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Experimental Simulation Set-Up for Validating Out-Of-The-Loop Mitigation when Monitoring High Levels of Automation in Air Traffic Control

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Abstract**—**An increasing degree of automation in air traffic will also change the role of the air traffic controller (ATCO). ATCOs will fulfill significantly more monitoring tasks compared to today. However, this rather passive role may lead to Out-Of-The-Loop (OOTL) effects comprising vigilance decrement and less situation awareness. The project MINIMA (Mitigating Negative Impacts of Monitoring high levels of Automation) has conceived a system to control and mitigate such OOTL phenomena. In order to demonstrate the MINIMA concept, an experimental simulation set-up has been designed. This set-up consists of two parts: 1) a Task Environment (TE) comprising a Terminal Maneuvering Area (TMA) simulator as well as 2) a Vigilance and Attention Controller (VAC) based on neurophysiological data recording such as electroencephalography (EEG) and eye-tracking devices. The current vigilance level and the attention focus of the controller are measured during the ATCO's active work in front of the human machine interface (HMI). The derived vigilance level and attention trigger adaptive automation functionalities in the TE to avoid OOTL effects. This paper describes the full-scale experimental set-up and the component development work towards it. Hence, it encompasses a pre-test whose results influenced the development of the VAC as well as the functionalities of the final TE and the two VAC's sub-components.

Keywords**—**Automation, human factors, air traffic controller, MINIMA, OOTL, Out-Of-The-Loop, EEG, electroencephalography, HMI, human machine interface.

I. INTRODUCTION

OVER the past few years, the global air traffic growth has exhibited a fairly stable positive trend, even though economic immobility, financial crisis, and increased security concerns. It is now clear that traffic flow patterns will become more complex, making conflicts and situations harder to identify for a human operator and will put immense pressure on the air traffic control system. In this context, several solutions have been proposed for modernizing air traffic control to meet the demands for enhanced capacity, efficiency, and safety [1]. These different solutions rely on higher levels of automation as supported by both SESAR JU and HALA! Research Network [2], [3].

A. Out-Of-The-Loop Phenomenon

On the one hand, implementing higher levels of automation can improve the efficiency and capacity of a system. On the other hand, automation can also have negative effects on the performance of human operators such as a set of difficulties called the OOTL phenomenon [4]. In the current context of a continuous increase in automation, understanding the sources of difficulties in the interaction of humans with automation and finding solutions to compensate such difficulties is a crucial issue for both system designers and human factors society. While this OOTL phenomenon is considered as a serious issue in the human factors literature, it remains difficult to characterize and quantify. Despite the great improvements of neuroscience in measuring human mental states [5], detecting the occurrence of this phenomenon, or even better detecting the dynamics toward this degraded state, is an important but still open issue in order to develop tools for evaluation and monitoring.

B. Vigilance and Attention of Operators

Attention, in a wide extent, is a cognitive process defined as concentrating selectively only on the relevant part of an information ignoring the useless ones. Attention is adopted for a wide range of every-day activities, such as driving a car, watching a movie, or talking with friends, and it becomes even necessary in most of the workplaces like a hospital, a construction site or air traffic control. According to the present theories, attention is a multifaceted concept, generally divided into two main and complementary domains: intensity and selective aspects [6], [7]. The intensity aspect of attention embraces alertness and sustained attention, hereafter named Vigilance [8]: task execution with an optimal level of performance is possible because, for the entire duration of the task, there is an appropriate level of arousal managing resources involved in orienting and selecting. This capacity of controlling the focus represents the second main aspect of attention that involves the selective and the divided attention [8].

While the tracking of the attentional and conscious focus of

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the user is a direct measure obtainable by using eye-tracking devices, the Vigilance is a covert mental state that requires a deep investigation of brain activity. Several studies, by using ad-hoc tasks, investigated the possibility to characterize Vigilance based on human brain activity, in particular recording EEG data [9]-[13]. The main evidence consists of an increased beta activity at frontal site and theta activity over parietal site in comparison with rest condition. In addition, increased frontal and fronto-temporal temporal beta activity, occipital alpha and frontal beta power, more in right than in left hemisphere, suggested increased Vigilance. However, there are no unique and well-established theories about EEG features related to Vigilance.

