Adaptive Consoles for Supervisory Control of Multiple Unmanned Aerial Vehicles

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Abstract. With the prevailing increase of complex operational scenarios, involving multiple unmanned aerial vehicles (UAV), the concerns with the natural increase of operator workload and reduction of situational awareness have become paramount in order to safeguard operational security and objective completion. These challenges can be tackled through alterations of the autonomy levels of the vehicles, however this paper explores how these issues can also be mitigated by changing the way information is presented to the human operator. Relying upon an established framework, that supports operational scenarios with multiple UAVs, a series of display alterations were performed to existing operation consoles. After test sessions, in a simulated environment, with human participants of different levels of operational certification, feedback and results are distilled and analysed. Operator feedback demonstrated an overwhelming preference for the developed consoles and results showed an improvement of situation awareness, as well as reduction of workload.

Keywords: Operator, Situational Awareness, UAS, UAV, Workload, Command and Control, Interface.

1 Introduction

Recent years have witnessed unprecedented technological developments in computing, communications, navigation, control, composite materials and power systems. These developments have allowed the design and deployment of a multitude of extremely capable unmanned aerial vehicles (UAV) and unmanned aerial systems (UAS). As the operational capacity of UAS continues to grow, these systems can include multiple UAVs operating as a team, furthermore solidifying their employment in military and civilian scenarios. This causes an increase of the workload felt by the human element of these UASs, as well as a decrease in their situational awareness during the operation.

Normally workload and awareness issues are handled by changing the vehicles autonomy levels, increasing them in order to ease the human operator's experience. However we propose that changes made to the information's layout, and to the manner in which it is conveyed to the human operator, provide us a tool with which to affect operator workload and awareness in a positive fashion.

M. Kurosu (Ed.): Human-Computer Interaction, Part IV, HCII 2013, LNCS 8007, pp. 678–687, 2013.

2 Method

This work was conducted at the Underwater Systems and Technology Laboratory (LSTS) as poart of the work developed through the PITVANT project. At the LSTS we have been designing, building and operating a significant number of heterogeneous unmanned vehicles. These include Remotely Operated Vehicles (ROV), Autonomous Underwater Vehicles (AUV), Autonomous Surface Vehicles (ASV), and UAVs as a result of our collaboration with the Portuguese Air Force Academy. Furthermore we made extensive use of the LSTS's existing toolchain [1] for control and development comprised by the C4I (Command, Control, Communications, Computer and Intelligence) system Neptus [2], the vehicle task manager, control and navigation software DUNE (Dune Uniform Navigational Environment) and the IMC (Inter-Module Communication) communication protocol [3]. Since it is already amply used by both the Portuguese Navy and Portuguese Air Force Academy the toolchain allows us to receive a great amount of feedback and gives is access to a large number of potential test subjects.

2.1 Console Profiles

In order to adapt the console to the specific requirements of a situation, the concept of console profiles is introduced: A console profile is a predefined set of display elements which is geared towards a specific task. It is then possible to switch between profiles during a mission, either manually or automatically.

2.2 Operator Survey

In the beginning, several certified UAV operators are surveyed. They are asked what information an operator does or does not need to see, how much control he desires to have over the UAV, in different scenarios, and where his focus lies. Each of those questions is answered for 4 different tasks:

- Controlling a single UAV;
- Controlling multiple UAVs;
- Operating an onboard video camera;
- Operating as a tactical commander.

Based on this information, a decision is made regarding what elements to include or omit in each console profile.

2.3 Test Setup

As a first step, workload and situational awareness are evaluated in a simulated environment. During this test, the operator is asked to control an increasing number of UAVs and execute tasks such as changing flight plans, airspeeds and altitudes. The location and tasks to be executed are equal to those encountered in numerous previous flight tests performed at Ota airfield, Portugal.

Table 1. Questions asked during the test to assess operator situational awareness. Questions 12 was not asked as part of SAGAT but noted without the participants' knowledge.

#	Question	#	Question
1	How many UAVs are you controlling?	7	What is the heading of each UAV?
2	Which UAVs are those?	8	What are the UAVs' position relative to each other?
3	What is the main UAV?	9	What part of the plan are the UAVs executing now/next?
4	What is the altitude of each of the UAVs?	10	What is the status of each UAV?
5	What is the airspeed of the main UAV?	11	What were you last orders?
6	Where on the screen are the UAVs?	12	How many anomalies were detected?

