Situational Awareness of UAV Operators Onboard Moving Platforms

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Abstract

A helicopter-based operator of an unmanned aerial vehicle (UAV) has to deal with an additional frame of reference compared to a ground-based colleague. The goal of the research was to determine whether the situational awareness (SA) of a moving UAV-operator differs from the SA of a stationary operator.

In a simulator experiment, we provided UAV-operators with a set of displays having two design dimensions: map orientation (north-up / heading heli up / heading UAV up) and map center (heli / UAV). During half of the trials motion feedback was given, i.e. large visuals showed the imagery corresponding to a view from the heli. We assessed SA in world-centered terms and in vehicle-centered terms.

We found clear evidence that the feedback on the heli's motion influences the UAV-operators' SA. For instance, operators have more problems answering world-referenced questions when motion feedback is present, whereas heli-referenced questions are answered more accurately. Overall, the best display seems to be the north-up display.

Introduction

Moving observers may link their spatial observations in various ways to a reference frame. Roughly speaking, two types of frames can be distinguished: a frame based on fixed coordination points in the world (an allo-centric reference frame) and a reference frame attached to the observer or the observer's moving platform (an ego-centric reference frame). The reference frames can exist as an observer's internal representation or in various symbolic forms on media such as paper and displays.

An example of an allo-centric reference frame is a topographic map. Objects on this map have an absolute position related to a fixed co-ordinate system (usually the Greenwich meridian and the equator) and a direction is specified by means of a compass bearing. The orientation of the map is fixed, usually with left-hand and right-hand side of the map corresponding to west and east, respectively. Allo-centric reference frames are often used in situations where several observers have to communicate about positional information and for localization of stationary objects. They are generally used for planning long-term movement.

In an ego-centric reference frame the origin is located at the position of the observer and directions are related to the longitudinal axis or the direction of motion usually in terms of left, right, port, starboard, fore, aft and/or clock positions. Ego-centric electronic maps usually rotate to keep the heading of the ownship in a fixed direction on the display. They are used to convey time-critical information that is strongly related to the platform's current heading. A pilot of a low-flying Chinook helicopter needs to hear clearance information from his crew, given in platform related coordinates. "No clearance aft" is better than "A tree in the north-west". The latter description requires an interpretation that can take a dangerous amount of time and is prone to error.

In a nutshell, reference frames play a role in the user's internal representation, in his task and in the various media that support this task.

In our experiment we studied the situation of a moving operator of an Unmanned Aerial Vehicle (UAV). Usually, a UAV operator is stationary, but here we examined the special situation of the US Army's AMUST (Airborne Manned Unmanned System Technology) concept (Fayaud 2001). In AMUST, an Apache helicopter and a Hunter UAV form a team, where the UAV may perform all kinds of useful sidekick tasks, such as reconnaissance, laser-designation of targets and acting as decoy. The UAV can be either controlled from a Ground Control Station (GCS) or by the Apache's co-pilot/gunner.

The AMUST concept adds to the complexity of maintaining SA. The operator (the co-pilot / gunner) has to deal with at least three frames of reference, namely the world, the helicopter and the UAV. This leads to numerous questions, but we have focussed ourselves on one: *is the interpretation of positional and directional information by the observer influenced by his (visually perceived) motion and which type of display provides the best support?*

