Towards Cognitive Assistance and Teaming in Aviation by Inferring Pilot’s Mental State

Nele Russwinkel¹(✉), Christoph Vernaleken², and Oliver W. Klaproth³

¹ Chair of Cognitive Modeling in Dynamic Human-Machine Systems, Technical University Berlin, Marchstr. 28, 10587 Berlin, Germany
nele.russwinkel@tu-berlin.de
² Airbus Defence and Space GmbH, Rechlinser Street, 85077 Manching, Germany
³ Airbus Central Research and Technology, Hein-Sass-Weg 22, 21129 Hamburg, Germany

Abstract. Most assistance systems do not consider the cognitive state of the operator for providing support. However, especially in critical situations, it is highly relevant to know whether information has been processed correctly or been missed. We propose cognitive assistance and give an example of how formalized understanding and anticipation of pilot behavior in response to flight deck alerts can be implemented. The proposed cognitive assistance creates an understanding of the global context of the operation, comprising pilot state (cognitive, emotional), the environment (e.g. weather, traffic, obstacles), the operational context (e.g. Air Traffic Control instructions, system status), and the current task context. The concept of understanding others also provides the foundation for mutual understanding in future human-machine teaming, although additional aspects must be considered by such systems.

Keywords: Cognitive assistance · Cognitive modelling · ERPs · Emotional state · Mental state · Aviation · Surprise

1 Introduction

Automation has dramatically changed within the past 50 years. The initial idea of automation was to support human operators, to reduce workload and to reduce errors. Unfortunately, however, human operators are presently forced to adapt their skills and routines to the semi-autonomous systems [5]. This has a strong impact on the interaction between technical system and human operator and brings along various new problems such as out of the loop issues, automation surprises, lack of situation awareness [6] and the loss of agency in situation [3]. Humans perform much better in certain situations than semi-autonomous systems. They can cope with new situations, easily transfer knowledge to a new task, learn from single experiences and use a broad range of pre-existing knowledge. Humans have limited cognitive capacities, but usually a good idea of what features in a situation they need to attend to in order to proceed with their tasks. Semi-autonomous systems typically have a limited scope of tasks, and
they are neither flexible in behavior nor do they ‘know’ how to cope with unknown situations. For most cases, it is obvious that we need both the human operator – or rather with the focus of this paper – the pilot and the semi-autonomous assistance system\(^1\) because they both provide different capabilities that complement each other.

The imminent question at hand is how pilots and semi-autonomous assistance systems can work together in a rather natural way, to their mutual benefit, without imposing additional workload to the pilot.

Evidently, it is necessary to realize mutual understanding between pilots and semi-autonomous assistance systems and to enable a basis for easy and partly implicit communication to solve potential problems and misunderstandings.

Specifically, for critical situations, such as alerts provided by a Flight Deck Alerting System, there are numerous documented cases [e.g. 1] in which pilots did not adequately respond to the information provided by the system, and it is not always immediately obvious why the machine-to-human communication broke down. Potential explanations range from “simply overhearing” the alerts due to workload and attentional focus issues to an overall lack of trust in the respective system, leading to pilots ignoring its advice. Therefore, it would be necessary to enable the assistance system to understand whether the pilot did process the given information, and if not, why this is the case.

Generally, there are individual differences between people, and the amount and kind of assistance that is needed will differ to a large degree between human operators. As an example, hints and usage advice that may be very welcome for a novice might not only irritate experts, but also hamper their productivity. Furthermore, different process preferences between human operators would also call for individual support. The general task itself will be identical between human operators, but the human individuals, the operational context and the environmental circumstances will differ. These factors therefore need to be taken into consideration for an assistance system that enables mutual understanding.

