'Castling Rays' a Decision Support Tool for UAV-Switching Tasks

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Abstract
This project is a collaborative research effort of the Israeli Air Force (IAF), Synergy Integration LtD. and Ben-Gurion University. It is directed to design and develop tools and display layouts to facilitate task switching and coordination among operators in Multi-Operator Multi-UAV (Unmanned Aerial Vehicle) environments. All for the benefit of improving overall mission performance.

In this paper we focus on one of the main tools that were developed – 'Castling Rays'. The 'Castling Rays' tool is a UAV-switching decision aid, enabling operators to visually view which UAV has the best view of 'their' target at any given moment. Structured interviews with experienced operators strengthened the necessity and importance of this tool in reducing operators' workload and improving their situation awareness.

Keywords
Task switching, castling, situation awareness, workload, decision support tools, UAV, Interaction design

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces: User-centered design.

General Terms

Design, Human Factors, Performance

Introduction

Multiple operators controlling multiple unmanned aerial vehicles (UAVs) will often require switching between UAVs. This switching is a time-critical, cognitively demanding task.

In the literature, task switching ranges from very simple stimuli-response tasks, where the switch costs are relatively low [5] to more complex domains such as UAV control and robotics [3]. In Multi-operator Multi-UAV (MOMU) environments, which are now common in battle management, switch costs may have a vital effect on mission accomplishment. Cognitive aspects of switch costs may be loss of orientation and situation awareness, increase in workload, and decrease in efficient verbal team communication. Thus, the switching between UAVs can disrupt operator performance [2]. As the autonomy of UAVs increases and interfaces improve, switch costs gradually become the bottleneck which limits the number of UAV's that a single operator can manage or be aware of [4].

Consequently, the aim of this project was to identify what information and which tools may facilitate quick and efficient task switching and coordination among MOMU operators, in order to decrease switch-costs and improve mission performance. For this purpose, The Israeli Air Force (IAF) collaborated with Synergy Integration LtD. and Ben-Gurion University to design and develop superior display layouts and tools. One of the main tools is the 'Castling Rays', which is the focus of this paper. The 'Castling Rays' tool is a UAV-switching decision aid, enabling operators to visually view which UAV has the best view of 'their' target at any given moment.

In the next sections, we describe, from a human-computer interaction perspective, the UAV switching task and the design and evaluation of the 'Castling Rays' tool.

UAV Switching

In MOMU environments, the main reason for switching is concealment. Thus, the operator foresees that a moving target (e.g. a designated target vehicle) might enter a concealment zone (e.g. drive under a bridge, be obscured by buildings, or perform a turn) that would block the UAV's view. In order to maintain line of sight with the target, the operator is forced to switch to another UAV which has a complementary view.

Following human information processing [e.g. 6], the UAV switching task may be divided into three stages: (1) problem recognition (2) decision making and (3) action implementation. Such decomposition enables a more comprehensive evaluation of system performance [6] and encourages the design of tools supporting each stage:

1. Problem recognition - recognize situations where the operators might lose line of sight with their targets.
2. Decision making - identify and select which other UAV/s may be acquired (switched to) in order to fulfill the viewing gap and confirm that the desired UAV is available for switching.
3. Action implementation - switch between the UAVs while preserving line of sight with the target.

The above process is time consuming, produces mental workload, and requires high individual and group situation awareness, including communication among operators. Thus, in each of the above stages, a human error may occur which may disrupt operator performance and lead to losing the target.

The main goal of the design and development of the 'Castling Rays' tool was to simplify the second stage (decision making) of the task switching process. This was done by presenting a visual display overlay on the dynamic video, enabling a visualization of which other UAV/s have the best view of 'the' target at any given moment. Thus, operators can acquire the desired information at a glance.

Previous research on presentation of synthetics visual overlay, in real time on the video imagery, has been demonstrated to reduce scanning time, reduce the need to mentally integrate spatial information from disparate sources, and facilitate attentional management [9]. Only recently, synthetic visual overlays were evaluated for UAV missions (for a detailed review see [2]). However, research in general on tools which facilitate UAV switching is scarce. The tools that exist concentrate mainly on the 'Action implementation' stage (the switching itself) [e.g. 3], and not on the 'decision support' stage. Thus, we are not familiar with other tools which were evaluated for facilitating the 'decision making' step, aiding operators to identify and select the optimal UAV for switching. Consequently, tools such as the 'Castling Rays' may be essential for completing the process of UAV switching successfully.

