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ENHANCING MILITARY HELICOPTER PILOT ASSISTANT SYSTEM THROUGH RESOURCE ADAPTIVE DIALOGUE MANAGEMENT

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Assistant systems investigated today are beneficial in principle, but may induce additional load for the pilot, especially if the system intervenes at a time when the human has no more free cognitive resources to adopt the offered support. This article describes an approach how to enable a knowledge-based pilots’ assistant system in the domain of military helicopter missions to interact with the pilot by resource adaptive dialogue management. To minimize the automation induced additional load for the pilot, the assistant system estimates the pilots’ residual mental capacity and furthermore the current cognitive workload in the first step. This assessment enables the system to direct dialogues to the perceptual modality and code, which can be assumed to provide spare resources. Within this article, we provide a description of the implemented resource model, the conducted experiments as well as results of the overall evaluation of the adaptive capabilities in a relevant mission context provided in our research flight simulator.

1. Introduction

In the domain of civilian aircraft, the rising utilization of automation has been motivated primarily by technical feasibility without investigating the needs of the operator (cf. Sarter et al., 1997). As a result of this process, a variety of automated functions have been developed, which are acting more or less independently in their limited operating range without considering superior mission objectives. Monitoring, control and diagnosis of the various sub-functions is due to the human operator.

To cope with the high complexity of such automated systems and resulting handling-errors, more technical functions have been introduced in evolutionary design cycles (cf. vicious circle, Onken & Schulte, 2010). As a consequence of increasing complexity, the automation is neither operable nor understandable for the crew particularly in critical situations (cf. mode confusion, Sarter et al., 1997).

Billings (1991) specifies requirements for “human centered automation” thereby mitigating the appropriate described “automation induced errors”. In further pursuit of Billings (1991), Onken and Schulte (2010) derived three basic requirements for such human-machine cooperation as a specification for the desired behavior of assistant systems. Schulte (2012) claims that the human operator shall perform his/her tasks by using the given operation supporting means, as long as he/she is able to do so under normal workload conditions. As long as the human succeeds without errors or excessive demands, the assistant system would not be intervening at all (region I in Figure 1). Consequently, electronic aids support the human (e.g. by interactions / interventions) in situations of discursive attention or even in periods of excessive demands (section II and boundary between region II-III in Figure 1). Here, assumptions are made that the provided support reduces the workload (WL) of the human again to a manageable level (section IV).

However, the human operator has to invest additional cognitive resources to recognize the offered support or interact with the system in any way. Due to the increased demand of resources, the workload level may increase at first rather than declining (boundary between region II and III in Figure 1). In extreme cases, the human is not able to provide sufficient free cognitive resources to benefit from the offered support optimally. Wiener (1989) ascribes such adverse automation induced effects to deficient human-machine-interfaces, not considering the current mental state of the operator.

Figure 1: Desired and real relationship between interventions of an associate system and workload of the human operator.
To solve suchlike (automation induced) problems, an approach is presented in this article how to optimize an electronic aid in the domain of military helicopter missions. The aim of this work is to minimize the demands on additional cognitive resources, which have to be provided by the pilot to perceive and handle the offered support of an electronic aid. A vivid indicator to be minimized within this work illustrates the orange-hatched area in Figure 1.

2. MiRA, a resource adaptive associate for military helicopter pilots

In the context of future army helicopter missions, the Institute of Flight Systems of UBM developed the Military Rotorcraft Associate (MiRA) for the pilot flying. The purpose of our investigations was to enable this knowledge-based associate system to predict the human operator’s workload and the remaining capacity of his/her mental resources in the current task situation. These estimations will be used to determine the optimal interaction modality in order to minimize the additional (automation-induced) demand on the resources of the pilot.

