An Intelligent Infrastructure for In-Flight Situation Awareness of Aviation Pilots

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Abstract. This paper presents an infrastructure that integrates intelligent agents in order to monitor, in real time, the attention of aviation pilots during training/operative flight missions. The primary goal of this infrastructure is to make the decision process easier and increase Situation Awareness, thus to increase flight safety pro-actively. The proposed hardware/software platform could be able to anticipate the onset of problems which can lead to incidents, and to make easier the decision making process toward a positive solution of the problem. To attain the goal, a multi-agent system is designed using the most recent technology in the field of artificial vision and of the measurement of psychophysical parameters, starting from the most recent knowledge of visual attention to arrive at the development of an original and innovative model of Augmented Reality. Finally it is provided a case study based on an event actually occurred to prove effectiveness of the proposed platform.

Keywords: Situation Awareness, Intelligent Agents, Augmented Reality.

1 Introduction

With the doubling of air traffic predicted for 2020 ([1]) the total number of incidents will rise even though the ratio of incidents/flight hours will stay low, and this will impact on the passengers' perception of the safety of air transport, as they take more notice of the number of incidents than their ratio. Since it has been widely documented that at least the 70% of commercial aviation incidents, in the last 15 years, are connected with human errors [2,3],. This is linked with the increasing difficulties to interact with ever more complex planes, as was found by the different studies [4] and [5], that highlight how on the one hand there has been an enormous increase in avionics and on-board systems which, taken one by one, should increase safety (FMS, Narrow spacing for VHF frequency, TCAS); on the other hand, budget requirements, the need to retrofit numerous old-generation aircraft (forced to suffer invasive technological upgrading to be able to use airspaces efficiently and economically), have produced the installation on board of low cost apparatuses and with often in-existent considerations of the ergonomics of the interface used, leading to an overall increase in the workload and a compromise of the global situation awareness.

Therefore the complexity of modern flight deck of commercial and / or military aircraft puts the pilot on the sidelines of a huge flow of information that helps to

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create a safe and efficient flight profile. The various aircraft systems, however, offer only a limited set of data for pilot analysis, e.g. only the information that are deemed useful to maintain the pilot within the attention loop needed to exercise appropriate control over the system and to take the right actions to maintain the level of safety and efficiency expected. This leads both the marginalization of the situation awareness of the pilot, that in routine operations has to perform simple and repetitive actions through the instrumentation and to monitor the environment; on the other hand relevant data are processed by the aircraft systems only in order to do not interfere with the perception of the pilot and to avoid overloading of the cognitive process of the subject. In case of detection of an anomaly in the profile of flight the pilot must: (i) Take all the information; (ii) Elaborate them all, focusing the problem; (iii) Develop one or more coping strategies; (iv) implementing a decision of containment of the event. Usually the time available to the pilot for problem solving is short, in which he must seize as much information as possible and process them all starting from the already established patterns, using its system expertise, in order to arrive at an answer to the original problem. In the case of high workload, however, the capacity to collect and analyze information and matching the current case with past experience is severely penalized and often the decision making process arises as a result of an inadequate analysis of information and a substantial revival of behaviors already encoded is applied, and it is not adapted to the new situation. The heterogeneous composition of aircraft and avionics makes even more critical the decision making process and even more important to capture the largest possible number of appropriate information for a correct interpretation of the actual situation.

To help the pilot we propose an integrated infrastructure, based on intelligent agents, to monitor in real time the attention given by aviation pilots during flight operations, to facilitate decision-making and to enhance situation awareness (i.e. awareness of the events in surrounding environment). The infrastructure is based on pilot's eye and gaze tracking, as well as on the monitoring of attention arousal in flight deck, using real-time hardware systems that process signals from opto-electric and psychophysiological sensors. The output from the tracking system will be send as input to a comparison agent that determines the level of attention and its allocation in the cockpit. If the infrastructure detects a form of inattention it shall issue a warning signal with the aim to restore the level and / or the appropriate allocation of attention, according to the criticality detected.

The proposed infrastructure works comparing the behaviors shown by the pilot himself in similar situations to the behaviors measured in real time during the flight. To this end the infrastructure include a virtual cockpit system, that records in real-time both the telemetry data of on-board avionics system and the behavior of the subject, and compares them all with previous records in telemetry and behaviors databases. If computing these elements it is identified an inappropriate attention process, either for quantitative or for allocation, the infrastructure will produce a warning signal that will stimulate the situation awareness and, providing useful information to the analysis of the problem, the process of decision-making.