To compensate the lack of naturally occurring stress in an operational scenario, inherent to having real hardware that would be lost in case of a catastrophic failure, the number of UAVs to be controlled, as well as the number and frequency of ordered tasks, are increased significantly.

Even though 4 different profiles were created, this test concentrates on the control of a single UAV and multiple UAVs, therefore only the profiles for single and multi UAV control are used.

Two different measurement techniques are used to judge the operator's workload and situational awareness: NASA TLX [4] and SAGAT [5], respectively. Additionally, the participants are asked to point out any anomalies they encounter. These include a sudden change in altitude/airspeed or subsystem failures. A summary of the questions is given in Table 1, while Table 2 shows when each measurement was taken.

Table 2. Test scenario showing how the tasks are made more complex and when measurements are taken

Situation encountered	Measurements
Start with 1 UAV	SAGAT
Add 2nd UAV	SAGAT
Add 3rd UAV	SAGAT
Induce errors in simulation	SAGAT
Add 4th UAV	SAGAT
Induce errors in simulation	SAGAT
End of test	NASA TLX

3 Implementation

Each of the created profiles is representative of a control task as defined before (Controlling a single UAV, controlling multiple UAVs, operating an onboard camera and operating as a tactical commander). The improvements that were made are described in the following sub-sections while a direct comparison is shown in Fig. 1 and Fig 2.

3.1 PFD

One drastic change that was made was the removal of a classical primary flight display (PFD) present in all modern aircraft. Normally, such a PFD includes the same information as the basic T (airspeed indicator, attitude indicator, altimeter and heading indicator) [6].

There are several reasons for this step. First, heading information is already included in the main map. Second, the operator survey has shown that attitude information was not deemed critical. This is backed by the fact that the UAVs are not controlled directly but through a series of waypoints which are followed by the autopilot.

Instead of having a traditional PFD, the airspeed indicator and altimeter are coupled with the map. This has the advantage that operators need not deviate their focus from the map to assess the UAV's state. Additionally, this step increases consistency between single UAV and multi UAV display configurations. It is known that poor visual momentum - a concept borrowed from the film industry [7] - induces cognitive difficulties when switching between displays [8] [9]. So in order to improve the quality of the overall console, individual items may have to be designed in a non-optimal way [10].

3.2 Status Indicators

It is necessary for the operator to quickly detect any malfunctions the UAV might have. Tasks requiring integration of information rather than precise measurements are best served by object like displays [11]. Therefore, the text list of subsystem statuses currently present in Neptus is replaced by a set of indicators. These indicators show a green light when a subsystem is functioning correctly and change color to inform the operator of a failure. This means that operators can immediately detect any changes of subsystem statuses.

In order to provide a fast overview of multiple UAVs, all subsystems are aggregated in a single indicator when the operator is controlling multiple UAVs. This way operators only have to sample very few indicators to acquire the status of all UAVs.

3.3 Airspeed Indicator and Altimeter

There has been extensive research about how to present altitude and airspeed information to a pilot. The principal of pictorial realism [12] dictates that the indicator representation should match the pilot's mental model. This includes the differentiation between digital and analogue information, as well as the orientation (up and down) and shape (circular vs. linear). Displaying digital information that must be transformed to a mental model means that processing time is increased [13]. Therefore, a ruler type display is used in modern aviation.

In contrast to full sized aircraft, the UAVs designed through the PITVANT project fly at low speeds and altitudes. This has the advantage that while showing the full range of possible airspeeds and altitudes, the resolution is still high enough to perceive small differences. As a result, the scale does not change and only the indicator itself moves. This means the direction of the indicator is equivalent to the pilot's mental model and also the principle of the moving part is satisfied [12] [14].

As these principles of compatibility - which are among the most important guidelines for display design [15] - are satisfied, definite improvements are expected.

3.4 C4I Specific Improvements

In addition to the improvements mentioned before, several other changes were made. These changes were specific to the use of Neptus as platform. Among others, they include additional filtering of waypoints and vehicles to be displayed.

