Controller Adaptive Digital Assistant (CODA): Interim Conclusions on the Development of a New ATC System

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Abstract. This paper aims to outline the development of adaptation strategies and HMI guidelines for a COntroller adaptive Digital Assistant (CODA) to support Air Traffic Controllers in their operational duties by dynamically managing their workload. The strategies and guidelines were constructed using relevant literature and interviews with operational experts. The interim results include areas of specific interest based on operational knowledge, fourteen adaptation strategies and fifteen HMI guidelines. These results will serve as input for subsequent mock-ups that consider technical factors as well, and ensure an effective and usable support to controllers. These interim results provide valuable insights for developing supportive tools in the highly regulated, safety-critical domain of ATC, contributing to the advancement of operational safety and efficiency.

Keywords: Air Traffic Controller · HMI · automation · adaptation strategies · mental state assessment

1 Introduction

Overseeing and controlling air traffic is a highly demanding task that requires a continuous high level of attention and a specific skill set [1]. Air Traffic Controllers (ATCOs) are responsible for acquiring and analyzing various information such as radar data, flight plans, weather conditions, and making critical decisions to ensure safe aircraft separation and operations [1]. Managing ATCO workload is crucial, as high workload can lead to stress and reduced situational awareness, increasing the risk of errors. Dynamic support tailored to the ATCO's mental state is essential for maintaining optimal performance.

Developing automated tools for air traffic management is seen as a key technology to reduce controller workload and enhance airspace capacity [2]. Artificial Intelligence (AI) is increasingly being explored to support ATCOs [1] and may play a crucial role in managing traffic [3], and it has been shown that automation can significantly improve ATCO situation awareness and performance for example, especially when this aids in information acquisition of the ATCO [4]. Hence, such technological developments show great promise in aiding ATCOs in executing their operational tasks.

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1.1 The Aim of CODA

With the increasing rate of developments in AI and associated benefits, ATCOs are likely to perform their tasks with increasing support of automation. To demonstrate this Human-Machine Teaming (HMT) within the context of ATC, the CODA (COntroller adaptive Digital Assistant) project aims to develop a system in which ATC tasks are dynamically allocated to either the ATCO or AI based on (neuro)physiological measurements of the ATCO and relevant current and future traffic parameters or other relevant aspects. Thus, CODA can then support the ATCO by performing specific tasks or by providing certain information to manage the ATCO's workload.

2 Methods: Development of CODA

The scope of this paper is limited to the development of the HMI of CODA. As a first step, literature was gathered and consulted non-systematically by project members. As there is little to no literature on a system as CODA, papers concerning more general technological developments in ATC were included in the search, as well as papers from domains such as the automotive industry. All information deemed relevant for the development of CODA was subsequently gathered in a document, which was then reviewed and refined by project members based on their expertise. Next, several sessions were organised by the task lead to brainstorm about how these literature findings could be integrated into specific adaptation strategies and HMI guidelines for the CODA system. Once this was finished, an initial draft was written up. Finally, a session was organised with three external ATC experts with operational knowledge to discuss the resulting strategies and guidelines. Key points are discussed in the Results section. The section also details a summary of the resulting adaptation strategies and HMI guidelines that will be used in the development of subsequent HMI mock-ups, a playbook detailing the moment CODA should change one's level of automation based on operational situations, and a resulting CODA system for initial validation.

2.1 Assumptions

To design a functional adaptive assistant in ATC, the ATCO's cognitive state needs to be monitored. However, for the purpose of this paper, it suffices to say that (neuro) physiological parameters are collected for the automation to assess the ATCO's state to be one of the following, other than nominal: *stress, fatigue, mental workload, overload* and *underload*. This classification, in combination with relevant traffic parameters (e.g. number of aircraft in the sector or traffic complexity), will then inform the automation mode. The ATCO's state should always be interpreted in the context of traffic complexity and other external factors, and must be measured robustly and unobtrusively.

