AUTOMATION AND MULTIPLE UA CONTROL

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Abstract

This paper presents the results of an initial experiment examining the effects of different automation strategies on workload, situation awareness and operator performance while supervising multiple unmanned aircraft. The experiment was conducted on an unmanned aircraft system operator interface simulation testbed designed for a team of operators to supervise up to four unmanned aircraft. It was shown that two operators could successfully conduct a simulated mission using up to four aircraft to search for and identify ground targets. Increasing the amount of aircraft did not significantly influence situation awareness or operator performance. While adding additional aircraft did increase workload, providing automation for system failure diagnosis did not significantly decrease subjective ratings of workload.

1 General Introduction

The need for Unmanned Aircraft (UA) in civil and military domains has significantly increased over the past decade. The growing demand has brought into focus several challenges associated with automation and multiple UA control. For example, due to manning reductions, the control of multiple UA is currently being assigned to a decreasing number of team members. To achieve this, automation support is required, thereby placing operators in a more supervisory role.

1.1 The Need for Automation in Supervisory Control Systems

Controlling multiple UA will result in the consequent increase of the cognitive workload demands on the operators. Automation is needed to support human-system performance. However, research has shown that ‘blindly’ automating all possible features may not lead to the best solution [1,2].

The challenge is how automation can be used to aid the operator. Automation decision support can range from fully automatic, where the operator is completely left out of the decision process, to minimal levels, where the automation offers basic data filtering or recommendations for the human to consider (see e.g. ten Levels of Automation (LoAs) formulated by Sheridan and Verplank [3]). For rigid tasks that require no flexibility in decision-making and with a low probability of system failure, higher LoAs often provide the best solution in terms of operator workload [4]. However, even partially automated systems can result in measurable negative side effects on human performance, such as reduced situation awareness, complacency and decision biases [5]. For successful implementation of automation in supervisory control systems the effects on human performance will have to be considered.

1.2 Previous Experimental Studies on Automation and Multiple UA Control

Several studies experimentally examined the impact of controlling an increasing amount of

UA on operator performance. Cummings and Guerlain [6] showed for example that operators could control up to twelve UA, given significant aircraft autonomy.

Ruff, Narayanan and Draper [7] determined in their research that higher LoAs can actually degrade operator performance when operators attempted to control up to four UA. Results showed that management-by-consent (in which the operator must approve an automated solution before execution) was superior to management-by-exception (where automation gives the operator a period of time to reject the solution). In their scenarios, the implementation of management-by-consent provided the best situation awareness ratings and the best performance scores.

1.2 Current Research

This paper presents the results of an initial experiment examining the effects of different automation strategies on workload, situation awareness and operator performance while supervising multiple UA. In this experiment, a team of two operators supervised up to four UA using a simulated setup.

2 Method

2.1 Participants

A total of 16 college students (8 teams of 2 operators) participated in the experiment on a voluntary basis. Participants (3 females, 13 males) were between the ages of 18 and 28 years (*M* = 22.2; *SD* = 2.8). The inclusion of actual UA operators was considered not required as the execution of the experimental tasks did not need specific operational knowledge. Most participants had (extensive) gaming experience. Participants were compensated €10 per hour.

2.2 Apparatus

The experiment was carried out on the Multi-UA Supervision Testbed (MUST), which is a generic, reconfigurable simulator facility that was developed by the National Aerospace Laboratory NLR. MUST was tailored for the current experiment by creating a two-screen interface (each screen manned by a single operator) that allowed simulated missions using up to four UA.

One screen of the testbed (Figure 1)

