Measuring Self-adaptive UAV Operators' Load-Shedding Strategies under High Workload

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Abstract. This article focuses on the experimental identification of changes in human behaviour patterns of UAV-operators guiding multiple UAVs from a helicopter cockpit. These changes are based on self-regulation mechanisms of the operators to adapt to the current task and workload demands. Main objective of the use of these so called self-adaptive strategies is to avoid overload situations, and to retard exceeding capacity limits, to maintain overall acceptable performance as long as possible. Expressed by shedding and deferring tasks of lesser importance, or the relaxation of self-imposed criteria, these strategies lead to an observable change of human behaviour patterns, prior to grave performance decrements. This article describes a laboratory experiment utilising a virtual flight simulator to stimulate operator's workload and observe their mitigation strategies by means of gaze detection and a detailed interaction monitoring. Using the observed behaviour changes in an assistant system as indicator for high workload situations of the operator, it shall be possible to support the operator prior the occurrence of errors.

Keywords: multi-UAV guidance, subjective workload, self-adaptive strategies, human behaviour model, eye movements.

1 Introduction

UAV-operators are predominantly faced with supervisory control tasks, comprising the control of UAVs as such, the analysis of sensor images provided by the UAVs and the classification of detected objects, i.e. the tactical situation management. Increasing the number of UAVs guided by a single UAV-operator, results sooner or later in an overload situation for the human, due to the limited available attention resources, which need to be shared between the numerous tasks associated to the guided UAVs. In such situations the human is not able to compensate any further demands by investing more effort, so any further increase of task load often results in a decrease in operator performance and therefore in performance decrease of the overall system. To avoid such overtaxing situations for the human an assistant system needs, among other things, the ability to detect if the human operator is currently overtaxed [1]. To provide support at an early stage, theses systems should recognise such overtaxing situations of the human, prior to the occurrence of errors, thereby facing the challenge, that there are no well defined criteria or measurable values, indicating the limit

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between high workload and overtaxing. Furthermore the underlying notion of workload can be seen as a multidimensional, psychological, subjective phenomenon which is inaccessible to a direct measurement. Several different approaches try to infer human operator workload by the use of observable parameters. These approaches range from methods solely based on estimations up to methods, which continuously access performance (e.g. reaction time, error rate) or psycho-physiological data (e.g. EEG, pupil diameter) [2]. Depending on the method, their theoretical underpinnings and measures used, these approaches either act proactively or reactively, i.e. using feed forward estimations on the basis of the current task load, but without any consideration of the actual operator response, or providing a deviation or error correction based upon the detection of certain human response patterns [3].

2 Behaviour Based Approach

We propose an approach aiming at the detection of critical operator workload prior to the occurrence of errors, or grave performance decrements. We use certain sets of continuously accessible human performance and behaviour parameters. Therefore, we observe the manual and visual interactions of the operator with the technical system during task accomplishment. This allows to gain insight in how (and not just how well) the human operator accomplishes the given tasks. We hypothesise to detect the self-regulating mechanisms of the human in high workload situations, while trying to adapt themselves to the current task and workload situation. In literature these mechanisms are referred to as self-adaptive strategies [4].

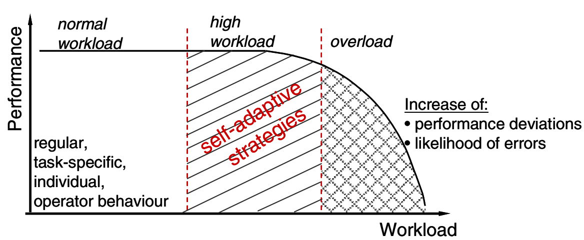

Fig. 1. Self-adaptive strategies occur prior to performance decrements

Applying these strategies, tasks of lesser importance will be shared, shed or deferred, which leads to an observable behaviour change. In general, there can be distinguished two fundamental classes of self-adaptive strategies, i.e.

- *load-sharing strategies*, i.e. the transfer of tasks to other team members or to functions of the automated system, and
- *load-shedding strategies*, i.e. changing the way a task is accomplished.

In the first case, the applicability of load-sharing depends upon the availability of automation or other team members. In the second case, load-shedding depends upon the flexibility (i.e. the degrees of freedom) the task itself provides. In both cases, the selection of the strategy is dependent on the operator's available work capacity.