C. Objectives of the MINIMA Project and Development

The general objective of MINIMA is its acronym, meaning to mitigate negative impacts of monitoring high levels of automation. Therefore, adaptive automation is triggered by real-time assessment of vigilance and attention of the ATCO to keep the operator in the loop. Thus, the comprehension of the OOTL performance problem especially according to a future air traffic scenario needs to be improved. Further, the MINIMA team has conceived and developed tools to detect and compensate the negative impact of this phenomenon. The MINIMA concept with its components is depicted in Fig. 0.

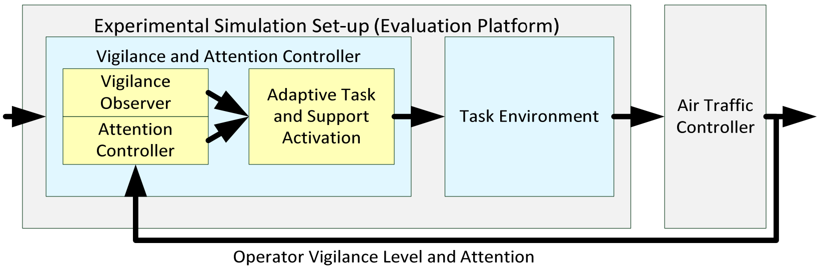


Fig. 1 MINIMA components in the concept

The detection of the OOTL phenomena and, in particular, of the decrease of vigilance level (Vigilance Observer) and lack of attention (Attention Controller) is performed by the VAC. The VAC also triggers the adaption of support functionalities and task allocation between the human agent and the automated system (Adaptive Task and Support Activation). This trigger is connected to the automation level (0, 1, or 2, i.e. low, medium or high automation) that results from vigilance and attention. The VAC component is integrated in a highly automated TMA simulator, i.e. the MINIMA TE which reacts on the trigger. The ATCO has the task to perform its air traffic monitoring work using the TE with its currently offered automation level dependent functionalities.

When controllers show low levels of vigilance, the level of automation is lowered and vice versa. Lower automation shall force the controller to interact with the air traffic situation more actively and thus avoid OOTL problems. In case of a high vigilance level and a reasonable attention focus, the automation level can be increased again after certain dwell time.

Four experimental steps are fulfilled in the preparation and execution of the MINIMA project. First, a Psychomotor Vigilance Task with 13 students was used to calibrate and tune the EEG for the Vigilance Observer. This was done with a small-scale experimental laboratory set-up with traditional equipment.

Second, a preliminary experiment with five ATCOs for testing the integrated VAC and TE was conducted with a medium-scale experimental set-up. This set of preliminary tests took place in the University of Bologna Virtual Reality Laboratory on a first release of the TE in a simulated controller workstation, thus in realistic settings. In this regard, the aim of such preliminary experiments was to identify brain activity characteristics, i.e. EEG features, directly related to human vigilance. Third, an ATM expert performed a full technical rehearsal with the final full-scale experimental set-up. Fourth is the MINIMA validation trial with 15 ATCOs using the full-scale experimental set-up (Fig. 0) were conducted to gather results about OOTL mitigation success (again at University of Bologna).

In Section II the design and results of the Psychomotor Vigilance Task for the Vigilance Observer through EEG signal capturing are reported and discussed (first phase). Section III outlines the succeeding experiments of the second phase. The complete TE is presented in Section IV, whereas Section V points out the characteristics of the VAC. Section VI finally summarizes the findings and gives an outlook.