From a methodological point of view, we will propose the development of new closed loop technologies by means of the computerization of the environment in which pilots find themselves operating, so that the system can identify attention lapses, analyze potentially dangerous situations and produce alert signals which allow correct decision making and/or full situation awareness. In this sense the proposed multi-agent infrastructure will be integrated with the on-board instruments. The infrastructure is composed of optoelectronic sensors, which produce useful information about the physical environment in which pilots operate. In addition the proposed system will allow us, for the first time, to model the attention process based on real individual vision. The computerized psycho-physiological study will thus allow us to integrate into a group behavior model the specific, individual, results of the subject, and definitively, to have both a complete panorama of the information present in the operative context, and feedback based on the correlation of actual data and perceived data and/or those taken into consideration, as well as a comparative analysis between the current parameters and previous ones (sampled in other experiences), with the relative decision results. The computerization of behaviors measured thus will allow us to set up a database aiming at reducing the work load brought by knowledge based happenings relative to routine and/or non-routine situations through the development of an appropriate alert protocol which informs the pilot of a difference between an effective operating situation and the perceived one.

But what will place this study strategically at the edges of current technology will be the integration of the outcomes with the concept of Augmented Cognition. The Augmented Cognition program, developed by the Defense Advance Research Projects Agency (DARPA) [7], has as its core elements the focus on the real time measurement of the subject's cognitive state, measured by modern neuroscientific/psycho-physiological instruments, and the concept of "closed loop", in which the cognitive state of the operator is identified in real time and produces an appropriate adaptation of the system around him [8,9]. The current state of the art sees augmented cognition still to be implemented in the field of the measurement of visual parameters which, in the aeronautical field, are rendered even more complex by the dynamism of the environment. The most recent studies have underlined this gap, highlighting the inadequacies of psycho-physiological (visual) parameters which did little to help the measurement of inattention [10].

The rest of the paper is organized as follows: Section 2 shows the model of the proposed infrastructure; in Section 3 we will study the effectiveness of our system model using a real world event actually occurred. Finally Section 4 reports our conclusion and future works.

2 SAMI: A Multi-agent Infrastructure for Situation Awareness Monitoring

It has been demonstrated in various fields that productivity can be greatly enhanced through the use of automation technologies. In order to be fully accepted in aviation, automation not only needs to increase productivity but do so cooperatively with the pilot. That is, the pilot must know what the automation is currently doing and what it will do in the future. Rather than replacing what the pilot currently does, we aim to augment his capabilities with signals that back up his internal knowledge and enhance his SA. The main aims of our infrastructure is to increase flight safety pro-actively through early detection of problems that can lead to incidents, and to make easier the decision making process which will lead to a positive solution of the problem. To attain the goal, in this section we will introduce a multi-agent system, which exploits the most recent technology in the field of artificial vision and of the measurement of psychophysical parameters, starting from the most recent knowledge of visual attention to arrive at the development of an original and innovative model of Augmented Reality.

The Agent-based Model of SAMI. In our model the information flows in a feed-forward fashion, from flight deck, where two interface modules collect and select relevant data, toward the reasoning module of SAMI that is in charge to take decision if the attention is adequate or not and, if not, to send a signal to pilot. Therefore, the output of SAMI is to alert the pilot either if he loses quantitative attention during the routine of the flight or if he lacks of qualitative attention in non-routine operations. In other words SAMI will send a warning signal to restore the attention level when the pilot shows a low level of attention during routine or will send an alert signal to focus the pilot's attention to a rising problem.

As the attention level during the flight operations has a gradual degradation, and, meanwhile, the attention focus can be more or less near to the points which need constant supervision, the adequacy of the attention must be computed as a fuzzy value [11]. For this reason they are modeled using fuzzy logic, that is able to deal with reasoning that is robust and approximate rather than brittle and exact [12]. Therefore fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

As shown in Figure 1 three main components form the system, they are listed with a brief description of their functions in the following.

HMI: Human Machine Interaction Recorder. This component records all the interactions of pilot with the cockpit. It uses the available technologies to track psychometric, neural-physio-logical parameters, e.g. eye and gaze movements, heartbeat, blood pressure, skin conductance, EEG.