In the case of *load-shedding strategies* the tasks will be accomplished in a more economic, not necessarily perfect way. Primary objectives will be pursuit at the expense of secondary objectives. This leads to the observable behaviour adaptations such as task prioritisation, disregard of subtasks, change in task accomplishment, or altered attention allocation [5].

Main objectives for the use of these strategies are to avoid overload situations by keeping the workload within bearable limits [6] and to retard possible capacity limits as long as possible to maintain overall performance [7][8]. Since increasing task load will lead to a progressive change in human behaviour of a human operator, the observation of the behaviour can be used as an indicator for workload.

To use these self-regulating mechanisms of humans as trigger for supporting functions in future assistant systems, human behaviour models are required, representing human behaviour within normal and high workload conditions. Hence, we need to consider that human behaviour is

- *individual*, as a consequence of e.g. skills, abilities and training,
- *task specific*, since each task or task combination implies a certain set of interactions (e.g. manual, visual), and
- *dependent on the current perceived subjective workload situation of the human*, referring to the change of human behaviour as a consequence of the use of self-adaptive strategies.

3 Experimental Operator Behaviour Acquisition

To gather and investigate human behaviour of UAV-operators in the accomplishment of their supervisory control tasks within different workload conditions (normal and high workload), extensive simulator trials were performed.

3.1 Experimental Design

The experiments, performed within a fixed based research helicopter and multi-UAV simulator, referred to a MUM-T scenario, i.e. the guidance of multiple UAVs by a human UAV-operator located in a helicopter cockpit. Here, UAVs were used as remote sensor platform for real-time reconnaissance during a simplified military air assault mission (Fig. 2). The UAVs were guided along pre-planned routes (*FMS-based*), which could be adapted to the current situation by the operator at any time. The main tasks of the UAV-operator were the guidance of the UAVs as such, the analysis of sensor images, taken by the UAVs and the classification of recognised objects. Therefore, the UAVs were equipped with a thermal camera and a video data link. The total time of the experiment was 95 minutes. To provoke the occurrence of self-adaptive strategies as a consequence of an increase in task load and subjective perceived workload of the operator, the task load was systematically increased over the course of mission by the introduction of embedded secondary tasks (i.e. mission re-planning, threat localisation), as well as by the increase in the number of UAVs to be controlled by the UAV-operator within two consecutive missions (Fig. 2, right side). To get familiarised with the UAV-operator station layout and the handling of the FMS-based guidance of UAVs, as well as with the reconnaissance task, the subjects got one full day of training.

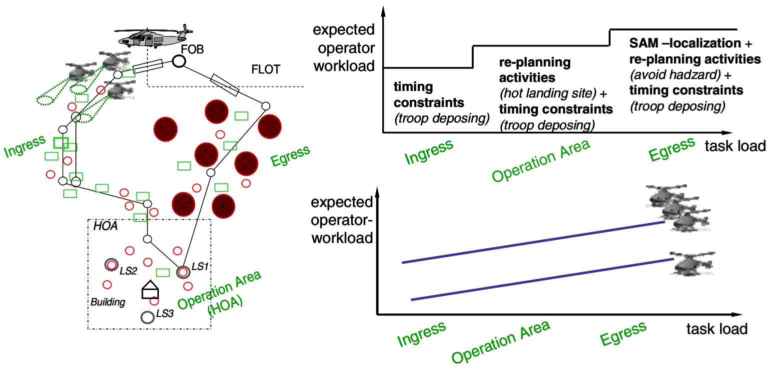

Fig. 2. Scenario (left), increase of task load during mission (right, top), increase of task load over two consecutive missions (right, bottom)

To capture human behaviour during task execution the simulator was equipped with faceLAB, a contract free, video-based eye movement measurement system. Furthermore, manual interactions of the UAV-operator, e.g. button presses were recorded. To get a relationship between the observed operator behaviour and his subjective perceived workload subjective workload ratings (NASA-Task Load Index) were performed in discrete intervals. In addition the operator performance was captured by the use of the following performance parameters: the number of classified objects, the required time for the accomplishment of the object-identification task, classification errors, operating errors. The subjects were four military helicopter pilots, two of them average experienced (around 550 flight hours, 150 hours as commander, around 30 yrs.) and the other two highly experienced (around 1700 flight hours, 1550 hours as commander, around 42 yrs.); the latter ones were well-trained flight instructors.

