three amplitude and period constants were used in a 2nd order geometric series to provide simulated turbulence levels categorized as low, medium and high.

Design

A 4 (Symbology: none, Anvis, Collar, Theta) x 2 (Condition: single-task vs. dual-task) x 3 (Turbulence:

low, medium, high) design was used with repeated measures on each factor.

Procedure

Each subject completed 4 sessions. Each session consisted of 5 blocks of trials with blocks 3-5 representing the core of the experiment:

Block 1: Free-flight familiarization
Block 2: Practice attitude maintenance
Block 3: Single-task attitude maintenance
Block 4: Single-task auditory probe
Block 5: Dual-task

Single-task attitude maintenance (block 3). For this block subjects were given 10 x 45s frames. The 45 s frames were separated by 2 s intervals. Each frame included 15s low, 15s medium, and 15s high turbulence (randomly inserted). At the start of each frame the helicopter was set at 7000', 100 knots, and 00^0 North. In order to force the subjects to rely on the symbology rather than on external (world) cues, the helicopter was placed in simulated dense cloud. Subjects were instructed to minimise deviations in pitch and roll throughout each 45s frame.

Single-task auditory probe (block 4). The auditory probe task was included to index mental workload. For this task a go/no-go paradigm was used (Herdman, 1992; Herdman & Dobbs, 1989; Logan & Burkell, 1986) in which subjects were to elicit a response when a high-pitch (360 Hz) tone was presented but to refrain from responding when a low-pitch (313 Hz) tone was presented. Subjects were instructed to respond as quickly and as accurately as possible by depressing a trigger on the cyclic with the index finger of their right hand. Block 4 provided a baseline measure of performance against which performance in a dual-task could be compared. This block consisted of 10 x 45 s frames. For each frame, a total of 18 tones were presented, 9 high and 9 low pitch. Each tone was presented for 50 msec using the speaker of the computer located directly behind the pilot's seat. The presentation of the tones was organized into 3 x 15 s intervals (with 3 high and 3 low tones per interval) to correspond to the turbulence intervals used in the flight task. The presentation order of the high and low tones was random within each 15 s interval. To prevent subjects from predicting the onset of a tone, the ISI separating the tones was between 1 and 3 s, randomly determined.

Dual-task (block 5). In this block, the attitude maintenance task and the auditory probe task were performed concurrently. Subjects were instructed to protect performance on the attitude maintenance task (i.e., concentrate on minimizing deviations in pitch and roll), but to respond quickly and accurately to auditory probe task. There were 10 x 45 s frames with each frame divided into 3 x 15 s intervals (one per each turbulence level).

RESULTS

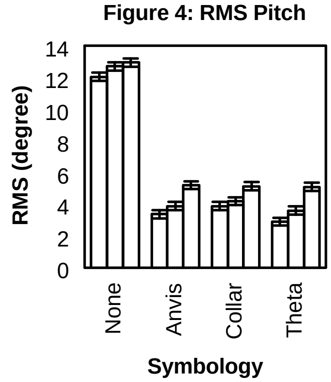
The data are shown graphically in Figures 4-6. In each figure, the open bars represent a left-to-right ordering of low, medium and high turbulence for each of the attitude symbologies. An alpha level of .05 was adopted for the present research: all effects that are discussed are significant at this level. In accord with Loftus and Masson (1994), main effects and simple effects were assessed using 95% confidence intervals. The 95% confidence intervals are shown in the figures rather than error bars.

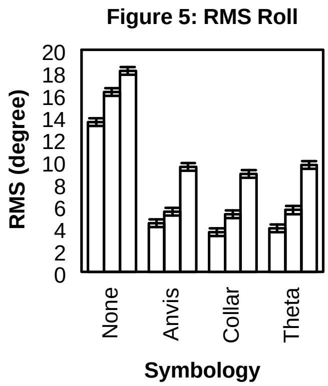
Attitude Maintenance Task

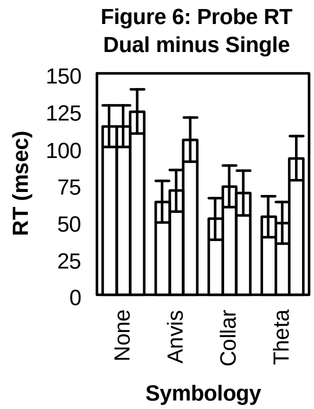
RMS pitch and roll values did not differ in single- vs. dual-task conditions, indicating that, as instructed, subjects successfully protected performance on the attitude maintenance task in the dual condition. Thus, analyses were conducted on the combined single- and dual-task RMS values.

