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Ecological Display Design for the Control of Unmanned Airframes

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1. INTRODUCTION

Unmanned airframes may be used for reconnaissance, target tracking, and battle damage assessment. Important operator tasks are the steering of the platform along the desired path, and the control of the on-board camera. The (sensory) information presented to the human operator is scant. No auditive, haptic, or tactile information is available, and the visual information is of degraded quality (Agard, 1995). This results in poor operator performance. Because information on airframe and camera position and heading is essential but can not be deduced from the outside world images, it is usually presented by additional pictorial displays, by walking tapers, or by points and lines on an electronic map. This paper describes an alternative approach: present the characteristics of the visual information as normally used in steering and orientation tasks. The visual system has evolved to use information contained in optic flow, and may pick-up this information without effort (Gibson, 1950). This is fundamentally different from pictorial or numerical information presentation. We call this *ecological display design*. The ecological approach contrasts sharply with the organismic approach (Vicente, 1995), which tends to ascribe skilled behaviour to elaborate mental constructs and cognitive processes (Kirlik, 1995). The ecological approach places emphasis on environmental analysis (Effken, Kim & Shaw, 1997).

Ego- versus world- frame of reference

Searching for and tracking of targets and other relevant points in 3D space calls for a different state of knowledge than steering the airframe along the desired route, viz. global awareness versus local guidance. The information for global awareness must be presented in a world referenced (north-up) display (Wickens, 1992; see also Roscoe, 1968). However, local guidance tasks predominantly need correspondence between display and control in terms of left, right, etc. This means that steering the airframe requires an *ego-referenced* display (heading-up).

2D versus 3D egocentric displays

The characteristics of an ego-referenced 3D (perspective) display are more ecological than of a 2D display (Warren & Wertheim, 1990): correspondence between display and controls, forward cone of visual space, zoomed-in, and the 3D perspective (see Figure 1). A 3D presentation has advantages for local guidance, as shown by the results of experiments in a flight simulator: with a 3D display, tracking error is reduced (Haskell & Wickens, 1993; Prevett & Wickens, 1994). The specific character of an ego-referenced 3D display is determined by the elevation angle. An elevation angle of exactly 90° (looking down) or 0° (looking to the horizon) leads to compression of one dimension, and thus to a 2D display. Ellis, Kim, Tyler, McGreevy & Stark (1985) found a U-shaped tracking error curve, with best performance at 45°. Kim, Ellis, Hannaford, Tyler & Stark (1987) replicated these results, and found little effects in the range between 30° and 60°.

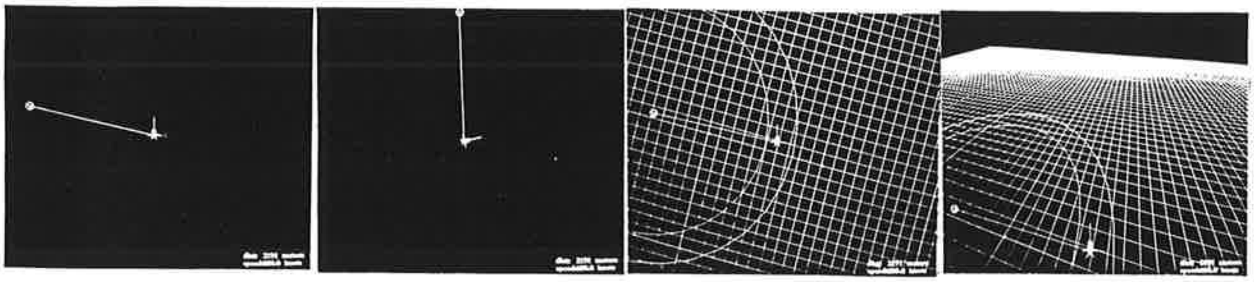

Figure 1. The four displays used: pictorial heading-up and north-up, and ecological 2D and 3D. Airframe speed and standoff distance depicted in the right corner.

One might argue that relatively large elevation angles support lateral tracking, and that relatively small elevation angles support vertical tracking. In steering the airframe, lateral tracking may be more important, because the airframe often flies at a fixed altitude. This pleas for an *elevation angle between 45° and 60°*.

Digital versus pictorial presentation of the standoff distance

Designing the ecological display, three principles for airborne displays (Roscoe, 1968) are relevant for depicting the standoff distance to a target: 1) display integration (which states that it is beneficial to integrate indicators into a single presentation), 2) pictorial realism (which states that graphically encoded information (symbols) can be readily identified with what they represent), and 3) pursuit tracking (which states that pursuit tracking is superior to compensatory tracking). This pleas for a *graphical* presentation of the standoff distance which allows *pursuit tracking*.