Fig. 1. Final console profile for simultaneous control of multiple UAVs

4 Results

The test was done with a total of 6 participants from the LSTS and the Portuguese Air Force Academy, comprising certified and uncertified UAV operators. The initial reaction of all participants was that the workload was too high and much higher than in a real operational scenario, which was as expected. Nevertheless, overall feedback was that the console profiles made the tasks significantly easier to cope with.

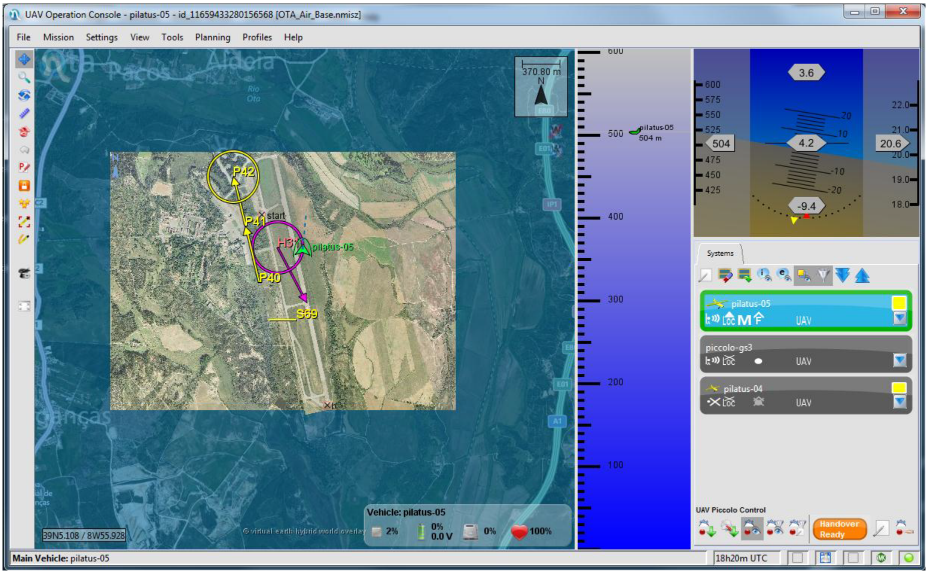

Fig. 2. Original console profile

Alongside these statements we have gathered test results. As can be seen in Table 3 and in Fig. 3, the average workload is reduced from 89.72 to 72.17, which is a reduction of 19.57 %.

Similarly, Table 4 and Fig. 4 show us that the average of correct answers increases from 51.62 % to 65.65 %, which is an increase of 27.17 %. The highest increase is shown for questions **4** and **12**. It is noteworthy that for question **3**, the percentage of correct answers actually drops.

Table 3. Total workload as measured with NASA TLX for each participant and console

Participant	Old console	New console	Reduction
1	81.00	73.33	9.47 %
2	92.33	63.00	31.77 %
3	87.67	81.00	7.60 %
4	94.67	64.67	31.69 %
5	96.67	76.67	20.69 %
6	86.00	74.33	13.57 %
Average	**89.72**	**72.17**	**19.57** %