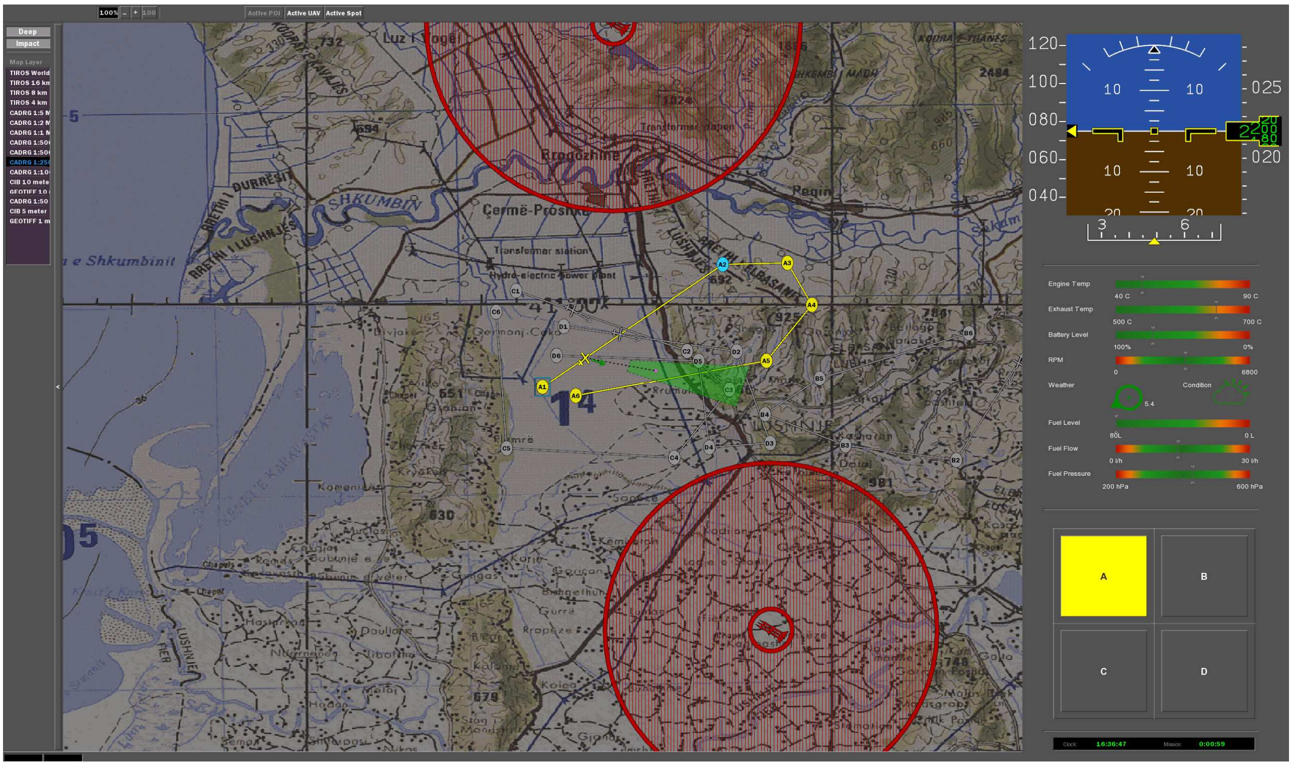

Fig. 1. AVO Screen

provided a map for geospatial tracking of the UA on predetermined flight paths. This work station was manned by the Aerial Vehicle Operator (AVO), who was responsible for operating up to four vehicles, including monitoring the UA system instruments. Control inputs included moving / adding / removing waypoints and switching between ‘active’ UA.

The second screen of the testbed (Figure 2), manned by the Payload Operator (PO), provided the sensor images derived from the UA. The PO was responsible for tracking the sensor output of up to four UA. Control inputs included zooming in / out the sensor, manually steering the sensor, commanding the sensor to automatically follow a point of interest, inserting a point of interest, and switching between ‘active’ UA.

A text messenger tool was available on both screens for communication purposes.

2.3 Experimental Runs

Each experimental run entailed a different scenario in which the mission was to detect, count and report certain ground targets of interest. The rough locations of the targets were distributed by the experiment leader (via text message) at the beginning of each run. AVO and PO were expected to communicate (using voice) with each other to successfully complete the assigned mission.

Each run was characterized by a predefined set of way points per UA. Without intervention of the AVO, the UA would automatically follow the flight path. Crossing Surface-to-Air Missile (SAM) sites (i.e. threat rings) was not allowed. Additional events such as thunder storms could be introduced by the experiment leader. The same accounts for UA system failures. After the mission was completed the UA should be returned to the final way point as soon as possible. AVO and PO were required to text report their findings to the experiment leader.

Various mission scenarios were developed that were on the one hand similar to each other to enable comparison and on the other hand different enough to avoid familiarization.

2.4 Experimental Design and Conditions

In the current research two experimental conditions (or independent variables) were examined. One condition related to the amount of UA to control. Four different conditions

