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A human factors' approach for multimodal collaboration with Cognitive Computing to create a Human Intelligent Machine Team: a Review

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Abstract. In the Horizon 2020 funded Clean Sky 2 programme, the Cognitive Collaboration for Teaming project aims at positioning a roadmap towards Single Pilot Operations (SPO) and human intelligent machine teaming. Built on top of the states-of-the art of human factors, a careful examination of the factors and parameters to be taken into account to form a Human intelligent Machine Team (HiMT) was carried out. Each parameter can influence positively or negatively teaming. A good HiMT is a HiMT that communicates, shares knowledge, information, collaborates and trusts each other to ensure flight safety at the highest level. This review shows the added value of multimodality for bidirectional communication in the HiMT. Multimodality will allow both verbal and non-verbal communication to be maintained in both directions. A review was conducted on the benefits of each of the modalities and means of interaction under different conditions and how each modality can complement each other for better bidirectional communication that is natural, efficient, and reliable. The objective is to transmit information in a clear, accurate and concise manner, but also to ensure that it is well received by the receiver (i.e. the CCTeammate and the pilot) and well understood. Each modality will allow the CCTeammate to present and/or represent the information in the best possible way to the pilot depending on the context and the task at hand.

1. Introduction

During a flight, pilots must master complex situations, while facing increasing system complexity due to the amount and type of information available. As part of the Horizon 2020-funded programme Clean Sky 2, Co2Team (Cognitive Collaboration for Teaming) pursues the idea that a system based on artificial intelligence can effectively support the pilot using cognitive computing towards single pilot operations (SPO). To create collaboration between the pilot and the intelligent agent, an innovative bi-directional communication paradigm and an intelligent allocation of roles and tasks are needed, based on the concept of keeping "pilot in the loop". In this way, it is possible to benefit from the most effective pilot skills, such as decision making, to achieve flight objectives and guarantee a maximum level of safety and better acceptability.

1.1 Towards Single Pilot Operations (SPO)

One of the objectives for airlines and aircraft manufacturers in the years to come is to move towards SPO and maintain the level of flight safety at its highest level in all circumstances. But SPO without extra help for the pilot or without a total redesign of the cockpit adapted to SPO is hardly conceivable. A study of single-pilot operations in a legacy cockpit [1] showed that flight performance decreased, and that safety margins and workload were considered unacceptable by pilots, especially in an emergency situation. So, to help the pilot, different strategies are envisaged such as assistance provided by automated systems and replace the co-pilot and his/her role as Pilot Monitoring by automation. Increasing automation in a cockpit would reinforce the automation paradox and increase the burden of system monitoring [2, 3] by the pilot alone in the cockpit. To minimize this effect, several research works [4, 5] are studying the establishment of a relationship of trust by creating a Human Automation Team (HAT). Co2Team's project goes further by proposing a Human Intelligent Machine Team (HiMT) with cognitive computing as a teammate for the pilot instead of more automation. The recommendations proposed by Cummings et al. and Shively et al. [5, 6] for HAT comply with Co2Team Cognitive Computing Teammate (CCTeammate). It keeps verbal and non-verbal communication, with a good HMI², and create a HiMT with the human that understands the machine and the machine that understands the human and establishes mutual trust. The CCTeammate of the Co2Team project aims to help the transition to SPO but will not replace the pilot in the role of decision maker (captain) and Pilot Flying.

2. What is Cognitive Computing (CC)

CC and Artificial Intelligence (AI) use the same technologies i.e. machine learning, deep learning, Natural Language Processing (NLP), neural networks and so on. Both can solve complex problems, but they have different purposes. CC aims at improving human decision-making and focuses on natural interaction with humans. Whereas AI aims at automating processes and solve problems without human intervention. CC attempts to build computer systems modelled after the human brain (using deep learning approach), which possess NLP, learning and decision-making capability. CC systems have six major characteristics:

1) Information adaptability to integrate big data from heterogeneous sources and then creating ideas from them (e.g. multi-sensory integration)

2) Dynamic Training and adaptation - learning and chaining as they receive new information, new analyses, new users, new intersections, or new activity

3) Probabilistic - discovering relevant patterns based on context, statistically generating and evaluating series of evidence-based hypotheses, predicting the probability of valuable connections, and returning answer based on learning inferencing. This also includes detection of unexpected patterns.