CAV: Cockpit Artificial Vision. This component simulates a reference pilot that is able to acquire and to process all the information from the aircraft. In fact, it derives telemetry data from all on-board control systems, like for example the Flight Management Guidance System (FMGS) and the Enhanced Ground Proximity Warning System (EGPWS). Collected data is computed and aggregated in real-time, then relevant parameters are sent to SAMS for processing.

SAMS: Situation Awareness Monitoring System. This component is the core of the infrastructure. It is modeled as a fuzzy inference system, which is the process of formulating the mapping from a given input to an output using fuzzy logic. SAMS is divided into two elements: the ***Pilot Attention Monitor*** (PAM) and the ***Situation* Awareness Monitor (SAM).** PAM has three modules: the Attention Level Evaluator (ALE), the Attention Focus Evaluator (AFE) and the System Database (SD). In a preliminary phase PAM identifies the current pilot and does an initial assessment of the attention level. Next, during flight operations, all three modules receive raw input information from HMI and CAV. ALE and AFE evaluate two indexes that indicate respectively the pilot's (quantitative) attention level and the pilot's (qualitative) attention focus. The SD stores the input data from flight deck and the two indexes evaluated by ALE and AFE, meanwhile SD compare new inputs with the reference data and select the fuzzy rule and data bases according to the current pilot and flight situation. Personalized fuzzy rule and databases are sent, along with ALE and AFE indexes, to the SAM. PAM uses the information in SD to personalize the computation to the specific individual that is recognized by the preliminary identification as the current pilot. Feedback information received from SAM is used to update the personalized fuzzy rule and data bases. Data for individual information database can be collected during simulated training.

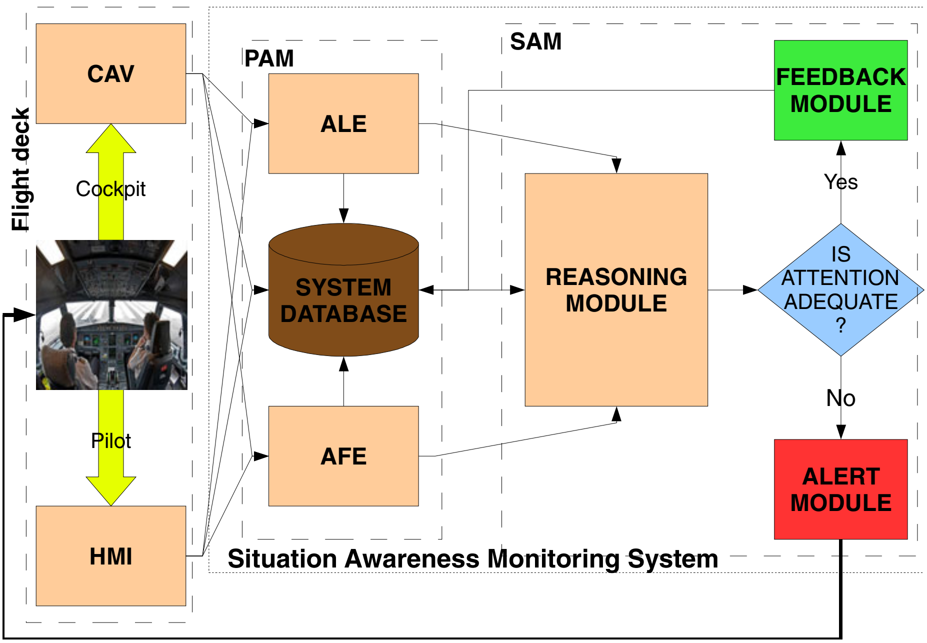

Fig. 1. Model for an Agent-based Situation Awareness Monitoring Infrastructure

SAM main module is the Reasoning Module (RM) that computes the fuzzy inference system to evaluate if the attention of the current pilot is adequate for current flight situation. The three input variables of the fuzzy inference system of SAM are the artificial indexes that PAM evaluates from raw data collected by HMI and CAV. If the answers are positive SAM send a feedback to the SD to update the information about the current pilot. If the answer is negative SAM activates the Alert Unit, which will send a signal to the pilot. Signals could be of three main categories: "*wake up*" signals, that are sent in case of loss of quantitative attention (i.e. SAMS output is *low attention*) with the aim to restore the correct level; “*warning*” signals, that are sent in order to catch pilot's attention in case of critical situations, when the pilot attention focus is in a wrong position (i.e. SAMS output is "*wrong-focus*"); "*alarm*" signals, that, in case of "*not adequate*" attention and "*dangerous*" situations, intervene with on-board instrumentation to cut off the unnecessary information and thus increase situational awareness. At the end of its computation SAM send feedback information to PAM to update the SD with the new data for system customization.