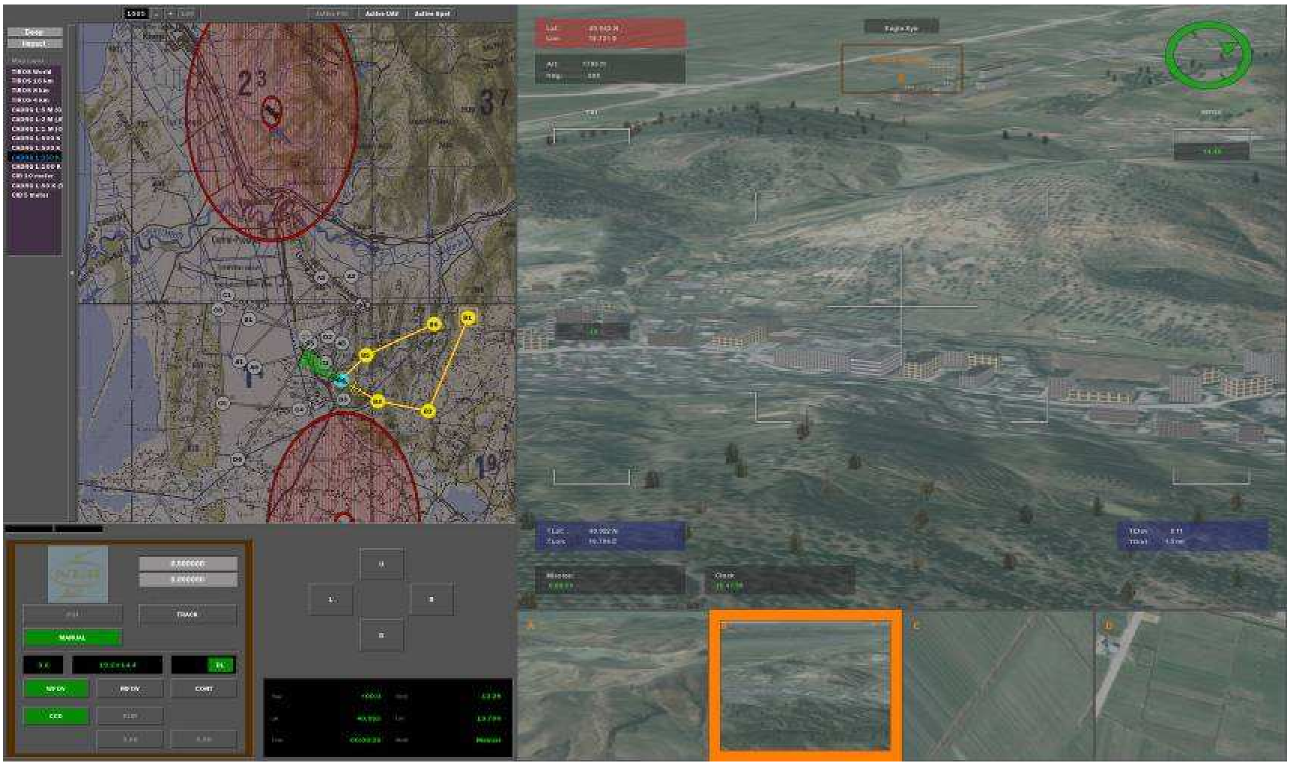

Fig. 2. PO Screen

were defined: controlling one, two, three, or four UA.

Another experimental condition related to the LoA that the AVO was working with. The AVO worked with two different LoAs: low LoA and high LoA.

The experiment consisted of eight simulated mission runs (4 x 2). The order of the runs was randomized, with the exception that the experiment always started with the “1 UA” condition, either with a low or high LoA. This was to establish a baseline.

2.4.1 Condition: Multi UA Control

As stated above, the goal of each mission run was to detect, count and report targets of interest. Each UA had its own simulated mission or target. This means that in case of the “1 UA” condition, one target had to be detected; in case of the “2 UA” condition, two targets; etc.

2.4.2 Condition: Automation

The experimental automation condition that was built in the MUST simulator focused on monitoring the UA system instruments. This task was performed solely by the AVO.

A system failure (e.g. high engine temperature or low fuel level) was simulated during each mission run. Again, this means one failure in case of the “1 UA” condition; two failures in case of the “2 UA” condition; etc. Note that, in case of more than one UA in mission, the AVO had to switch between ‘active’ UA to monitor the system instruments.

In the “low LoA” condition, no annunciation of a system failure was provided to the AVO. The AVO had to monitor the instruments in order to discover any failures. In the “high LoA” condition, the AVO was automatically warned by the system’s failure annunciation that appeared a few seconds after failure onset. A red bar specifically indicated which UA experienced a failure.

After text reporting the failure type to the experiment leader, the AVO could press an acknowledge button that was activated by the experiment leader, and the failure would correct itself.

2.5 Procedure

Participants were provided with a concise briefing guide explaining the purpose of the experiment. The main points of the briefing guide were repeated during a verbal briefing at the start of the experiment day.

Participants got approximately 20 minutes to familiarize themselves with the MUST simulator. They performed two training runs operating the “2 UA” condition. The training runs for the AVO involved both LoAs.

Participants then flew eight simulated mission runs. Each run lasted approximately 15 minutes, including five minutes for filling in the post-run questionnaires.

After all runs were finished, the participants were debriefed.

2.6 Dependent Variables

The dependent variables in the current research were workload, situation awareness and operator performance. Workload was measured using the NASA Task Load indeX (NASA TLX). The NASA TLX [8] is a multi-dimensional rating tool that derives an overall mental workload rating based upon a weighted average of workload sub-scales ratings. The NASA TLX was administered post-run.