4) Highly integrated - automated systems workload management through which all modules contribute to a central learning system and are affected by new data, interactions and historical data.

5) Meaning-based - performing natural language processing and using embedded analytics to leverage language structures, semantics and relationships.

6) Highly interactive - providing tools and interactions design to facilitate advanced communications within the integrated system and incorporating human-computer interactions (HCI), data analysis and visualizations [7].

CC is a barrier-free communication between human and computer in a natural language (in verbal and nonverbal forms) is one of the primary goals of CC systems. The CC systems should augment human abilities assisting their decision-making processes in the real world [8].

The functionality of CC however, strongly depends on the methods and techniques of AI. In such a way, cognitive computing is an AI based system with a strong focus on helping humans to make decisions by communicating with them in a natural manner. That is why a CC system would have more chance to pass through the Turing Test than an AI system.

3. Human factors as the main and central approach

The state of the art carried out, examines the different human factors (HF) identified in the literature that are involved in the integration of an intelligent agent for cockpit operations with all that this implies in terms of complexity.

The Human intelligent Machine Team (HiMT) will operate in a legacy cockpit and will therefore deal with the automated systems of the aircraft. The review highlights the benefits and weaknesses of avionics automation [9–12] and how cognitive computing could address or help manage them. The human tendency towards automation bias is of particular concern, as it occurs when a human decision-maker ignores or does not seek conflicting information and favours the computer-generated solution that is accepted as correct [13–15]. This bias affects teams of people as much as individuals [16]. Co2Team wants to take a different approach and see how cognitive computing can help the pilot in a different way than automatization and avoid automation bias. On the contrary of avionics systems that are not designed and does not behave like a team member, the focus here is on how to create a HiMT.

Previous attempts in the field of aviation have been studied, such as the French "Electronic Copilot (FR)" for Rafale [17–20], the US "Pilot Associate" by DARPA (Defense Advanced Research Projects

Agency) and US Air Force's Wright Laboratory [21], Rotorcraft Pilot's Associate (RPA) [22–24]. And also more recent attempts such as IBM and Airbus CIMON [25–27].

3.1 Teaming

Co2Team aims to build a HiMT, so a review has been conducted to look at what cooperation is, how it works for human-human cooperation, and for human-machine cooperation [28–32]. A recent experiment in 2019 [33, 34] showed that human-AI cooperation is possible and that the team's performance is improved as a result. But Co2Team is about human- intelligent agent collaboration, which is why a precise study has been carried out on what collaboration is and the differences with cooperation. In both there is an allocation of tasks and roles between the team members, but collaboration is spontaneous and based on commitment. It is more an active and voluntary act where each member of the team is responsible for the whole [35–38]. The cultural effect and context on communication and collaboration in a small-group was considered, based on what is already applied, such as Crew Resource Management. Since CRM trainings have given pilots the tools to move from good cooperation to better collaboration, it may be important to maintain this even in the SPO and to adapt it to the HiMT [39]. More specifically Co2Team means Cognitive collaboration for Teaming, collaboration was presented, but what is teaming from a cognitive point of view for each individual and as a team? Team cognition [40] is a dynamic team activity inextricably linked to context that applies to the team (i.e. shared mental model [5, 37, 41]). This implies that the CCTeammate must also be equipped with the ability to deduce certain elements from a real situation (i.e. theory of mind ToM [42–44]). In other words, it means knowing the capacities and limits of the other teammate and being able for each member of the team to deduce, foresee and adapt his/her behavior, actions, needs.