3.2 Investigated Task

The overarching tasks of the UAV-operator were the reconnaissance of the ingress and egress route and the Helicopter Operation Area (HOA) including the landing sites and a building located within the HOA. The focus for the behaviour investigation was the object identification task, which is a self-contained, repetitive subtask of the superior route-reconnaissance task. To get sufficient behaviour data, a great number of objects (friendly and foe ones) to be recognised and identified by the operator, were placed along the course of the mission (Fig. 2, left side). The task can be further divided into three subtasks:

- *"recognise and tag"* is the phase between the recognition of a hotspot, and the tagging of the hotspot in the map,
- *"classify"* starts with centring a live video-streaming sensor of the UAV on the hotspot, followed by the classification (civil or hostile) of the object,
- *"insert result"* is the insertion of the result into the interactive map.

Each of these subtasks can be broken down into several sub-subtasks, which are characterised by certain observable manual and visual interactions of the operator (for further details see [9]). Fig. 3 shows the UAV-operator control station, consisting of two touch-displays and the available display modes.

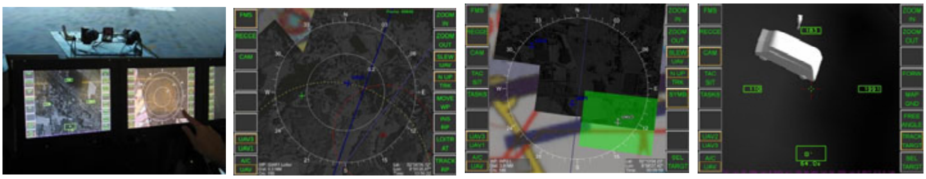

Fig. 3. Operator control station (left), available display modes

4 Experimental Findings

The following sections discuss the findings concerning performance parameters, subjective workload, and self-adaptive strategies of the human operator.

4.1 Operator Performance and Subjective Workload

In brief the following observations concerning mission performance were made during the experiments. The *relative number of detected objects* slightly went down from the Ingress to the HOA mission phase and fully dropped on Egress. The latter effect will be further discussed in the following sections. Managing three UAVs as opposed to one decreased the number of detected objects as well. *Errors in object classification* could almost not be observed throughout the missions and subjects. *The time required for the full object identification task* increased only slightly over the course of mission as well as in the guidance of three UAVs. The *number of errors in the handling of the system* varied along the independent parameters mission phase and number of UAVs. To sum up, the operators overall maintained their performance on a good level, although first slight performance decrements could be observed.

Subjective workload ratings (NASA TLX) were collected in discrete intervals. Independent of the guidance of one, or three UAVs, or over the course of mission there was only a very slight increase of subjective workload of all operators. In summary, we could observe that despite of the massive increase of task load, no explicit increase in the subjective perceived workload could be registered. The results of the subjective ratings hardly allow an inference of overtaxing situations.

4.2 Self-adaptive Strategies

As shown before the expected increase in the perceived subjective workload of the subjects due to the massive increase in task load could not be observed. Only slight performance decrements in the task accomplishment could be noticed. The overall success in the classification of attended objects remained quite stable. Instead, the human operators responded with a various behavioural changes, which were not introduced consciously at all times. By use of those load-shedding strategies, the operators tried to keep their subjective workload within bearable limits. The observed adaptations of the subjects' behaviours within the studied task were:

1) *proactive task reduction*, i.e. the sole use of only one of the available UAVs for the route reconnaissance task,
2) *less exact task performance*, i.e. consciously accepting an ambiguous live video stream of the object, insufficient to make a secure classification,
3) *omission of subtasks*, i.e. cutting down certain operating steps,
4) *complete neglect of object identification task* during entire mission phases,
5) *purposeful delay of task accomplishment,* i.e. the intended interruption of tasks in highly demanding situations, and the continuation of this task in lower workload situations.

It appears that some of these strategies occurred only once, however other strategies could be observed more frequently, with more than one subject, or in different mission segments.