The 'Castling Rays' tool

Today, in order to identify which UAV is optimal for switching, the operator mentally integrates spatial information from disparate sources. First by locating the other UAV's in the command and control map (see figure 1), then by analyzing their field of view (line-of-sight) according to their location, and finally, by computing how the specific UAV will view his target. This process is not only time consuming but also requires mental and cognitive efforts, which are susceptible to human errors.

figure 1. UAV's on the command and control map. Here operators can view the location of all UAVs in the arena. Specifically in this example there are three UAVs (marked in red, green and yellow).

The 'Castling Rays' (shown in figure 2), enable the operator to view on the video stream window, at a glance, which UAV has the optimal line of sight to his/her target. This reduces the need of the operators to view and analyze data from the command and control map (Figure 1).

The 'Castling Rays' can be displayed automatically or by a press of a button, according to users' preference definitions. The tool has several characteristics:

- The color represents the color of the UAV.
- The width displays the distance of the UAV from the target - the closer the target is, the thicker the line.
- A dashed-line represents a limited line of sight.
- The inclination angle of the UAV is displayed in addition to the ray. An open-angle versus a closed-angle (wider angles indicate that the UAV may be more susceptible to occlusions).

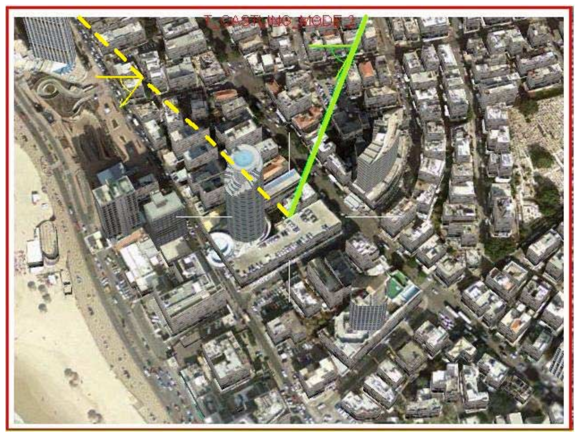

figure 2. 'Castling Rays' tool. Here in this example, the operator is monitoring a target with the red UAV. The castling tool shows the green UAV with a continuous line indicating that it has a good line of sight of 'my' target. The yellow UAV on the contrary is shown with a thinner dashed line which indicates that it has no line of sight of 'my' target.

Design Evaluation

Structured interviews, which include first experiencing the tool followed by questioning, were performed with four subject matter experts (SMEs). The objective of these experience-based interviews was to evaluate whether the 'Castling Rays' tool enhances participants' overall situation awareness, decreases workload and improves performance on a switching-UAV task.

Methodology

Participants performed a representative surveillance task (following a target vehicle). When they entered a concealment zone, they had to switch UAVs. There was no hierarchy among the MOMU team members. Hence, when one operator requested switching, the other operator had to agree (assuming the operator initiating the switch had the more prioritized task). Situation awareness, workload and specific objective performances were examined after participants completed trials both with and without the tool in a MOMU control simulation environment.

Experiential environment

The interviews were held at Synergy Integration LTD, simulation facility. To avoid group consensus, each SME was interviewed individually, but was told that he was one of 3 operators handling 3 UAV's in a networked environment. One of the experimenters acted as the "two other operators" generating a MOMU team. The interview room included three working stations (a simulator running on a 17" PC with a mouse), one for the SME and two for the experimenter. Each interview was videotaped and notes were taken.

Interview procedure

4 highly experienced male operators with similar military background, skills and experience were interviewed. Their age ranged from 25 to 28. Each interview session lasted 7-8 hours (~ 30 hours for all four interviewees), examining several tools and layouts. The orders of the layouts and tools were counterbalanced for participants and scenarios.