Characteristics of the Military Rotorcraft Associate

MiRA, like other known approaches of knowledge-based military pilot associate systems, e.g. CAMA (Schulte & Stütz, 1998) and the RPA (Miller & Hannen, 1999), is designed according to the principles of cognitive and cooperative automation (Onken & Schulte, 2010). This type of automation is at first characterized by the assertion that the associate system has to cooperate with the human operator in a similar way a human assistant would do. Consequently, not only the human pilot but also the associate system needs to understand the given work objective in order to derive the necessary tasks in the course of the work process. As a consequence, we developed task models, incorporating the a-priori knowledge on military transport helicopter missions.

The cooperation is characterized by the basic requirements for human-automation interaction (Onken & Schulte, 2010). According to this, the associate system shall guide the operators’ attention to the most urgent task if necessary. In the second chain of cooperation, the associate should manipulate the task load, to keep the subjective workload on an appropriate level. To follow this requirement, MiRA takes own initiative to start appropriate dialogs. However, dialogues as such initiated by the associate system require the pilot to provide additional mental resources. If the system does not account for the current mental resource situation, i.e. the workload of the human operator, the system-initiated dialogs might not even come through in an extreme case.

For the reasons mentioned above, we developed human resource models, which enable MiRA to estimate the human operator’s workload and the remaining capacity of his/her mental resources for the current task situation. This model connects information about the resource demand to each individual task. In a second step, the demands of concurrent tasks are overlaid. In general, this model assumes that the interference between several tasks is directly proportional to the predicted workload (Wickens, 2002). In a second step, the associate system proactively assesses the impact on residual operator’s resources induced by additional dialogs on distinct human modalities in advance. For this purpose, MiRA adds the work demands of its intended dialog(s) estimated on the basis of the resource model, thereby going through all potential human perceptual modalities. Potential resource conflicts caused by the associate system initiating a dialogue can thereby be anticipated and, hence, prevented by selecting the modality with the lowest additional conflict, respectively mental workload.

3. Detailed concept for resource adaptive information transfer

Our implemented concept to adapt the information transfer (particularly the dialogs) according to current pilots’ spare cognitive resources is summarized in Figure 4. For realization of an assistant system providing the desired capability to adapt dialogs, we build two models at first:
1) **Model of pilot tasks** for the purpose of estimating the current tasks of the pilot
2) **Model of pilot resource consumption** to estimate the resource consumption and WL for current tasks

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**Model of pilot tasks**

In the first step, we capture all external influences on the pilot during a military transport helicopter mission (i.e. the state of the helicopter, the mission objective, the current flight and mission phase as well as environmental conditions). The interpretation of the helicopter task agenda leads to a pilot-specific task agenda. After aggregating this data into a full situational picture, this can be used to determine the current tasks the pilot should be executing. For this purpose, we deployed models of mission-typical task situations. These transition state networks have been developed based on knowledge acquisition experiments with German Army aviators.

To give dynamic to this normative task models, we synchronize the assumed tasks with the tasks the pilot is actually executing. Therefore, human-machine-interactions such as visual information acquisition (e.g. gazing at moving map) as well as manual interactions are analyzed. In this context, assumptions are made that observing the gazes as well as observing the manual interactions enables the assistant system to draw conclusions on the tasks actually processed by the human operator. Manual interactions that are taken into consideration include the currently displayed page on the CDU, pushed buttons, current system settings (e.g. landing gear), as well as control stick inputs. Visual interactions taken into account for this model are provided by a commercial eye-tracking system (FaceLAB®) and its integrated object-related gaze-tracking.

**Model of pilot resource consumption**

In a further step the determined actual task(s) are associated with our model of human resource consumption. This model is based on Wickens’ (Wickens & Hollands, 2000) so called multiple-resource theory and estimates the required human resources by use of eight-dimensional demand vectors (Wickens, 2002). Every demand vector symbolizes the demand a single task poses on the human operator expressed in the terms of information acquisition, information processing and response. Hence, data were gathered through knowledge acquisition experiments, in which German Army aviators had to rate individual resource demands that arise during the different mission tasks. To eliminate subjective influences from these models as far as possible, laboratory experiments have been conducted to better match the predicted resource conflicts within distinct task situations with the objectively measured pilots’ performance. Based on these experiments, we applied machine learning methods (i.e. genetic algorithms) to adapt the underlying human resource model to the measured human performance exemplary (Maiwald & Schule, 2012).