In the development of the following strategies and guidelines, it is assumed that the system has current and past knowledge of the ATCO mental state and the current, past and (predicted) future operational situation. Moreover, the ATCO is assumed to have sufficient capabilities to execute all tasks in a nominal state and has the capacity to take over tasks from the automation in case of automation failure. The CODA system will match the flexible nature of ATC operations, yet for the time being, it is assumed that the ATCO is unable to override the CODA system and that the system is not customizable. Importantly however, CODA and the ATCO must share the same operational goals to achieve the objective to effectively and safely manage the air traffic. The adaptation strategies and the HMI guidelines are described below for the CODA system.

3 Results: Adaptation Strategies and HMI Guidelines

3.1 Key Points of ATCO Session

Three male former operational ATCOs were consulted at the premises of a European ATSP regarding their views on the concept of CODA. The session started with an introduction on the project and on the developments thus far. Then, they were asked to explain their views concerning the system and its potential parameters in detail. Some key points are outlined. First, the ATCOs highlighted the flexible nature of ATC operations, and that no operational situation is the same. This is important when planning the actions of CODA, as it needs to ensure it does not interfere with the specific plan an ATCO has in mind for that operational situation. Second, the ATCOs emphasized that experiencing some stress is beneficial to an ATCO and their efficiency, indicating that the detection of stress is not immediately problematic. Third, the CODA HMI should not overflow the ATCO with warnings or notifications once CODA initiates an action, as the ATCO needs to maintain a mental model of the situation. The mental state of the ATCO should be considered when notifying the ATCO. Finally, the notion of criticality should be reconsidered in a CODA setting, as in current terms it suggests a non-nominal situation. It is suggested to define it as ‘requiring an action within a limited timeframe’ instead, for which the ATCOs think CODA could substantially ease them.

3.2 Resulting Adaptation Strategies and HMI Guidelines

An adaptation strategy can be seen as a prescription of the task allocation between human and machine for different situations. Such strategies are crucial for the functioning of a system like CODA, and for maximizing the positive effects on the ATCO. Research by [1] and [5] highlights the benefits of adaptive automation in reducing mental workload and preventing the Out-Of-The-Loop (OOTL) phenomenon in ATCOs. By incorporating physiological computing, these strategies aim to optimize ATCOs’ performance by adjusting automation levels based on their cognitive states and workload. The following adaptation strategies are suggested in summary (Table 1).

Table 1. Adaptation strategies for the CODA system

#	Adaptation strategy
1	CODA and the ATCO can communicate with each other through a HMI, e.g. the CODA dashboard or radar screen, about selected automation modes and other tasks performed by either the ATCO or the CODA system
2	CODA can explain their actions to the ATCO, to help improve trust [6, 7]
3	In case of conflict management, the ATCO's input is always leading
4	CODA will operate in different modes operandi, though the exact order number will have to be backed by empirical studies and operational experts
5	There is a standard automation level, which might be referred to as the baseline and which can be expected to be applied most of the time
6	The implications of each automation mode should be clear and logical to the ATCO
7	The ATCO is informed about the current mode and is notified of any changes
8	CODA selects a mode on the basis of knowledge about current and past mental states of the ATCO and knowledge about the current, past and future operational situation
9	The preferred automation mode counteracts any negative effects of ATCO mental state
10	CODA considers the effectiveness of an ATCO's actions when determining the appropriate automation mode, distinguishing between effective and ineffective stress
11	The automation adaption avoids frequent changes to let the ATCO recognize and adapt to the mode. The maximum frequency of automation changes needs scientific backing
12	Critical tasks are always performed by the ATCO, and not by CODA. The circumstances under which a critical task becomes critical is backed by operational experts
13	CODA shall not take over too many or too demanding tasks, ensuring that if CODA fails, the ATCO can take over all tasks effectively without endangering safety
14	CODA shall take over tasks in such a way that the ATCO will not over-trust or become overly dependent on CODA to ensure ATCOs remain competent and current

Next, the design of HMIs for the CODA system plays a critical role in ensuring efficient and safe operations in ATC, as this is the only means of communication between the ATCO and the system. While the CODA system involves an HMI philosophy, for the purpose of this paper the focus lies on the specific guidelines proposed to enhance the usability and effectiveness of the interfaces (Table 2), again in summary.