To maintain the human in-the-loop also means to understand how the situation is understood by the pilot. Pilots do not only need to perceive and process information but also needs to build up a mental representation (or model) of the current situation – typically called situation awareness [6], and to anticipate the next events. This includes awareness of the state of the semi-autonomous assistance system. These representations provide an understandable rationale for the pilot’s decisions. Assistance systems that do not anticipate the current understanding or representation of the pilot can cause severe problems (e.g. silent mode changes). Furthermore, assistance should consider the pilots understanding of the situation and just add information that is needed to complete knowledge required to complete the task or address differences to the situation as the system perceives it. Also, decisions or proposals performed by the system need to be presented in a form to add information to the situation understanding of the pilot and to support mutual communication and understanding.

---

\(^1\) In this paper, we use the example of a pilot assistance system, but the concept applies to assistance and collaboration systems in other domains.
These arguments call for a novel approach towards assistance functionality. To understand the pilot, behavior needs to be tracked and put in relation to a pilot model that captures the cognitive requirements of the task, the task dynamics, the individual characteristics of the pilot, the operational context and the environmental circumstances. A special focus should be set on a prediction and enrichment of the pilot’s situation understanding. We propose a so-called cognitive assistance that relies on an approach of understanding the pilot and builds up the cognitive state of the pilot, the situation and environmental factors to provide assistance appropriate in the form, the timing and content to the current pilot’s situation and mental state.

2 Cognitive Assistance

2.1 Aspects to Consider for Cognitive Assistance

For a cognitive assistance approach, as we suggest it in this paper, it is necessary to consider several types of information and put these into relation to provide the basis to gain a good understanding of the pilot in the task context, operational context and the environment.

![Diagram of Cognitive Assistance]

Fig. 1. Cognitive assistance - information that needs to be coordinated for providing appropriate assistance for the pilot

The Environment is the actual environment in which the operation takes place and includes weather, terrain, obstacles or traffic. All these environmental elements may create essential boundary conditions or constraints for the operation, but they typically cannot be influenced by the pilot.
By contrast, **Operational Context** comprises systems, services and other stakeholder support enabling the current mission, first and foremost the aircraft and its systems. Obviously, any system failures will, depending on their criticality, more or less immediately result in a need for pilot action. Additionally, Operational Context also involves Air Traffic Control as well as requests by the airline and covers the infrastructure (such as airports and navigational aids) and its status.

In contrast to the “environment”, which typically cannot be influenced by pilot or assistance, interactions with the operational context are feasible. System failures can be recovered, and it is entirely possible to request a different runway than the one currently in operation.

In combination, Operational Context and Environment characterize the situation at hand, and can immediately be used to derive a potential objective need for action. Accordingly, **Task Context** encompasses the actual pilot tasks at hand, i.e. the specific procedural steps that are currently taken in the cockpit, involving both normal procedures such as cockpit preparation, as well as potentially abnormal procedures such as handling an engine fire.

Evidently, the **Operator States** could be a result of changes in the task, the operational context or in the environment. To gain a good understanding about the pilot in the situation and anticipating the next steps or evaluate deviation actions we need a detailed approach that also considers cognitive mechanisms. Cognitive Assistance must therefore “understand” all the above aspects in order to assist pilots in judging the (useful) options they have, and therefore corresponds to a meaningful course of action analysis and trade-off, which in turn results in a specific proposal of assistance, which is ideally supplemented by a rationale the pilot can understand.

### 2.2 Understanding Others

How can we achieve a concept of automation assistance or even teaming that is able to support the pilot appropriately through understanding of arising problems or challenges in the evolving situation?

There are numerous theoretical approaches on how people understand others, but only few of these consider that humans are normally in an interactive situation and have limited time.

Newen [9] proposes the Person Model Theory (PMT) that considers interactive situations. The theory posits that we understand others to a large amount based on the situation they are in, which is called a situation model. This situation model might include environment factors as well as operational context and task context. This situation model, as well as the interdependence of personal models (individual factors such as emotions, preference and capabilities – similar to the operator state) can be used to observe, explain, or predict the behavior of the other person. This way we can find an explanation of e.g. situational emotions, intentions and actions.