Realization Remarks. For all devices present in an aircraft the main rule to follow is "*do not interfere with the other on-board systems*". After this the proposed infrastructure can be classified as a "add-on", in other words it is not critical for the correct function of the other on-board systems and if it has problems it can be simply switched-off without any loss in the standard safety of the aircraft. However it is better to include in its design a self-check system able to automatically switch off the SAMS infrastructure in case of malfunctioning. Moreover it is safer to avoid false signals from it, for this reason even if a single module of the system is not functioning the whole system must be shut down. It is preferable that the pilot wears sensors that should not hinder the movement. For commercial pilots, in order to increase eye and gaze tracking performance without using invasive sensors, a camera can be integrated in glasses that the pilot should wear during the flight. This is not needed for military pilots that wear a full helmet in which it is yet possible to integrate a lot of devices, including a camera.

3 Case Study

In this section we will demonstrate the effectiveness of our system model using case study, based on an event actually occurred. The case under consideration is a Controlled Flight Into Terrain identified as CFIT. This category of accidents is one that aims to reduce the SAMI system. Implement the CFIT category represents worldwide the second leading cause of serious accidents on commercial aviation aircraft, behind the loss of control of the aircraft caused by damage to facilities or systems.

In this section we will report the actual development of the incident step by step and, in parallel, we will describe how the events could have been carried out if our SAMI model was operational.

The Incident with and without SAMI. On 11 March 2005, an Airbus A321-200 operated by British Mediterranean Airways, executed two unstable approaches below applicable minima in a dust storm to land in Khartoum Airport, Sudan. The crew were attempting a third approach when they received information from ATC that visibility was below the minimum required for the approach and they decided to divert to Port Sudan where the A320 landed without further incident.

In the following the record of the incident is divided into 5 steps, for each one we highlight the expected actions of SAMI and how they would be useful to improve situation awareness and thus flight safety.

Step	Official Report of the serious incident	SAMI actions
1	*Runway 36 was in use but the ILS on this runway was out of service. The commander assessed the weather conditions passed to him by ATC and believed that he was permitted, under his company's operations policy, to carry out a Managed Non-Precision Approach (MNPA) to Runway 36. This type of approach requires the autopilot to follow an approach path defined by parameters stored in the aircraft's commercially supplied Flight Management and Guidance System (FMGC) navigation database*	At this step there is no criticality on this scenario, the proposed SAMI model would not found anything unusual, but thanks to the CAV module it would record a non-precision approach on FMGC, loading the corresponding baseline parameters for this procedure from the system database as benchmark.
2	*On the pilot's approach chart, which was also commercially supplied but from a different supplier, the final descent point was depicted at 5 nm from the threshold of Runway 36 whereas the FMGC's navigational database had been correctly updated with a recent change to this position published by the Sudanese CAA which placed it at 4.4 nm from the threshold. The discrepancy amounted to a difference in descent point of 0.6 nm from the Khartoum VOR/DME beacon, the primary navigation aid for the non-precision approach.* *The pilots commenced the approach with the autopilot engaged in managed modes (i.e. the approach profile being determined by the FMGC instead of pilot selections). The aircraft began its final descent 0.6 nm later than the pilots were expecting. Believing the aircraft was high on the approach, the handling pilot changed the autopilot mode in order to select an increased rate of descent.*	Also at this stage our SAMI model records but does not intervene. It monitors the trajectory of the aircraft (altitude and position readings from FMGC) and the increase in the descent rate, meanwhile the attention level is monitored and compared with the benchmark. Outputs of SAMI at this step represent a situation compatible with standard safety operations : a strategic management of FMGS and in addition a subsequent tactical change by the use of selected vertical speed to handle the vertical trajectory. Furthermore, the sequence of actions recorded in the activation of pilot vision and psychophysical parameters when there is a change between strategic and tactical management are still part of the routine of the flight.
3	*The approach became unstable and the aircraft descended through 1,000 ft agl at an abnormally high rate.*	Now CAV detects the abnormal descent rate in relation to the position of the aircraft. According to our model CAV output shifts *operative situation* from n*ormal* to *critical* and AFE moves a*ttention focus* towards *far*, due to the analysis of the pilot being off the target parameter (high descent rate below 1000 ft agl). SAMI output is now *wrong-focus* and a warning signal is triggered in order to lead the pilot attention toward the target parameter (descent rate)