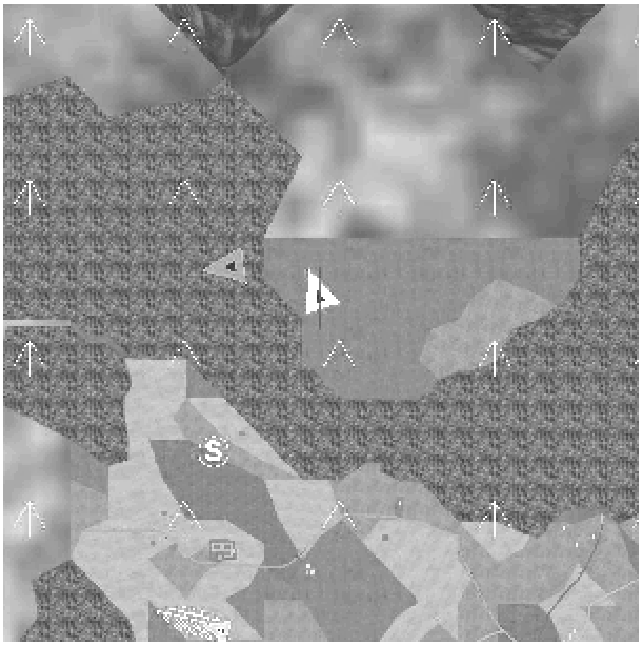

Figure 1: Part of a north-up map (one of the six possible formats) centered on the heli. To the left the UAV is visible and towards the bottom of the map the football stadium and the column of tanks can be seen.

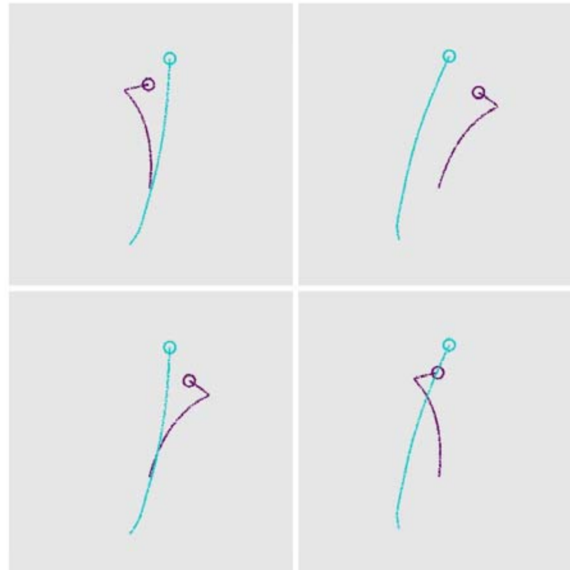

Figure 2: Screen shown to the participants after a run. Each of the four boxes shows a possible trace of the finished run.

Method

Global Description

In a simulator experiment, participants serving as UAV operators were seated behind a UAV console situated in a helicopter mock-up. The console displayed an electronic map of the geographical situation of UAV, helicopter and a few other objects using various formats. The simulator visuals could be either on or off to examine the influence of the visually perceived self-motion on the operator's SA. For each run, the participants watched the movements on the display after which their SA was assessed by means of a questionnaire.

Apparatus

The helicopter mock-up used a spherical dome to show the outside visuals, generated by three Evans & Sutherland "SimFusion" image generators. This system delivered images of about 150º (h) by 40º (v).

The electronic map (see Figure 1) was presented on a 17 inch touchscreen monitor which was also used for the questionnaire. The display behavior could be varied by making a choice of map orientation and map center. This yielded a total of six possible formats. The "map orientation" dimension consisted of three levels:

- north-up: map has a fixed orientation with north-up; when entities in the world rotate, their symbols rotate correspondingly,
- heading heli up: map rotates to keep the heli's heading upwards on the map, and
- heading UAV up: map rotates to keep the UAV's heading upwards on the map.

The "map center" dimension consisted of two levels: either the heli or the UAV position could be fixed in the center.

Apart from UAV and heli, indicated by triangular symbols, two other objects were present in the experiment: a football stadium (marked by a circle) and a column of tanks (marked by a set of triangles).

Task

Both the UAV and heli movements were scripted. The participants' only task was to monitor the UAV, heli, tanks, and the stadium for 40-60 s.

After each run, the map disappeared and the participants were asked to answer three questions on either absolute or relative position of the football stadium with respect to column, UAV or heli. 'Absolute' questions called for an answer in world coordinates (compass directions) and 'relative' questions asked for an answer relative to the motion direction or longitudinal axis of the reference object (column, UAV or heli). The questions were answered by touching a position on a large circle with the reference object in the center.

A screen showing four possible traces of the UAV and heli (see Figure 2) followed the three questions. Subjects touched the box they thought corresponded to the real traces. All questions were to be answered as quickly as possible.