Table 1. Load-shedding over mission phases and number of UAVs

load-shedding stategies.	***subject 1***	***subject 2***	***subject 3***	***subject 4***
task reduction	3 UAV, Ingress			
less exact perf.				1 UAV, Ingress 3 UAV, HOA
omission of subtasks	1 UAV, HOA 3 UAV, HOA	1 UAV, Ingress 1 UAV, HOA		1 UAV, Ingress 3 UAV, HOA
neglect of task	1 UAV, Egress 3 UAV, Egress	1 UAV, Egress 3 UAV, Egress	1 UAV, Egress 3 UAV, Egress	1 UAV, Egress 3 UAV, Egress
purposeful delay		1 UAV, HOA		

Table 1 shows the above mentioned load-shedding strategies, for each individual subject. The table entries show the number of UAVs and the mission segment.

Proactive task reduction. The overall task of the UAV-operator was the reconnaissance of the helicopter route (ingress and egress, as well as the operational area) by the use of all available UAVs, either one or three. Therefore, the operator had to alternately point his/her attention to the sensor images of the different UAVs in order to search for target candidates (i.e. the hotspots). This was done as expected by the operator within the initial mission segment, ranging from the FOB (start point of HC and UAVs) up to the FLOT, to be crossed via an ingress corridor. With entering the corridor by UAV1, one operator completely dropped allocating attention to the remaining UAVs (UAV2, UAV3) as well as to their sensory output. From this moment the operator only focused his attention to UAV1 (see Fig. 4, left). Fig. 4 (right) shows the attention allocation (measured by fixation dwell times) of the operator to the sensor images of the different UAVs prior to and after entering the ingress corridor delineated by the dashed line. By the use of this strategy the operator proactively reduced his tasks, trying to avoid reaching his capacity limits in terms of attention resources and therefore avoided the possible upcoming of an overtaxing situation.

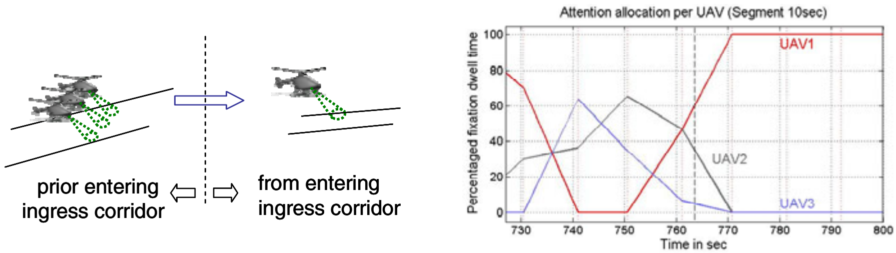

Fig. 4. Load-shedding by the proactive task reduction visible in the attention allocation of subject 1 to the different UAVs

Less exact task performance. This strategy refers to an observed behaviour change of operators solely within the "classify" phase of the studied task. For the accomplishment of this subtask the subjects had to view the live video stream of the currently selected UAV, which was previously aligned to the hotspot to be classified. To clearly classify the object, the operator needs to select the maximum available zoom. Furthermore, there needs to be assured that the distance between the UAV and the object is less than 1 nautical mile.

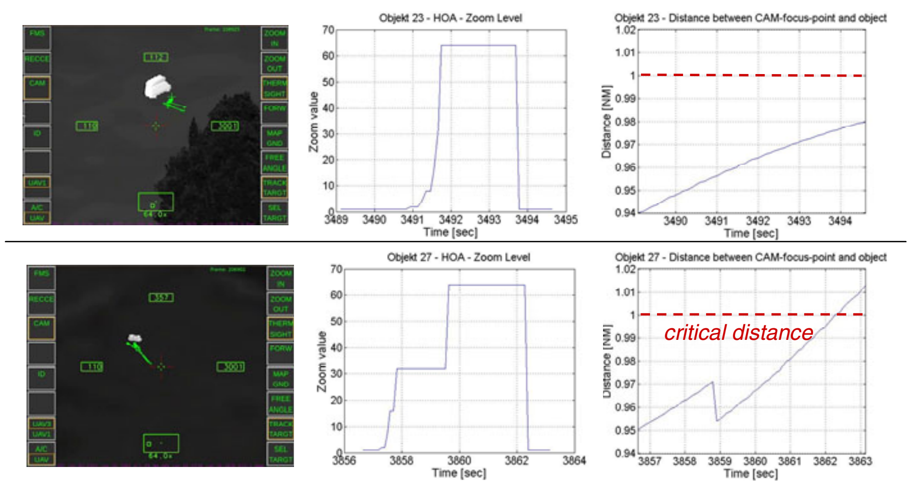

Fig. 5. Classification subtask under normal conditions (top), modified as a consequence of load-shedding (bottom)