II. PRELIMINARY TESTS (FIRST PHASE)

In order to tune the Vigilance Observer developed for the full-scale experiment, a first preliminary experiment was conducted. This section will describe the experimental design used for the pre-tests (first of four experimental steps), outline the respective results, explain how the results are used for the MINIMA Vigilance Observer, and describe why the pre-tests are a necessary pre-requisite for the full-scale experiment.

A. Experimental Design of Pre-Test

1) The Experimental Task during Pre-Test

The experiments were conducted following the principles outlined in the Declaration of Helsinki of 1975, as revised in 2000, and received the favorable opinion from the Ethical Committee of the Sapienza University of Rome (UNISAP).

Thirteen healthy volunteers (seven males, six females, 27±3 years old), students of UNISAP, participated in the experiments, after signing their informed consent.

The Psychomotor Vigilance Task (PVT) was chosen as the experimental task, as it is a commonly used task in scientific literature about human attention and vigilance in particular [14]. The PVT consists of a total duration of 10 minutes of stimuli, presented at random inter-stimulus intervals ranging from 1 to 10 seconds: the "Target" stimulus consisted in a red circle lasting 2 seconds, while the "No Target", i.e. the inter-stimulus confound, was a light blue fixation cross lasting from 1 to 10 seconds. The subject had to press the "space bar" on the keyboard as quickly as possible only in response to the "Target", i.e. the red circle: the answer was considered "correct" only if the space bar has been pushed during the 2 seconds of duration of the "Target" on the screen (Fig. 0).

Fig. 2 Screenshots of the PVT

In particular, the subjects were asked to perform two blocks of PVT, each one 10-minutes-long, with the aim of spreading the probability to induce a Vigilance decrease, due to boredom. Actually, it is the same assumption of vigilance decreasing in operators facing with very low demanding tasks. The participants performed ten practice trials before starting the experiments, in order to avoid bias from learning processes.

Throughout the experiment, the electroencephalogram (EEG) and electrooculogram (EOG, used only to remove eye-related artefacts from the EEG signal) signals were recorded using a high-resolution 63-channel system. Participants were seated at a distance of 60 cm from the monitor. This preparation was followed by a one-minute "Baseline" condition of data collection for all physiological variables. During the baseline period, the participants were asked to sit calmly with their eyes open. Right after the baseline, the participants filled out the Visual Analogue Scale (VAS, a digital self-assessment about the subject's own vigilance level) in order to collect their baseline, i.e. their reference vigilance state, and then they started with the protocol. During the experiment, at the end of each block, participants were asked to rate their perceived attention level using the Visual Analog Scale (VAS) [15], while their performance, in terms of Reaction Time (RT), was gathered by the computer.

2) EEG Recordings

The BrainAmp system (BrainProducts GmbH, Germany) has been employed to simultaneously record the EEG and the EOG signals (Fig. 0 (a)). All 61 EEG electrodes have been referenced to both earlobes, grounded to both the mastoids and their impedances kept below 10 kΩ. The EEG signal was first band-pass filtered with a 5th-order Butterworth filter (High-Pass filter: cut-off frequency fc = 1 Hz; Low-Pass filter: cut-off frequency fc = 40 Hz). Independent Components Analysis (ICA, [16]) was performed to remove eye-blinks and eye-saccades artifacts, whilst for other sources of artifacts, i.e. muscular artifacts or interferences that affected the quality of the signals, specific procedures of the EEGLAB toolbox have been used [17].

In particular, the signals were segmented into epochs of two seconds (Epoch length), shifted by 0.125 seconds (Shift), and three criteria were applied to recognize artifacts: (i) Threshold criterion (if VEEG > ±100 µV, the corresponding epoch was marked as artifact); (ii) Trend criterion (if epoch slope was higher than three (µV/s), the considered epoch was marked as artifact); (iii) Sample-to-sample difference criterion (if the amplitude difference between consecutive EEG samples was higher than 25 µV, the EEG epoch was marked as artifact). At the end, all the EEG epochs marked as artifact were rejected from the EEG dataset with the aim to have an artifact-free EEG signal from which to estimate the brain variations along the training period. All previously mentioned values were chosen following the guidelines reported in Delorme and Makeig [17].