Procedure

The experiment lasted six days. On each day two participants were present. Instruction, training and measurements took the whole day. One of the participants started with outside visuals and the electronic map display, while the other was provided with the electronic map only. Halfway through the experiment their positions and corresponding outside visual condition were changed. For each outside visual condition the participants observed 96 trials. The trials were blocked by map condition in sets of 16 runs according to a Latin square design. Of the 16 runs, 8 runs were followed by a set of three ‘relative’ questions and 8 runs were followed by three ‘absolute’ questions. In total, each participant observed 192 runs, with 576 questions on positions and 192 questions on vehicle tracks.

Independent Variables

For both tasks we used the following independent variables:

- Motion feedback by means of simulator visuals (absent, present)
- Map center (heli, UAV)
- Map orientation (north-up, heading heli up, heading UAV up)

For the orientation estimation task we additionally used:

- Type of orientation used in question (absolute or relative)
- Reference object (column, heli, UAV)

Dependent Variables

We used four dependent variables. For the direction estimation angular error and reaction time were used and for the trace recognition task we used the percentage of correct responses as well as the reaction time.

Participants

Twelve male trainees of the Royal Dutch Airlines (KLM) with an mean age of 21.8 years took part in the experiment. On average, their experience consisted of 231 flying hours of which 38 in a flight simulator.

Results

Direction Estimation

Given the large number of dependent and independent variables we can only show a representative sample of the results. Figures 3 and 4 provide an overall impression of angular error and reaction time for each experimental condition. A clear difference can be seen between the patterns of the left and right panels (visuals absent or present, respectively). In Figure 3, the relative questions

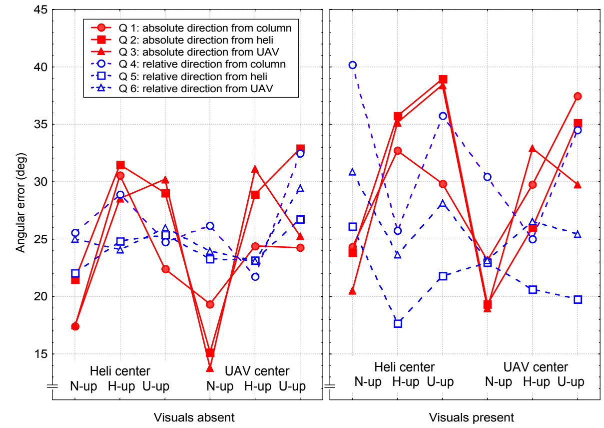

Figure 3: Angular error as a function of map type (x-axis) and question type (lines)

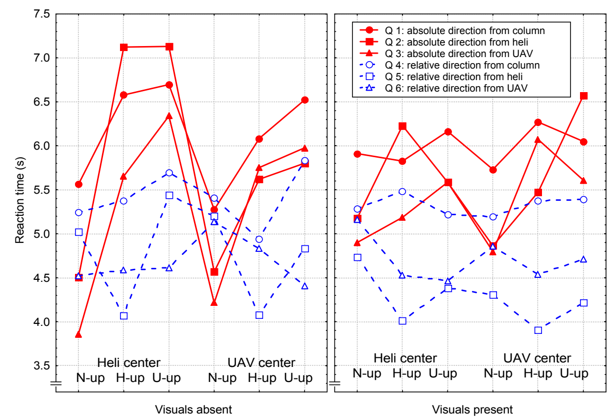

Figure 4: Reaction time as a function of map type (x-axis) and question type (lines)

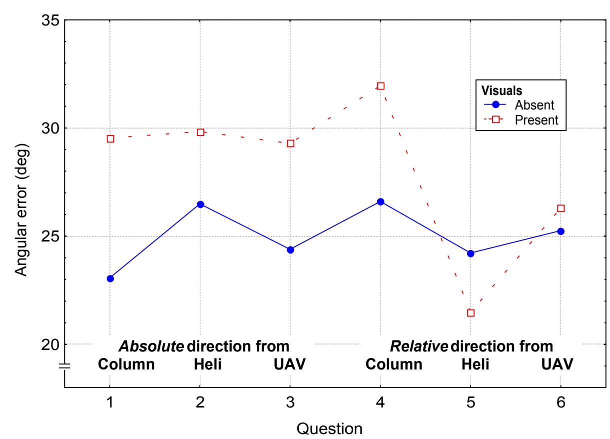

Figure 5: The interaction between question type and presence of visuals. The numbering of questions is the same as in Figure 4.