The core idea of this paper is that implementing an analogous approach to understand the pilot in a situation would provide a wide range of possibilities to design appropriate assistance to the pilot. Such a cognitive assistance would rely on an understanding of what kind of information the pilot needs, what information has been processed and explain divergent behavior or anticipate a possibly dangerous situation.
To achieve a modelling approach to account for this, we need a dynamic cognitive model of the pilot capable of tracing the pilot during a task, while interacting with the technical system, conducting a specific task, including environment events, checking for the reactions of the pilot and also enriching this model with measurable information about the individual pilot, such as surprise reactions (e.g. via ERPs – Event Related Potentials), visual attention (eyetracking) and actions (input to the technical device) providing information e.g. about the underlying situational understanding.

2.3 Cognitive Modelling of the Cognitive State of the Pilot

A first approach in this direction has been realized based on a study about pilots in a simulator that have to handle various alerts [7]. A cognitive modelling approach was implemented with the cognitive architecture ACT-R [2] that captures in which situations what kind of pilot interactions will probably be completed. The result of these action(s) will lead to a new situation including an altered visual display, for which the model predicts what kind of interactions the pilot will initiate next until the task goal is reached. The model integrates information about the real interactions of the pilot as well as information from the technical system, therefore matching the predictions with the real events. This modelling approach is not deterministic, different possible next steps are considered depending on the circumstances (processed information, environmental or operational cues) or preferences. In addition, ERPs are measured to capture attentional reactions of the pilot. This information can be accessed by the pilot model e.g. testing whether the pilot reacts to an alert and therefore has processed this information in contrast to inattentional deafness [4]. Such additional information about the pilot naturally increases the reliability of the model predictions.

Emotions are especially interesting on such a cognitive assistance approach. Understanding the emotional reaction of the pilot to an event is highly relevant, both for understanding among humans, but also for cognitive assistance. This provides information about the current understanding of a situation, in particular if an event has been expected or not, and whether the pilot still feels in control of the situation.

There is much potential in relating surprise reactions to the underlying mental representation of situational understanding. The question is what kind of situational understanding would cause such a surprise reaction, e.g. automation surprise. There have been some approaches to model expectations and surprise with cognitive architectures [8]. This line of research holds large potential for future assistance systems.

3 Discussion

3.1 Outlook Cognitive Assistance

In the future, technical systems, especially autonomous systems, will most likely continue to increase in complexity. Already today, several autonomous or semi-autonomous systems seem to be too complex for a human operator to fully grasp the whole system. Our approach for cognitive assistance aims at enhancing the effective
and efficient communication between operator and semi-autonomous system in order to enable a human operator to stay in the loop and make well-informed decisions.

A first example assistance system [7] shows how a situation model of the pilot including information about surprise reactions as the consequence of events can already predict pilot performance to a large degree. The underlying cognitive model provides the basis to compare situation understanding between technical system and the pilot. If both are deviating critically, some form of communication has to be initiated, considering that both views could be at least partially wrong. By addressing the divergence in human and system perception, critical situations might be prevented or solved. This would refer to the assistance proposal in Fig. 1.

In addition, the situation model could be more detailed, and cognitive mechanisms, such as mental simulation of different situational explanations to find the best fitting model, would be a good mechanism to include in such systems.

3.2 What We Need for Human Machine Teaming

For human-machine teaming, a mutual understanding and enabling an implicit communication about divergent ideas, or the understanding of a situation, is even more important.

Especially the representation of “what changes can I (as the system or pilot) cause in this situation and would this help for the common goal” (called self-model), is fundamental for real collaboration between technical system and pilot. For this, a more elaborate cognitive model of the pilot is needed, as well as some kind of “self-model of the technical system. The self-model is a representation of what the technical system itself can achieve in the present situation, including the possible course of action. This aspect is more relevant for the teaming approach, where the technical system must consider how it can support the pilot in terms of collaborating towards a specific goal, which then results in a specific assistance proposal with associated rationale.

References