The use of AI does not escape the need for mutual trust between the pilot and the CCT, nor from the trust the team will establish in the avionics. Therefore, an in-depth review has been carried out on how trust is built [45, 46] and maintained at the right level through positive and negative feedback, to avoid under and over trust [13, 14, 47–56]. Human decision making (DM) process [57–61] has also been considered as well as risk management to understand how the CCT may assist the pilot [62, 63], using the same DM model as the pilots (e.g. FORDEC). CCT will serve all the necessary insight to provide decision makers, the pilot with the information needed to make better and data-driven decisions and minimize the risks of DM bias and avoid some cognitive bias.

4. Multimodal Human Machine Interface and Interactions (HMI²)

Always with a human factors (HF) centered approach a review was conducted about the interactions between man and machine and how these interactions would be with a Cognitive Computing Teammate (CCT). The aim being to form a hybrid HiMT, the review focuses on the different aspects of multimodal communication (MMC) to keep the most familiar way of communication and collaboration for the pilot (i.e. Human-Human). It will be important to keep the verbal and non-verbal parts of communication. This last point is all the more important as the absence of non-verbal communication leads to more confusion (especially when discussing charts or briefings), and more difficulties in interpersonal tasks that require knowing the state of the teammate [64]. Bidirectional MMC is therefore promoted, aiming not only at keeping the non-verbal bi-directional communication, but also at task efficiency, fluidity and understanding. And it's through this bi-directional MMC that the HiMT will be possible. The use of bi-directional MMC should also ensure good usability and provide a form of redundancy and diversity (e.g. verbal + visual) which is one of the most useful tools to reduce the probability of a major fault and thus ensure good reliability of the interaction.

Most importantly the CCT will have to adapt the MMC to the context (e.g. ongoing task, gaze) but also adapt the content and representation to the context and modalities chosen. Jones (1990) [65] suggested, that if each modality performs better in relation to a specific task in a specific context, and if they complement each other and address each other's weaknesses, then combining them may be the most natural and effective method of interaction. But the use of MMC can overload the visual and audio space if it is poorly designed. A good MMC with adapted HMIs must not create a cognitive, visual, or auditory overload for the pilot. The means used for MMC must complement each other but not add up on the same channels.

The HF and user-centred approach led us to conduct semi structured interviews and cognitive walkthroughs with pilots to find out their needs and desires concerning the CCTeammate and this MMC.

Based on these interviews and the literature review, the CCTeammate will use as its primary modality of interaction the one favoured by the pilots i.e. oral. Oral communication using NLP as well as the other modalities and HMIs will have to be adapted to the culture of the pilots, the airlines and the manufacturer using the same phraseology, the right units, and the right terms, etc.

The different possibilities of interaction were investigated as well as the interests of each of them under different conditions and for both way of communication. The survey starts with the different inputs the pilot can provide, like the one already implemented like the voice via the microphone of the headset, the KCCU and the touch screen (TS). And those that are interesting to implement such as eye and gestures tracking. In addition speech to text (STT) and convolutional neural networks (CNN) technologies can be used for speech emotion recognition (SER) [66, 67]. Mainly because it is through speech that people communicate emotions, cognitive states and intentions [68]. So oral will be used as main communication modality, it is the one promoted by the pilots, it is the most natural and needs no additional equipment. TS can also be used, allowing a quick direct interaction [69–71]. But it cannot be used as main interaction modality because it requires a free hand and gaze [72, 73]. Eye and gesture tracking [74–82] can be used in a complementary way to enable non-verbal communication like pointing at something. The infrared cameras used for gesture tracking can also be used for facial emotion recognition [83, 84] to complement the SER as the emotions of the pilots cannot be neglected in the HiMT. Emotions affect, among other things, attention, startle effect, motivation, and ToM. Talking to an intelligent machine incapable of recognising and reacting to emotions and without empathy would be like talking to a sociopath you do not want to team up with.