Table 2. HMI guideline and their respective categorization for the CODA interface

#	HMI guideline (including categorization)
Visual design	
1	The CODA interface should use symbols, colors and layout conventions that are already familiar or logical to the ATCO, yet not identical or highly similar to existing symbols, colors and codes or that may be used as standards for ATC operations
Layout, navigation and accessibility	
2	The current automation mode should always be directly be accessible and clearly visible
3	Modes and their nomenclature should be clearly distinguishable from one another
4	The (estimated) state of the ATCO should always be accessible to the ATCO with minimal effort. The process of gaining this information is backed by operational experts
5	Updates on the state should be conservative, i.e. not change too often, to minimize distraction. Estimation of state should be across a ‘considerable’ time period
System feedback	
6	The expected future status or mode of the automation, should be clearly visible to the ATCO when 1) the system is changing modes or functionality imminently, and 2) what the likely next mode is based on the current situation
7	In the event of system failure, the interface must clearly alert the ATCO about the status of the system (“FAIL”) and the immediate consequences for their tasks
8	CODA dynamically adjusts the type and modality of alerts (visual, auditory, etc.) based on real-time assessments of the ATCO’s cognitive load and situational factors. Taking into account human cognitive limitations, such as change blindness and tunnel vision
9	System feedback from CODA to the ATCO should be integrated as much as possible into the current, familiar format, i.e. into the radar screen and on the flight strips
10	The interface should provide the ATCO with relevant information and suggestions. This should be high level, and should support the ATCO in reaching the goal/task
11	CODA should provide feedback to the ATCO in incremental steps in chronological and critical order, i.e. it shall only take over any tasks if the operational situation calls for it
12	Any notifications from the system to the ATCO should be ordered and colour-coded based on priority and criticality, backed by empirical studies and operational experts
Safety and security	
13	CODA should incorporate best practices in terms of security to protect data
14	CODA should clearly state any error messages when they are encountered
15	There should be the possibility to undo a specific action to prevent any mal-entries and accidental operations from taking effect

4 Discussion and Conclusion

This paper outlines the interim conclusions in the development of the adaptation strategies and HMI guidelines for a COntroller adaptive Digital Assistant (CODA). These strategies and guidelines are subsequently used as input to create a mock-up of the potential CODA system, and can be used as a checklist for the time being. However, any issues arising during their implementation (i.e. due to technical limitations of the current simulation platform) will be discussed and updates to these strategies and guidelines will be made accordingly for the first prototype.

The outlined adaptation strategies enhance key aspects of human-machine teaming, with the aim of improving ATCO's situational awareness, performance and trust. Maintaining predictability of actions and intentions aid in optimizing the performance of CODA, safety, and subsequent trust in the system, which is essential for the implementation of a digital assistant as CODA. Improving adaptation strategies ensures the efficiency of such human-autonomy collaboration.

The HMI guidelines aim to support transparent and effective communication between ATCOs and the CODA system, thereby enhancing user satisfaction and system usability. Information is provided according to priority, criticality, and hierarchy to avoid overloading the ATCO. These guidelines aim to present information in an easily accessible, readable, and intuitive manner, considering the ATCO's state.

Though the proposed adaptation strategies and HMI guidelines were constructed after consulting relevant literature and operational experts, empirical assessment and validation of ensuing mock-ups are required in a high-fidelity setting. Based on findings from this assessment, changes may be made to enhance the operational relevance in one or more iterations. We expect the final iteration of the CODA system to improve situational awareness, user trust, and performance and reduce workload for the ATCOs.

In conclusion, these interim conclusions offer meaningful insights into the development and potential benefits of technical support tools within the highly regulated, safety-critical environment of ATC. While the integration of new digital assistance systems in such domains presents unique challenges due to strict operational standards and the need for ATCO acceptance, the CODA project demonstrates that adaptive support tools hold significant promise for enhancing safety and operational efficiency. By contributing to the scientific literature, this work underscores the importance of further research and iterative development to align technical innovations with the specific needs and preferences of air traffic controllers, paving the way for advancements that support their critical role in maintaining airspace safety.

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