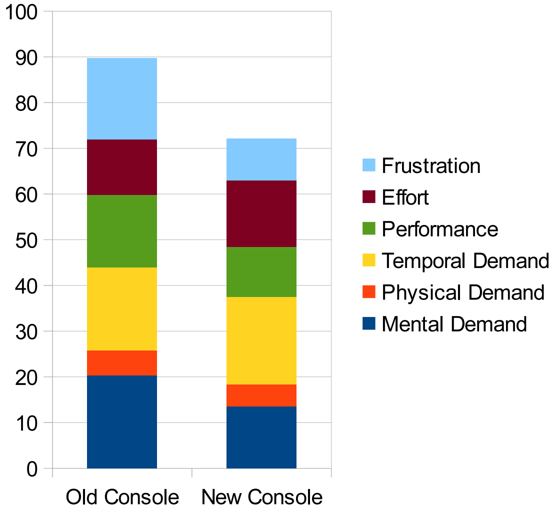

Fig. 3. Average workload as measured with NASA TLX

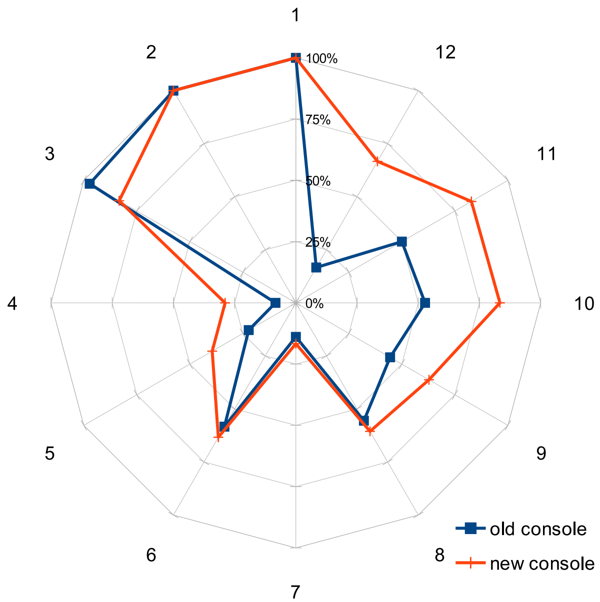

Fig. 4. Percentage of correct answers as measured with SAGAT

Table 4. Percentage of correct answers per question as measured with SAGAT for each console

Question	Old console	New console	Difference
1	100.00 %	100.00 %	0.00 %
2	100.00 %	100.00 %	0.00 %
3	97.22 %	83.33 %	-14.78 %
4	8.33 %	28.89 %	242.86 %
5	22.22 %	39.44 %	80.00 %
6	58.33 %	63.33 %	7.76 %
7	13.89 %	16.67 %	23.43 %
8	55.56 %	60.56 %	8.00 %
9	44.44 %	62.78 %	41.43 %
10	52.78 %	83.33 %	56.99 %
11	50.00 %	82.78 %	65.71 %
12	16.67 %	66.67 %	300.00 %
Average	**51.62** %	**65.65** %	**27.17** %

5 Discussion

The results presented in Sect. 4 show a clear improvement in workload and situational awareness when using the new console profiles. In terms of situational awareness, 3 individual results stand out: Considerably higher improvement for determining all altitudes; Improvement in detecting anomalies; Deterioration of determining the main vehicle. Questions 4, 12 and 3, respectively.

The high improvement for determining all altitudes can be traced to the way that altitudes are presented. In contrast to the original console profile, the new profile dedicated to controlling multiple UAVs shows all UAV altitudes in the same indicator. This gives the operator constant access to that information without any switching of vehicles. While the number of correct answers for this question is still not very high, it should be noted that most operators could at least indicate the UAVs vertical separation with the help of the new console.

Similarly, the improvement in spotting anomalies (changed altitudes, airspeeds, communication disruptions, etc.) can be awarded to the newly added state indicator. This information was previously hidden and had to be actively sought for. Now it is prominently displayed, which attracts the operator's attention to any problem.

However we cannot ignore the deterioration detected when answering question 3. We believe that this can be traced to the fact that with the new capacity of observing all vehicles simultaneously, the operator loses sight of which vehicle he is currently issuing orders to. This trade-off forces us to re-evaluate the way that we currently present the main active vehicle.

6 Conclusion

In order to improve operator situational awareness and reduce workload, through information presentation control, alterations were made to a pre-existing operational C4I application. Moreover, feedback was gathered from certified UAV operators before development began and 4 different console profiles were crafted. Each of these profiles includes several improvements in terms of layout and display design. With the completion of these new profiles test sessions were held, in a simulated environment, with both certified and uncertified UAV operators. These tests showed that the average workload was reduced by 19.57 % while the situational awareness was improved by 27.17 %.

In summary, our initial hypothesis that changes made to the information's layout, and to the manner in which it is conveyed to the human operator, provide us a tool with which to control operator workload and awareness is supported by preliminary software in the loop tests.

Further Development. Although these results are promising, further tests are advised. Firstly, tests including real UAVs will provide more realistic stress levels and therefore provide a better workload gauge. Secondly, the operation scenarios must expand to include the other two profiles developed (video operation and tactical commander). Thirdly, the actual process of switching between profiles should be tested.

Finally, the different console profiles should be classified according to their levels of autonomy so that the process of switching between profiles can be automated [16].

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