2. METHOD

To evaluate the ecological display design, a controlled simulator experiment was conducted. Ten paid male under graduate students participated. The experimental task was tracking a target ship with the camera, while flying the airframe in a circle (counterclockwise) around the target ship. An important instruction was to keep a standoff distance of 2250m to the target, without coming closer than 2000m.

The following dependent variables were calculated: RMS of the camera tracking error; percentage time closer than the minimum standoff distance, and standard error (s.e.) from 2250m standoff distance. A full factorial DISPLAY DESIGN (4) × AIRFRAME SPEED (3) within subjects design was used. See Figure 1 for the display designs. Airframe speed had three levels (60, 120, and 180 knots), and was introduced to vary task difficulty.

Participants always came in pairs for two consecutive days: one could rest, while the other was engaged in the experiment. After arrival, they received a written instruction, and an introduction training, during which the experimenter explained controls and images. During the experiment a recurrence training was given before every new display condition. Participants completed three 200 s scenarios in succession.

Two high resolution monitors (MITSUBISHI HL7955SBK) depicted the camera image (generated by an EVANS AND SUTHERLAND ESIG 2000 (800×600 pixels, 30 Hz, 4° × 3°), and the different display designs generated by a SILICON GRAPHICS IRIS 4D (1280×1024 pixels, 30 Hz, 120° × 96°). The pictorial designs included symbols for the airframe with heading, and camera heading and pitch. The ecological displays included an earth-fixed grid, target fixed distance circles, and a symbol for airframe and camera heading and pitch. The ecological 3D display was generated for an elevation angle of 48°. For more details on mockup and instrumentation, see Van Erp & Kappé (1996).

3. RESULTS AND DISCUSSION

Camera control (RMS tracking error) showed a main effect of airframe speed only; $F(2,18) = 3.59$, $p < .01$. This indicated performance degradation with increasing airframe speed.

The dependent variables on airframe control both showed a main effect of display design; percentage of time with standoff distance too small: $F(3,27) = 11.96$, $p < .01$ and s.e. of the standoff distance: $F(3,27) = 3.83$, $p < .025$). A post hoc test revealed that performance in the two pictorial displays is worse compared to the ecological displays for both measures.

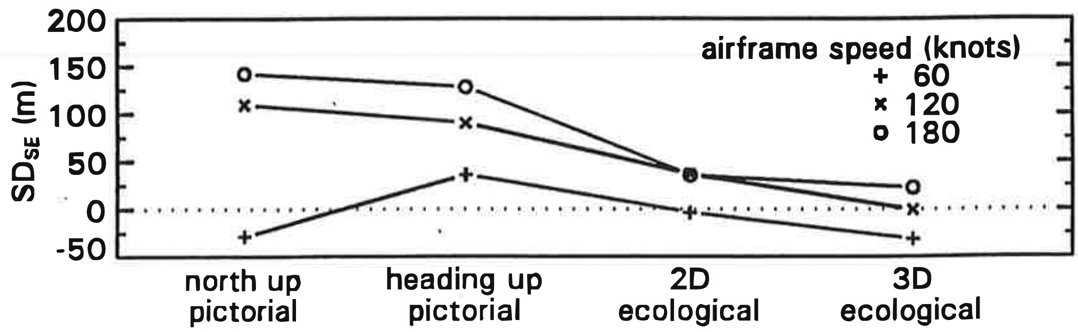

Figure 2. Interaction display design × airframe speed for the standard error of the standoff distance (SD_{SE}).

There was a significant interaction between display design and airframe speed on s.e. of the standoff distance: $F(6,54) = 3.06$, $p < .025$. A posthoc Tukey test showed that performance was independent on airframe speed with the ecological displays only, see Figure 2.

Absence of an advantage of the north-up display compared with the heading-up display may be explained by the fact that participants concentrated on the angle between airframe heading and camera heading, which should be fixated at 90° when the standoff error is correct. Performance improvement with the ecological displays is 30%. They help both in controlling the course of the airframe and preventing the airframe from coming too close. Furthermore, performance is less sensitive to task difficulty. The finding that performance with the 3D version is not significantly better is inherent to the task of lateral tracking only.

Although not all hypothesized effects were found, the results show that applying ecological display design rules (presenting a caricature of the visual information as normally used in steering and orientation tasks) improves the control of unmanned platforms.

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