Beyond that distance there is no unambiguous classification possible anymore. In this case the operator has to reduce the distance between the UAV and the object again, which is oftentimes accompanied with a laborious re-planning of current UAV-flight-path. Fig. 5 shows two different examples of the accomplishment of the *classify* subtask, depicted under normal conditions as well as under the use of a load-shedding strategy. Both show the received sensor image, the zoom-factor for display of the object and the distance between the UAV and the object. The load-shedding strategy in this case implies the operator accepting the insufficient image as a basis for the object classification. As a consequence, the operators were only able to guess the classification of the objects, resulting in an increased threat for the mission in case of a wrong classification of a hostile object.

Omission of subtasks. Usually the object-identification task consists of the three subtasks *"recognise and tag"*, *"classify"* and *"insert result"*. In demanding and often time critical situations, such as the reconnaissance of possible landing sites within the HOA, we observed that operators omitted some of these subtasks to a certain extent.

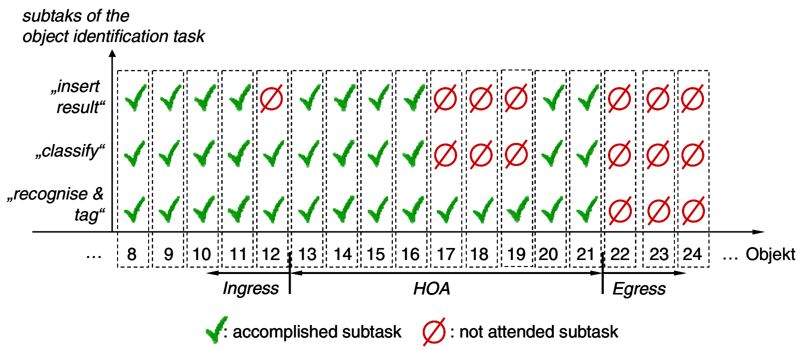

Fig. 6. Omission of subtasks of subject 1 managing three UAVs

This strategy is depicted in Fig. 6 for subject 1 managing three UAVs. Generally the omission of the subtask *"insert result"* is a consequence of a previously started but failed classification of the object, which the operator did not want to redo at a later time. The complete drop of the classification process (consisting of the subtasks *"classify"* and *"insert result"*) however is a phenomenon which occurred repeatedly in time critical situations. According to statements of operators during the debriefings, the omission of these subtasks was due to an attempt to avoid a critical overload situation. In the cases 17-19 (in Fig. 6) the operator informed his team-member (the pilot of the helicopter) to pay attention while passing the objects on his way to the landing site. Here the operator not simply omits the accomplishment of the subtasks, but he shifts the responsibility for a safe flight of the helicopter to the pilot. This behaviour might be classified as a *load-sharing* strategy.

Complete neglect of the object identification task. A complete drop of the object identification task including the search for hotspots could be observed for all subjects and in all configurations on the egress part of the mission (Fig. 7, left). During the egress phase the task load had been further increased by introducing SAM sites at unknown position. Detection and localisation of those threats created an additional embedded, secondary task. Due to their imminence it was expected that these secondary tasks for the time from a radar contact to the determination and entry of the position would become the primary task. However, it appears, that also in times, which were free of any hazard for the UAVs and the helicopter the subjects almost never resumed to the search for hotspots. Fig. 7 (right) shows the percentage of use of the different map range circles (i.e. map scale) over the course of mission. Only range circle values of 0.2 and below allow the detection of hotspots whereas the detection with range circle values above 0.2 is nearly impossible. As depicted in Fig. 7, during the egress-part of the mission the UAV-operator (subject 4) used the required range circle value (≤ 0.2) only in a few percent of the time (here referred to the time free of any hazards). This indicates that the UAV-operator did almost never resume the search for possible targets.