(dotted lines) show a large variation when visuals are present; in Figure 4 the decrease in variation when visuals are present is quite noticeable.

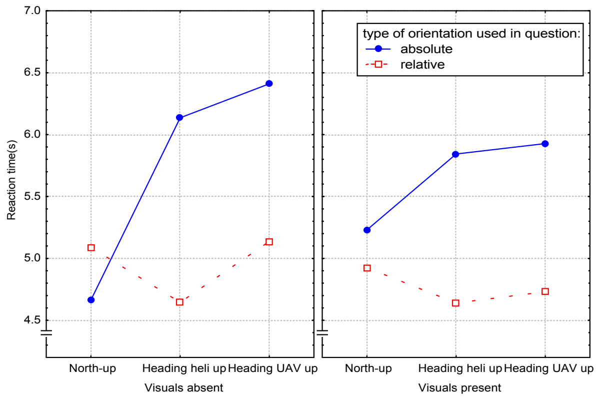

Figure 6: The interaction between map orientation (x-axis), question type (lines) and motion feedback (panels).

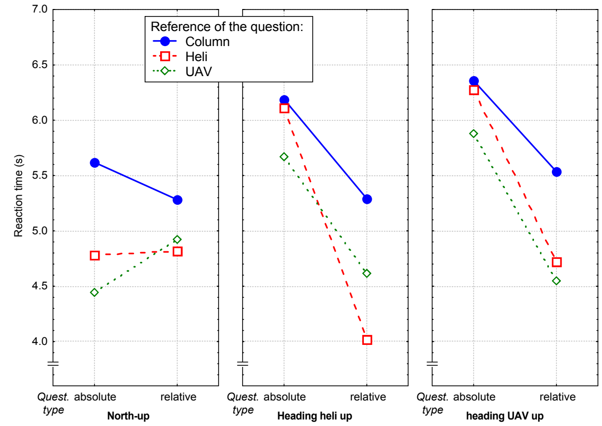

Figure 7: The interaction between question reference (lines), map orientation (panels), and question type (x-axis).

Examining the effects of the various display types on the angular error, it appears that it does not seem to make a difference which vehicle is used as map center except when relative questions are asked and motion feedback is present (dotted lines in the right-hand panel).

North-up displays are superior for absolute orientation questions. An analysis of variance (ANOVA) shows that there is a significant main effect of map orientation (p=.007 and p=.018 for angular errors and reaction times, respectively). This is a result similar to those of single-platform experiments (Wickens and Prevett 1995).

There are several significant interactions involving the presence of motion feedback. Figure 5 shows an example. The interaction between presence of visuals and question type is significant (p=0.04). The angular error for relative questions concerning the heli decreases clearly when the visuals are present. More unexpected is the decrease in errors on questions regarding the relative direction of the UAV. All other questions are answered worse when visuals are present.

Figure 6 shows the significant interaction (p=.0027) between map orientation, question type and presence of motion feedback. Absolute questions take more time than relative ones except when there is no motion feedback and a north-up display is used.

Track Recall

We did not find any significant effect of motion feedback on track recall. We did find, however, a significant effect of map orientation (p=.0001).

North-up displays yield more correct answers (77%) and shorter reaction times (9.2 s) than either heading heli up displays (68% and 9.9 s, respectively) or heading UAV up displays (60% and 10.4 s respectively).

Conclusions

We found clear evidence of the influence of motion feedback on the SA of the moving UAV operator. This source of information is interfering with absolute localization of objects. However, motion feedback improves SA tasks that are related to the orientation of the heli.

For that particular task, the best display was the “heli-centered heading heli up”-display. For an all-round set of SA tasks it seems to be better to use a north-up display.
The strong task dependence of the results makes it difficult to generalize the results to a broader set of operational tasks. Especially active control of the UAV by the operator, getting feedback from its sensors and vestibular inputs may shift the results. The current experimental paradigm can be easily extended to examine these cases.

References

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Wickens, C.D.; and Prevett, T.T. 1995. Exploring the Dimensions of egocentricity in aircraft navigation displays. *Journal of Experimental Psychology: Applied* 1: 110–135