Table 1 explains the demand vectors in detail using the sample tasks “Approach H/C to Pickup-zone” and “Change zoom on map”. To estimate the current resource utilization, a modified Visual-Auditory-Cognitive-Psychomotor model (VACP; Aldrich & McCracken, 1984) is used. This enables the assistant system to determine remaining available resources of the operator in case a manipulation of attention is required (first assistant system requirement from Onken & Schulte, 2010).
In addition the predictive resource consumption model inherits some metrics of task and resource conflicts for estimating current pilots’ workload. For this purpose, the demand vectors of current tasks are applied to a modified workload index model (W/INDEX; Wickens, 2002) in pairs. The modified metric we applied to the W/INDEX model, eliminates any limitation on the number of tasks examined in parallel. When considering n-tasks in parallel, we establish a quantity of k pairwise conflict values $T_{KW_i}$ $(i \in \{1, \ldots, k\})$.

$$k = \frac{n!}{2(n-2)!} \quad (1)$$

These resulting pairwise conflict values $T_{KW_i}$ can be summarized as a row vector. $\overline{T_{KW}} = \{ T_{KW_1}, T_{KW_2}, \ldots, T_{KW_k} \}$. The entire estimated workload is defined according to the following formula as the geometric sum of the pairwise conflict values.

$$\text{Workload} = 2^{\sqrt{(T_{KW_1})^2 + \cdots + (T_{KW_k})^2}} = 2^{\sqrt{\sum_{m=1}^{k} T_{KW_m}^2}} \quad (2)$$

### Estimating desired interaction modality with lowest additional resource consumption

To minimize the additional resources, the pilot has to provide to perceive system-initiated warnings or interact with the offered support, we developed the approach depicted in Figure 5. This procedure is based on the pilots’ current tasks and the derived level of workload, i.e. the utilization of resources. At first, we overlay the pilots’ current tasks with hypothetical interactions (e.g. dialogs) using four different codes and modalities. Within a one-step planning process, each of these task combinations is rated by the modified W/INDEX- and VACP-resource model referring to the resulting workload level, i.e. utilization of resources. In detail, we regard the following four potential interaction channels: visual-spacial (e.g. symbolic messages on displays), visual-verbal (text messages on displays), auditory-analog (symbolic auditory messages) and auditory-verbal (speech output). The assumed utilization of each regarded resource is represented by the traffic lights (c.f. Figure 5). Finally, we derive the desired resource for an interaction in the current situation generating the lowest additional workload value (i.e. the visual-verbal resource in the example of Figure 5). In a future stage of completion, the deviation of an interaction resource will also incorporate an optimization (i.e. ensuring an equal utilization) of regarded resources.

### 4. Experimental evaluation of assistant system prototype

To evaluate the overall benefits of the MiRA assistant system, in particular the adaptive automation aspects, we conducted an experiment in our generic, stationary, two-seat side-by-side H/C-cockpit in 2011.

#### Experimental Setup

Eight German Army aviators at an average age of 37 years (min. 28, max. 51) participated as test persons. Their flying experience ranged from 830h up to 5100h with an average of 1815h. The experiments were conducted using two different experimental configurations: In the adaptive configuration the MiRA assistant system communicated with the pilot by adaptive use of either speech output, text messages, audio-alerts or symbolic display messages (8 subjects). In contrast the non-adaptive configuration was further subdivided composing dialogues either via aural text messages (4 subjects) or visual speech messages (4 subjects). Each subject participated in the adaptive as well as in the non-adaptive configuration. They were initially briefed on the nature on human-machine interfaces.
The missions lasted about 30 to 45 minutes and had the primary objective to transport troops from friendly PickupZone into hostile DropZone. It was mandatory to pass corridors with distinct opening times to transit from friendly to enemy territory and back. The commander (represented by the pilot not flying, PNF) is entitled to control three UAVs, which support the mission by taking over reconnaissance tasks such as exploring the helicopter routes and landing sites located in hostile territory in real-time. Each mission contained a follow-up mission order that was received by the crew upon accomplishment of the primary mission (i.e., after dropping troops at Dropzone). The follow-up order contained either a second troop transport (within hostile territory) or the recovery of a crashed pilot (from hostile to friendly territory).