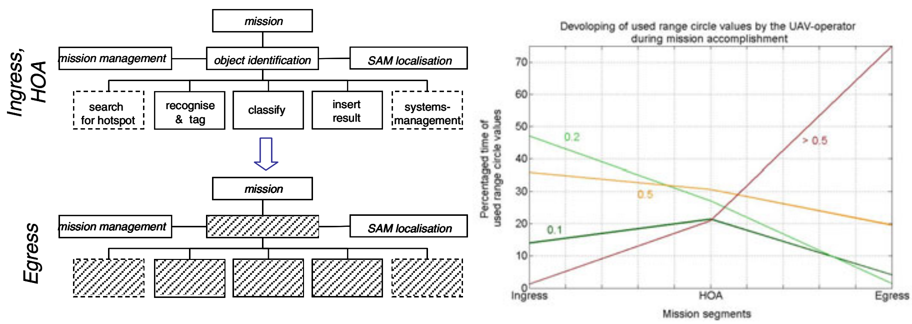

Fig. 7. Complete drop of the object-identification task of all subjects in both configurations (1 or 3 UAVs) during egress

Purposeful delay of task accomplishment. This strategy refers to an observed situation during the reconnaissance of the landing three sites in the HOA using one UAV. This situation is principally characterised as a time critical one, since the UAV-operator has to inspect all possible landing sites as fast as possible and thereupon direct the helicopter to a secure landing site.

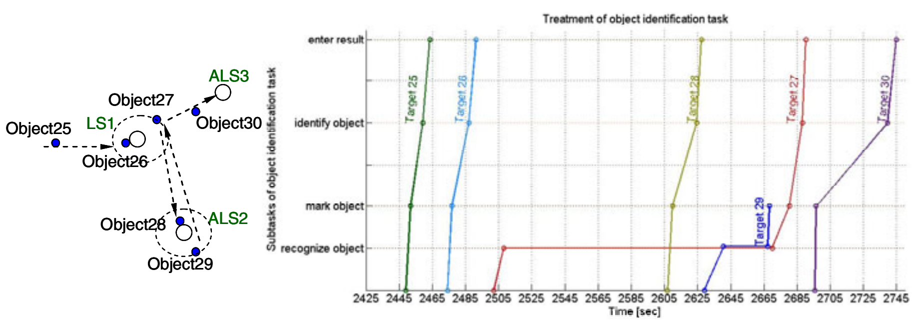

Fig. 8. Load-shedding through delay of task accomplishment and prioritising of tasks during time critical situations while landing site inspection

As shown in Fig. 8 the operator initially detects two hostile objects (Object 25, Object 26) on the way to landing site LS1, which implies that LS1 is "hot" and therefore inappropriate for landing. Then the operator detects Object 27, which could be proven by several, consecutive fixations on the hotspot followed by several fixations on the button, to initiate the tagging. As this object (Object 27) is close to the landing site LS1, which at that time already had been classified as hot, *the operator deferred this task*, and prioritised the reconnaissance of the route to landing site ALS2 first. Thereby, he encountered Object 28, which was immediately classified by the operator as foe, and therefore ALS2 as "hot" too. At the same time, the operator detects Object 29. Since ALS2 was also already classified as "hot", the classification of that object was irrelevant for the operator. Therefore, the operator immediately omits the classification and the insertion of the result for this object. Instead of that the operator focuses on the more urgent task, which means the reconnaissance of the route to landing site ALS3. Thereby, the operator passes the previously deferred Object 27, which he now processes. In this case it appears that the operator systematically defers the accomplishment of tasks in time critical situations, and prioritises the processing of other, in this situation more relevant tasks.

5 Conclusions and Perspectives

Experiments have shown that operators kept their workload within manageable ranges, while their performance only slightly decreased. This was achieved by the application of self-adaptive strategies of operators in high demanding work situations. During the experiments, several different load-shedding strategies could be observed. Next steps will be the development of computational models on the basis of the identified, quantifiable parameters. Using these models within an assistant system, an operator-adaptive support will be possible.

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