Situation awareness of the participants was measured using the Crew Awareness Rating Scale (CARS). The CARS [9] is a situation awareness assessment technique based on Endsley’s definition of situation awareness [10]. The CARS was also administered post-run.

Operator performance was determined by checking the MUST log and the text messenger log. The MUST logs indicated for example whether a certain UA crossed a SAM site. The text reports showed for example the amount of targets detected by the PO and the system failure type reported by the AVO.

Finally, participants were debriefed at the end of the experiment day. Participants had the opportunity to discuss their experiences and impressions of the experiment here.

3 Results

An α of 5% was used as a significance value.

3.1 Workload

3.1.1 AVO

The AVO analysis consisted of a two-way ANOVA (automation condition x multi UA control condition) for repeated measures on the second factor (Figure 3). A statistically significant main effect on workload for the condition multi UA control was found (*F* = 6.66, *p* = .049).

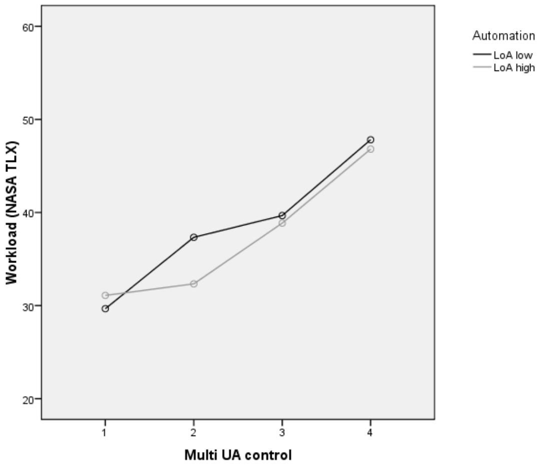

Fig. 3. AVO Workload: The Higher The Score, The Higher The Workload

3.1.2 PO

The PO analysis consisted of a one-way ANOVA (multi UA control condition). No statistically significant effect was found.

3.2 Situation Awareness

3.2.1 AVO

A two-way ANOVA (automation condition x multi UA control condition) for repeated measures on the second factor was executed for the AVO analysis. No statistically significant main or interaction effect on situation awareness was found.

3.2.2 PO

A one-way ANOVA (multi UA control condition) was executed for the PO analysis. No statistically significant effect was found.

3.3 Operator Performance

The analyses of the MUST logs indicated that none of the UA had crossed a SAM site.

The text reports showed that all POs were able to complete their tasks successfully; i.e. they found all targets and reported back to the experiment leader the correct amount of targets. In addition, all AVOs detected and reported back the correct system failures.

4 Discussion

UA require human guidance to varying degrees and often through several operators. For example, the Predator and Shadow each require a crew of two to be fully operational [11]. In order to increase the amount of UA flying without increasing personnel requirements, there is a need for research examining human interaction with multiple UA, with specific attention for the required automation support. In response to this need, this paper studied workload, situation awareness and operator performance as critical human interaction variables for the successful implementation of automation in supervising multiple UA.

The experiment results indicated that the workload of the AVO significantly increased due to the increasing amount of UA under control. This was as expected. The LoA did however not positively interact with this result; i.e. the use of a higher LoA did not result in a lower workload for the AVO. This result can be considered remarkable because the failure annunciation that was used in this experiment as “high LoA” condition has already proven its positive impact on workload in several operational settings, such as the civil and military cockpit.

The experimental conditions multi UA control condition and automation did not result in any changes in situation awareness and operator performance. This was not as expected. A possible explanation for the limited impact of the experimental conditions on these dependent variables could be that the simulated missions appeared to be too simple, and therefore, did not trigger participants to react differently to the increasing amount of UA to control and the higher LoAs.

The use of simulation can require operating in a somewhat simplified environment. Concerning the AVO task in this specific simulation, the operational follow-up activity resulting from a system failure was missing. This is of course not the case in real operations, where the AVO is also responsible for finding the right solution for the system failure. For the PO task, it would be far more realistic if tracking the sensor output did not only focus on the pre-determined (static) targets of interest that were distributed at the start of the experiment, but also on possible unexpected (and dynamic) targets of interest.

On the other hand, one might also argue that the design of the Human Machine Interface (HMI) of MUST caused the impact of the experimental conditions to be limited. Debriefing comments were very positive about the manner in which up to four UA were displayed at the same time on a single screen. A well-designed HMI could indeed influence, in a positive manner, human interaction variables in the supervisory control of a system.

4.1 Recommendations

Extending the amount of UA to control even more could be an interesting approach for future research, especially when the operational reality of the missions would be improved. A number of research efforts have already experimentally demonstrated in simulations that under various levels of automation, operators can control anywhere from one to twelve UA [6]. It would be very interesting to take this even further and consequently study the impact on variables such as workload, situation awareness and operator performance.

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