From the artifact-free EEG dataset, the Power Spectral Density (PSD) was calculated for each EEG epoch using a Hanning window of the same length of the considered epoch (two-second duration, that means 0.5 Hz of frequency resolution). The application of a Hanning window helped to smooth the contribution of the signal close to the extremities of the segment (epoch), improving the accuracy of the PSD estimation [18]. Then, the EEG frequency bands were defined accordingly with the Individual Alpha Frequency (IAF) value estimated for each subject [19]. Since the alpha peak is mainly prominent during rest conditions, the subjects were asked to keep their eyes closed for a minute before starting the experiment. Such condition was then used to estimate an individual IAF value for each subject. The brain scalp was divided into four main areas (Fig. 0 (b)): (1) Frontal (all frontal "F", and antero-frontal "AF" EEG channels); (2) Central (all central "C", and fronto-central "FC" EEG channels); (3) Parietal (all parietal "P", and centro-parietal "CP" EEG channels); (4) Occipital (all occipital "O", and parieto-occipital "PO" EEG channels).

The PSDs within the theta, alpha, beta, and gamma EEG bands were analyzed over such brain areas with the aim to find out the brain areas and EEG rhythms mainly linked to the considered human factors concept (e.g. Vigilance) changes across the different experimental. Fig. 0c shows an example of a scalp map between two experimental conditions, which were used to present the EEG results. Such representation highlights which brain areas are more involved (if no grey, there is a statistically significant difference between the compared conditions) and in which way (i.e. if the respective activity is increasing or decreasing along the conditions). The color bar decodes, in terms of t values, the colors of the map.

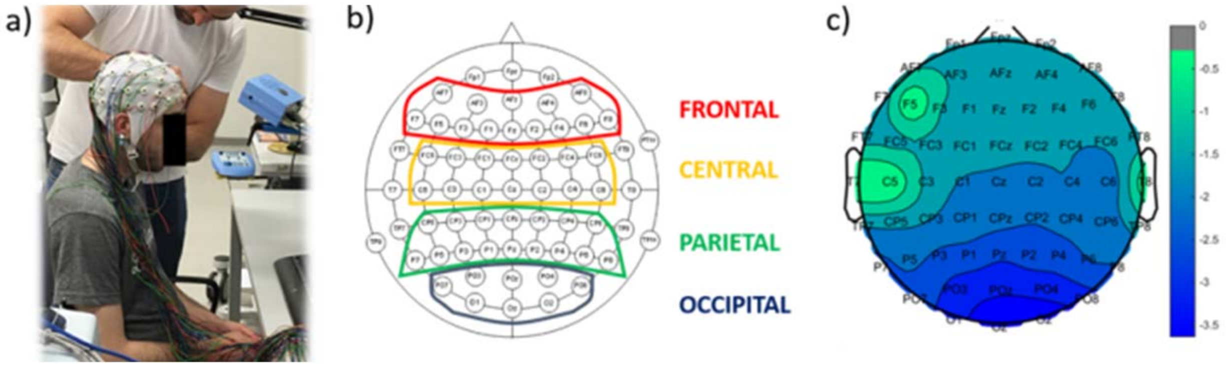


Fig. 3 (a) EEG equipment; (b) EEG AOIs; (c) Scalp map example

3) Performed Analysis

Performance between the two different blocks of PVT, i.e. PVT1 and PVT2 was compared by differences in readiness, the latter being assumed to be directly correlated to vigilance. Readiness was derived from subjects' reaction time (ms) to "Targets". Thus, for each subject the mean RT was estimated for each condition, obtaining a matrix of 13 (subjects) x 2 (conditions) values. In addition, a similar matrix (13 x 2) was obtained by using the VAS values of the vigilance level self-assessed by the subjects after each block.