As expected, RMS pitch (Figure 4) and RMS roll (Figure 5) increased across the three levels of turbulence. In addition, deviations in pitch and roll were minimized better when an attitude symbology was present as compared to when no attitude symbology (None) was available. This shows that the subjects were indeed using the attitude symbologies to perform the attitude maintenance task. For pitch, deviations where minimized better with the Theta than the Anvis or the Collar in the low and medium turbulence conditions. For roll, deviations were minimized better with the Collar than the Anvis or the Theta in the low and high turbulence conditions.

Figure 4: RMS Pitch







Mental Workload

The objective measure of mental workload was obtained by subtracting single-task probe RT's from the corresponding dual-task probe RT's. As shown in Figure 6, difference scores were all positive, indicating that mental resources were taken away from the probe task in the dual condition in order to concurrently perform the attitude maintenance task. Single- to dual-task decrements in probe performance increased across the three levels of turbulence: As turbulence was increased, subjects were required to expend more mental effort to perform the attitude maintenance task. Decrements in probe performance were greatest in the no-symbology condition. This compliments the RMS data in showing that having an attitude symbology present was beneficial. Of primary interest is that relative to the Anvis, mental workload associated with performing the attitude maintenance task was less with the Collar (high turbulence condition) and the Theta (medium turbulence condition).

DISCUSSION

The RMS pitch, RMS roll, and auditory probe results show that having an attitude symbology available resulted in better performance as compared to a condition when no attitude symbology was present. This finding is important in that it allows the conclusion that the subjects were in fact using the attitude symbologies to perform the attitude maintenance task. The effectiveness of the attitude symbologies was influenced by turbulence, such that increases in turbulence resulted in greater deviations in pitch and roll as well as increased mental workload. This confirms that the dependent measures used in the present research were indeed sensitive to variation (e.g., turbulence) imposed on the flight model.

Both the Collar (roll) and Theta (pitch) showed an advantage over the Anvis for minimizing deviations in attitude. Moreover, as indexed by the auditory probe task, the mental workload associated with performing the attitude maintenance task was generally less with the Collar and the Theta than with the Anvis. In fact, under high turbulence, use of the Anvis symbology resulted in a workload that was similar to that observed when no attitude symbology was present.

Objectness

Researchers have noted that objectness may facilitate the perception and interpretation of information in visual displays (Wickens & Long, 1995). In Gestalt terms, objectness can be defined as the extent to which features provide a sense of closure, similarity, spatial grouping, and continuity of form. In dynamic displays, a sense of objectness will be created when features move in a coherent manner. Objectness may also be defined by the extent to which features form a recognizable form.

To provide an index of objectness, the subjects in the present study completed a post-experiment questionnaire where the attitude symbologies were ranked in terms of the extent to which they represented a "unified object that moved in a coherent manner." Both the Collar and the Theta (average rankings of 1.42 and 1.5, respectively) were ranked as being significantly more object-like than the Anvis (2.75).

There are several reasons why objectness may facilitate processing of information in complex visual displays. For example, it is known that global (object) level information precedes processing of local (featural) level information (Navon, 1977). On this view, objects may be processed more quickly than a perceived disjointed collection of features. Research has also shown that object recognition can precede and influence the process of separating a visual scene in to figure versus ground (Peterson & Gibson, 1994). Figure/ground separation is a fundamental online requirement that is especially germane to HMD applications where symbology must be distinguished from the external scene. For situations where pilots are frequently directing their gaze away from the centre of the HMD, objectness may facilitate (a) the speed at which the attitude symbology can be re-acquired and located, and (b) the automatic perception of movement in the attitude symbology as it moves in the visual periphery.

Conclusions

The present research shows a benefit for object-like symbologies in an attitude maintenance task. Given that apprehending information on complex HMDs is often challenging for pilots, full consideration should be given to using objectness as a fundamental principle in designing attitude and other flight and power symbologies.

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AUTHOR NOTES

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