For the validation of the MiRA system prototype, only aspects relating to the pilot are discussed in the following chapters. Results concerning the UAV mission management by the PNF can be found in Strenzke et al. (2011). In our experiment, we required the H/C-crew to operate below an altitude of 150ft AGL in enemy territory. This altitude describes a safety-critical parameter, due to increasing exposure to enemy air defense when violating this requirement.

Results of Validation

We accumulated occurring altitude violations over the violation time as a performance parameter. This was computed for both, the adaptive and the non-adaptive configuration concerning the system generated altitude warnings. A t-test was used to compare these two configurations.

As a result, the violation decreased for more than 50% in the adaptive configuration in comparison to the non-adaptive configuration (cf. Figure 7). That means, the performance improved significantly in our experiments ($t(4)=2.17, p=0.048, n=4$ refers to the number of missions each containing approx. 20-30 minutes of low-level flight) when transferring information in a resource-adaptive way.

After each mission, questionnaires (i.e., NASA-TLX, ratings on different configurations of the associate system and on the overall system evaluation) were presented to the pilots. To ensure comparability, all NASA-TLX-ratings were normalized due to different utilization of the workload scales. As depicted in Figure 8, pilots rated the configuration with text messages only as their highest subjective workload level (42.6% on the average). In contrast to the resource-adaptive-configuration was appraised with an averaged workload level of 30.6% only. The workload reduction between these two configurations was proved significant by a two side t-test ($t(32)=2.06, p=0.047, SD=9.97, n_1=12, n_2=22$). In addition, the workload decreased weak significant in mean from 38.9% in speech-only-configuration to 30.6% in resource adaptive mode ($t(32)=1.87, p=0.07, SD=10.2, n_1=12, n_2=22$).

Further subjective ratings regarding the specific benefit of the associate system to the pilot benefit showed a weak significant trend ($t(14)=1.95, p=0.07$) that pilots perceived best support in the resource-adaptive configuration. Comparing the configurations resource-adaptive vs. text message only, the pilots...
felt significantly better supported in resource-adaptive mode ($t(10)=5.06$, $p<0.001$). A comparison between resource adaptive and speech-only mode showed no significant effect. As depicted in Figure 9, the eight pilots also rated if they experienced any difference in subjective workload between the non-adaptive and resource-adaptive system configurations. Two subjects stated no difference and six subjects attested decreased subjective workload in resource-adaptive configuration. Furthermore, the pilots attested the MiRA associate system to increase mission safety and efficiency.

5. Conclusions

In this article, we present an approach to enhance a knowledge-based assistant system in the domain of military helicopter missions with cooperative capabilities. For this purpose, we developed a concept for estimation of pilots’ residual capacity in human resources as well as an estimation of his current cognitive workload. By the use of models considering the current resource allocation, an assistant system was enabled to transfer necessary information on remaining resources of the pilot. This proactively prevents the pilot from being overtaxed, which maximizes the performance of the overall system.

The overall MiRA associate system evaluation trials showed that the altitude-related exposure to potential threats could be significantly reduced in the resource-adaptive mode. Pilots reported decreased workload and felt best supported in the resource-adaptive information transfer configuration. Finally, the MiRA associate system was rated to be a helpful electronic crewmember increasing the mission efficiency and safety. Our future work will incorporate trials for a further validation of our resource model prototype, in particular concerning the demand vectors. Furthermore, we will apply our presented concept in the domain of civilian aircraft, i.e. emergency helicopter missions. In this context, we intend to enhance the model based task prediction by developing a hybrid approach incorporating human behavior models along the lines of the work presented in Schulte & Donath (2011).

6. References