Finally, 12 (three bands: theta, alpha, beta; x four brain areas: frontal, central, parietal, occipital) similar matrices (13 x 2) were obtained by averaging the PSD values of a particular EEG band over a specific brain area for each subject. Paired two-tailed Student's T-tests were used to test differences of mean between conditions for significance.

B. Results

1) Performance

The T-test (Fig. 0) showed a significant increment of mean RT from PVT1 to PVT2 (p = .046).

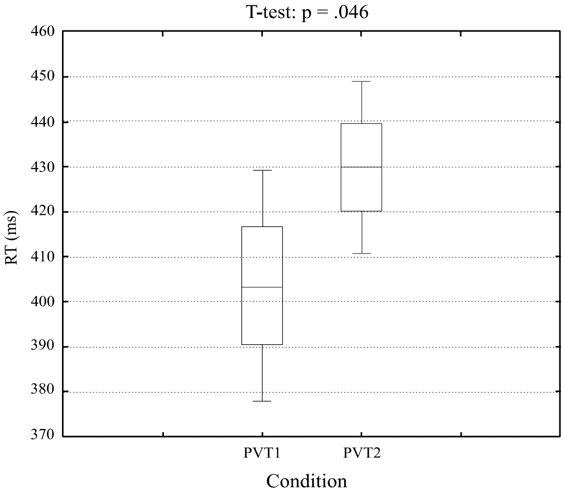


Fig. 4 IES variation between PVT blocks

2) Subjective Measures (VAS)

The results of the two-tailed paired T-tests on the VAS scores did not reveal any significant differences between PVT1 and PVT2 (Fig. 0).

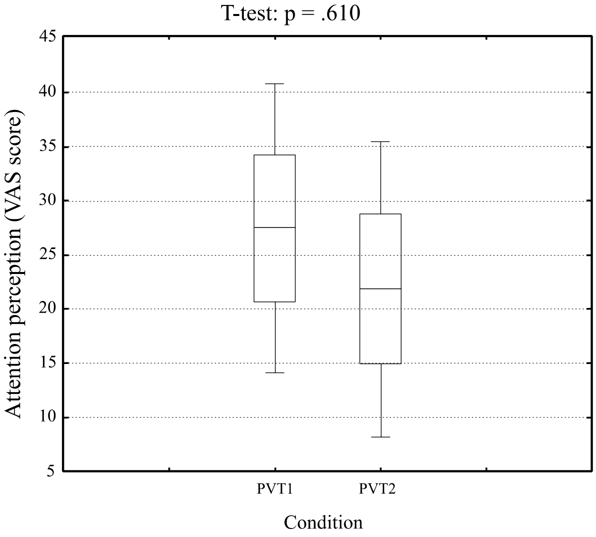


Fig. 5 VAS score for Attention perception, whit the result of the paired two-tailed T-test

3) EEG Features

The paired two-tailed T-tests on the PSDs reported significant effects within the theta and beta EEG bands (Figs. 0 and 0). In particular, between the PVT1 and PVT2 conditions, significant decreases (all $p < 0.040$) of the previous EEG rhythms on different cortical areas have been found.

C. Discussion and Future Steps

The performance results confirmed our experimental hypothesis: the PVT2 condition, i.e. the second block, which was supposed to induce decrease in vigilance, was characterized by significantly worse performance compared to PVT1. This result confirmed that the experiment actually induced two different levels of vigilance that appeared degraded during the second block, since subjects showed a significant performance decrease, despite the task equivalence.

The subjective measures confirmed in part this assumption, since a decreasing trend, although not significant, of vigilance perception was assessed by the subjects. The results' lack of significance could have resulted from the widely accepted low resolution of subjective measures, in particular if related to such covert mental states [20].

Not surprisingly, also EEG data analysis produced significant results comparing the PVT1 and PVT2: the latter, that is supposed to be related to lower vigilance level, was characterized by significantly lower values of PSDs of the Theta rhythms over central, parietal and occipital sites and of Beta rhythms over central and parietal sites.