But how the CCT can communicate in a multimodal way with the pilot using the different senses of the pilot? Oral communication will also be chosen as the main modality of communication e.g. NLP Text to Speech and also to convey emotions such as smooth talking to calm the pilot in a stressful situation. It will be possible to use a visual support e.g. if there is too much information at the same time. But it is not interesting or even useless to display information Head-down if the pilot is looking Head-up. For this it will be interesting to use the Augmented Reality to display information wherever the pilot is looking and to draw pilot's attention.

The Figure 1 summarizes the different modalities according to each direction of communication. Human factors and certification recommendations have been considered in this review to select an HMI² with good usability. The goal being for the pilot to have an intelligent teammate who is pleasant to use, reliable, and resilient.

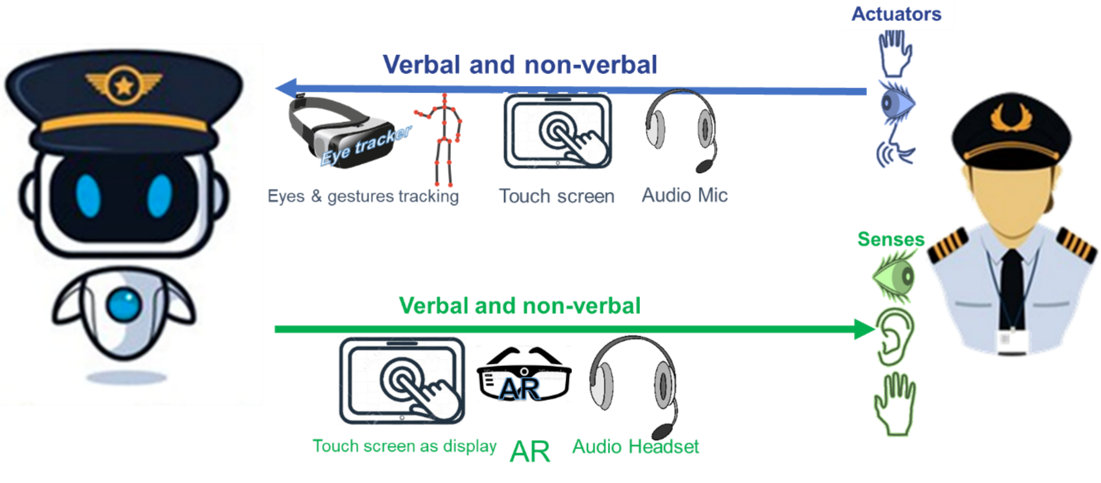

Figure 1: Bi-directional MMC

5. Conclusion

To move towards SPO, additional assistance is needed to ensure acceptable working conditions for pilots and maintain a high level of safety. This work examines the different human factors identified and involved in the integration of an intelligent agent for cockpit operations with all that this implies in terms of complexity (work, tasks and environment). And the factors involved in forming a hybrid team with a pilot, the HiMT. In the course of reading and research, a selection has been made of the factors that seem to be most relevant in the literature and most adapted to the intelligent agent. The goal being to design a HiMT with the human that understands the machine and the machine that understands the human and to maintain mutual trust. Based on a thorough study of the literature, a review and selection of each means and modality of communication was carried out for each of the two directions of communication. The survey studied the advantages and disadvantages of each of them and how they complement each other in their use, adding up their strengths and complementing their weaknesses. The use of multimodality will ensure operational resilience. Human factors and certification recommendations were considered in this review to select an HMI² with good usability. The objective being for the pilot to have an intelligent teammate who is pleasant to use, reliable, resilient, understandable with few constraints and with whom s/he will be able to communicate and collaborate effectively. By taking human factors into account, the power of human-machine symbiosis can be enhanced. Pilot and CCT collaborate by doing what they do best. Co2Team is in line with the vision of Horizon Europe's CleanSky2 programme with the use of the CCT, which could serve as an intermediate step towards opening avionics to the open world and intelligent unmanned aircraft.

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