Measures
A log file for each operator's experience was taken. Objective performance estimates included double-clicks (manual following of a target), UAV locks on target, and lock brakes (failure to lock on target due to concealment). These measures evaluate the task-switching efficiency. In addition, the utility of the tool as a decision aid was assessed using three subjective measures: Workload (SWAT – [7]); SA (SART; Situational Awareness Rating Technique – [8]); and Team SA (Teamwork dimensions and behaviors – adapted from [1]).

Results
Collapsing across the various display layouts that were examined, the 'Castling Rays' tool was found to be the most essential and useful tool. The tool was an efficient decision support aid, by improving situation awareness, decreasing workload and increasing team situation awareness significantly relative to when the tool was absent (Figure 3).

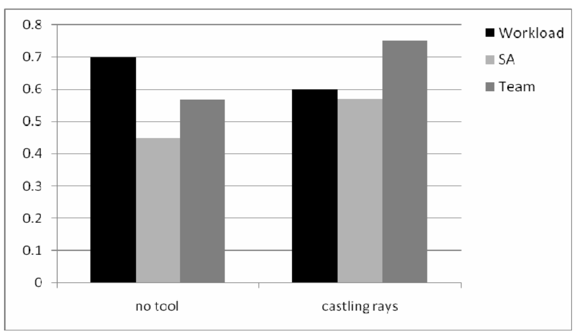

Figure 3 Normalized (scale of 0-1) subjective measures of Workload (lower workload is better), Individual SA, and Team SA, with and without the 'Castling Rays' tool.

The use of the tool also improved operators' interaction and objective task performance during switching (figure 4). Specifically, the number of 'target locks' was similar with and without the tool. However, the number of lock-breaks and the number of double-clicks (which is used to manually follow the target) was reduced when using the tool. This could also imply that utilizing the 'Castling rays' tool reduced both mental and physical workload.

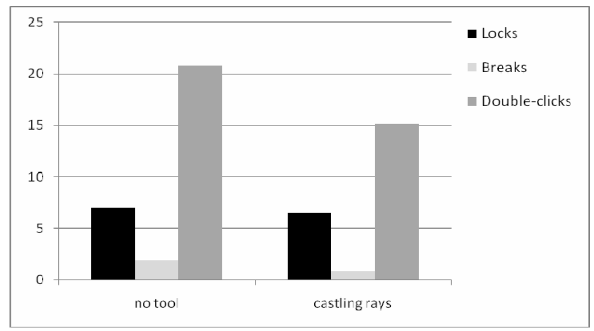

Figure 4 Objective measures of number of target locks, locks breaks and double-clicks, with and without the 'Castling Rays'.

While the necessity of the tool was unquestionable, suggestions for improving the tool were raised and are summarized below (participants' quotes are italicized):

- The rays should be thinner. A thick ray may obscure important information like a door of a vehicle. *"We often do not 'lock' on a target if the cross hair obscures the display".*
- The operators should be able to choose which rays of which team member they desire to maintain. *"Often some of the UAVs are not relevant and their rays are overloading the display".*

- Most interviewees thought that the angle display was not as useful, mainly due to the limitation of the information over prolonged time. *"By the time the switch is made this info is no longer relevant".*
- Interviewees suggested adding a timer for estimating the duration of time (countdown) that it will take the other UAV to reach 'my location'. This can assist also in getting ready for the switch (rather than getting a sudden exchange).
- Finally, interviewees thought that adding rays to the other UAV video windows (not just to the one that they are controlling) can be beneficial in initiating assistance to other team members.

Conclusion

The structured interviews have generated numerous insights concerning the unique 'Castling Rays' tool, which enables the operator to view at a glance which UAV has the optimal line of sight to his target. This visualized decision supporting tool aids operators in Multi-Operator Multi-UAV environments, to facilitate task switching by reducing their workload and improving their situation awareness, and hence their overall mission performance.

We are now implementing users' suggestions into our design for re-evaluation. In addition, we plan on examining the possibility to automate or semi-automate the 'Castling Rays' tool. For example, instead of displaying the castling rays to the user, the system will analyze the operator's state, and automatically or by user demand perform switching with the optimal UAV. Thus, the system will provide the user the optimal UAV that has the best line of sight for specific target in a specific moment.

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