It has to be observed that these results were obtained in a laboratory, in a very controlled setting, while the MINIMA observer will work in a real environment, where the subject will be free to move and to act. Based on this observation, we decided to not use Occipital features in general, because of the great amount of muscular artifacts from neck contractions, and Central features of theta band, because of the large involvement of the motor cortex, placed in correspondence of such central area. For the same reason, results in alpha band have not been presented, since the Alpha band is overlapped to the µrhythm, typical of the activation of the motor cortex.

In conclusion, the selected EEG features are Parietal Theta and Beta rhythms over Central and Parietal sites (probably with a right lateralization of parietal beta). These features were implemented in the algorithm constituting the Vigilance Observer of the MINIMA project, and have been tested on controllers in real settings during the second phase of the four experimental steps (see also Section I.C).

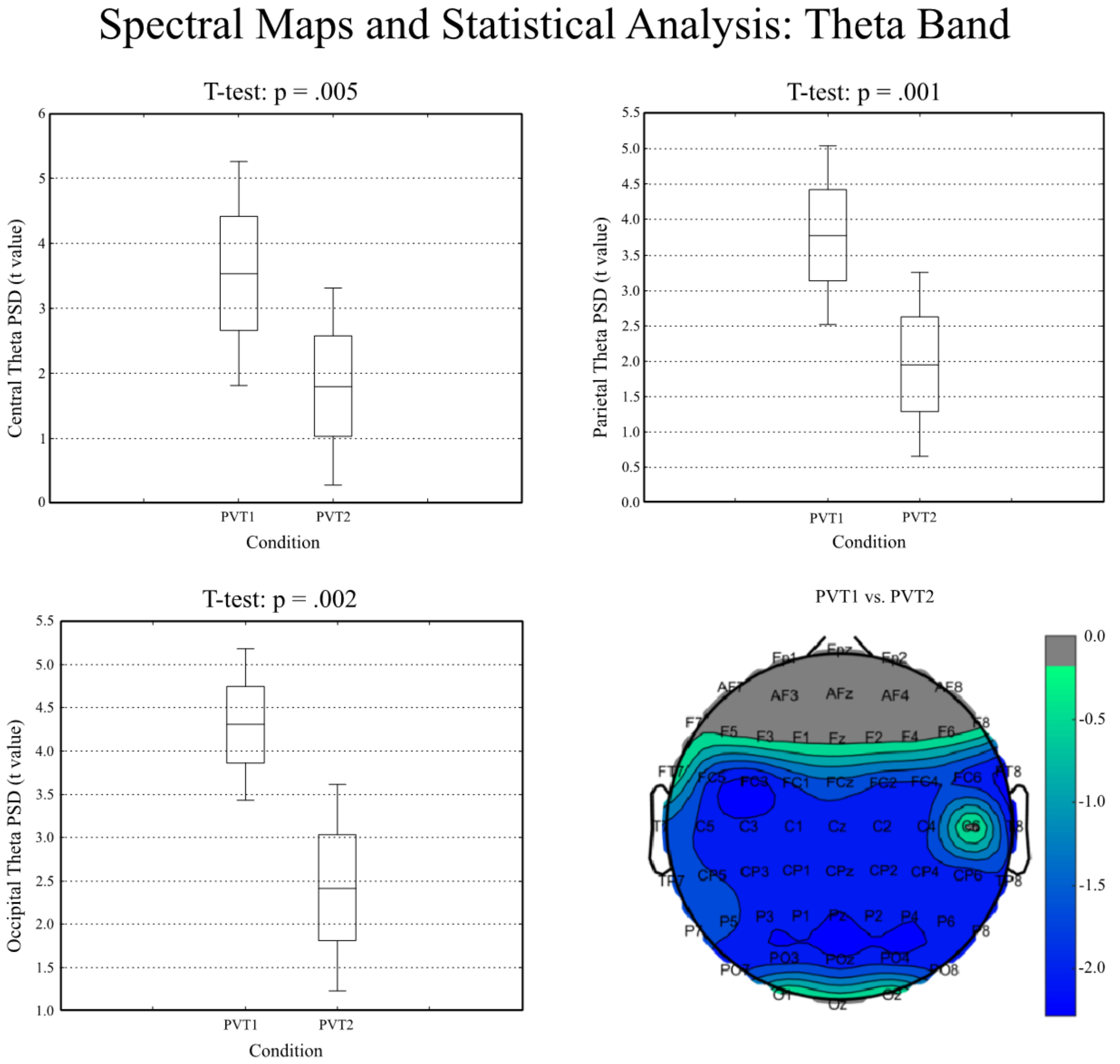


Fig. 6 Cortical maps and T-test in the theta band

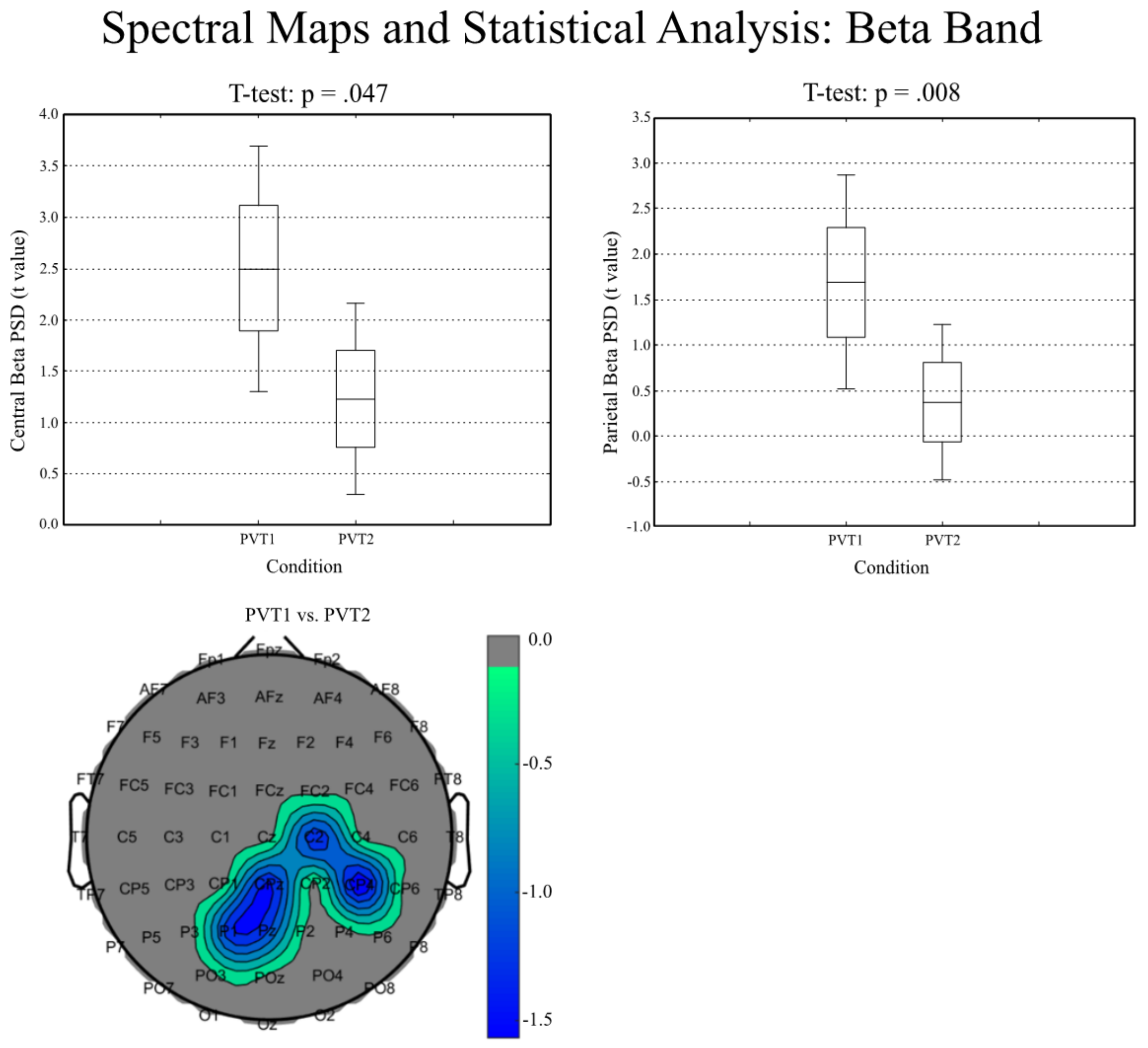


Fig. 7 Cortical maps and T-test in the beta band

III. PRELIMINARY TESTS (SECOND PHASE)