4	*The aircraft then passed through its Minimum Descent Altitude (equivalent to a height of 390 ft agl) with neither pilot having established the required visual references for landing. Instead each pilot believed, mistakenly, that the other pilot was in visual contact with the runway approach lights.*	At this step, SAMI output turns to l*ow-attention*, therefore monitoring pilot attention level, ALE detects the difference between the problem reported by the CAV and the current pilot vision. In this case activates a second signal, an alert to instruct pilots to stop the descent and follow the missed approach path.
5	*When the confusion between the two pilots became apparent, the aircraft had descended to approximately 180 ft agl and the handling pilot commenced a go-around. Between 3.4 and 5.1 seconds later, with the aircraft at a radio altitude of approximately 125 ft agl, in a position approximately 1.5 nm short of the runway, the Enhanced Ground Proximity Warning System (EGPWS) "TERRAIN AHEAD, PULL UP" audio warning was triggered. The correct emergency pull-up procedure was not followed in full, partly because the handling pilot had already initiated a go-around. The minimum recorded terrain clearance achieved during the recovery maneuver was 121 ft. One further non-precision approach to Runway 36 was attempted using selected autopilot modes*	SAMI detects a dangerous situation, because the confusion between the pilots is evaluated by PAM as *low-attention* and *far* focus. But the two warning signals from our SAMI model provided an important advance in time and avoid confusion between the two pilots. For this reason this step simply would not happen if a SAMI was present in the aircraft.

What made possible to interrupt the chain of events during the case is clearly the decision of the crew to stop the descent at 180ft (about 60 meters from the ground). In this case the only support system was identifiable in the EGPWS, which generates an alert at 125ft, with the AM aircraft located about 2km from the runway. The airplane was down about 55ft in roughly 4.5 seconds, and then considering the projection of a similar rate the aircraft would have been found to impact with the ground after about 13.5 seconds from the time when the alert signal is activated from EGPWS. Consider also that the go-around maneuver resulted in an initial decrease of altitude of 60ft and was started at 180 ft, if it was initiated activation signal EGPWS you can assume a minimum of 65ft and thus a time latency of the decision more than 4 seconds could lead to the impact with the ground even in the presence of a signal EGPWS correct and appropriate avoidance maneuver.

In this case the intervention of the SAMI instead would rise an alert prior to the signal from EGPWS and in strict adherence with the company's Standard Operating Procedures, thus providing also the correct, safe, execution of the missed approach procedure (go-around). SAMI provides an important advance in time (even if only a few seconds) but also acts as a disruptive element in chain of events, providing an important structural support to the process of situation awareness and decision-making. Furthermore we want to underline a second safety improvement related to

SAMI: the ability to discriminate the operational environment in which the aircraft is operating, and to relate it with the pilot's S.A. this can be evaluated in step 3, where the system shifts from *normal* to *critical* operational situation; the comparison between the situation detected and the current pilot focus or level of attention could lead to an alert well ahead the reaching of MDA, thus reducing in a significant manner the stress and the workload caused by the interruption of the descent path and of the subsequent missed approach procedure.

4 Conclusion

In this paper we presented the model of an infrastructure which integrates intelligent agents in order to monitor in real time the attention paid by aviation pilots during training/operative flight missions, to make the decision process easier and increase Situation Awareness (SA). To achieve this goal in our work we proceeded, from the methodological point of view, reversing the terms of the problem. In other words, we used the most advanced technology to build an agents-based infrastructure to interpret the reality in which the pilot is set. The model of the infrastructure, we called Situation Awareness Monitoring Infrastructure (SAMI), is based on intelligent agents, that cooperating with each other act like a virtual co-pilot in order to augment capabilities of the real pilot, enhancing his SA, and to maintain and recover pro-actively its attention. Starting from an event actually occurred, a case study scenario was given to prove the enhancement given by SAMI in pilot's SA and thus in flight safety.

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