As mentioned in the Introduction, the MINIMA VAC has been implemented and validated in two steps. The first step consisted of a 'calibration phase', i.e. taking into account evidence about reliable laboratory tasks and approaches in studying attention-related cognitive processes, a preliminary test was arranged in order to highlight those particular brain activity features (in terms of EEG rhythms, cortical sites) strictly related to the vigilance level, with the final aim to use them during the second phase. The outcomes of this phase have been:

1. Selection of significant EEG features, in order to apply a machine-learning approach within the Vigilance Observer, and also to reduce the number of channels to use in operational settings (increasing wearability).
2. First version of the EEG-based "Vigilance index".

The second step comprised a set of preliminary tests conducted in the University of Bologna Virtual Reality Laboratory on a first release of the TE (Fig. 0).

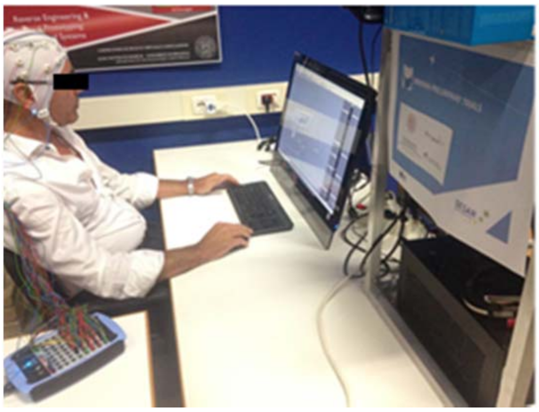


Fig. 8 Experimental set-up of the second experimental phase

Such early test phase has been conducted according to the results of the first phase. Therefore, 32 EEG channels have been recorded for $N = 5$ professional ATCOs from ENAV. Although the data analysis is still in progress, the outcomes of this phase have been:

1. Testing of the overall integrated validation environment;
2. Refinement and validation of the vigilance index computation, both in low and high vigilance conditions;
3. Collection of Lessons Learned for a more efficient conduction of the MINIMA evaluation phase.

IV. THE MINIMA TASK ENVIRONMENT

The MINIMA TE (used and enhanced during second to fourth phase) consists of a situation data display with special automation functionalities, air traffic scenarios for a TMA, and a database supported arrival management system. This TE reacts on the input data from the VAC, comprising the computation of a vigilance level and current area of attention (Section V).

Three vigilance levels 0, 1, and 2 (low, medium, and high vigilance) are mapped to the TE's automation levels 0, 1, and 2. Level 2 serves as the Baseline as we take a highly automated scenario as a pre-condition for the MINIMA trials. Some automation functions are switched off while additional tasks are switched on in the lower automation levels 1 and even more in level 0.

A. Airspace and Air Traffic Characteristics

We chose Munich airport (EDDM) as the basis layout input for our TMA. Hence, two parallel runways are in use for arrivals and departures (26L and 26R).

However, the Standard Arrival Routes (STAR) and Standard Instrument Departure (SID) are artificial. Five arrival corridors with mostly three independent parallel arrival routes can be used to approach EDDM airport from different cardinal directions (see Fig. 0).

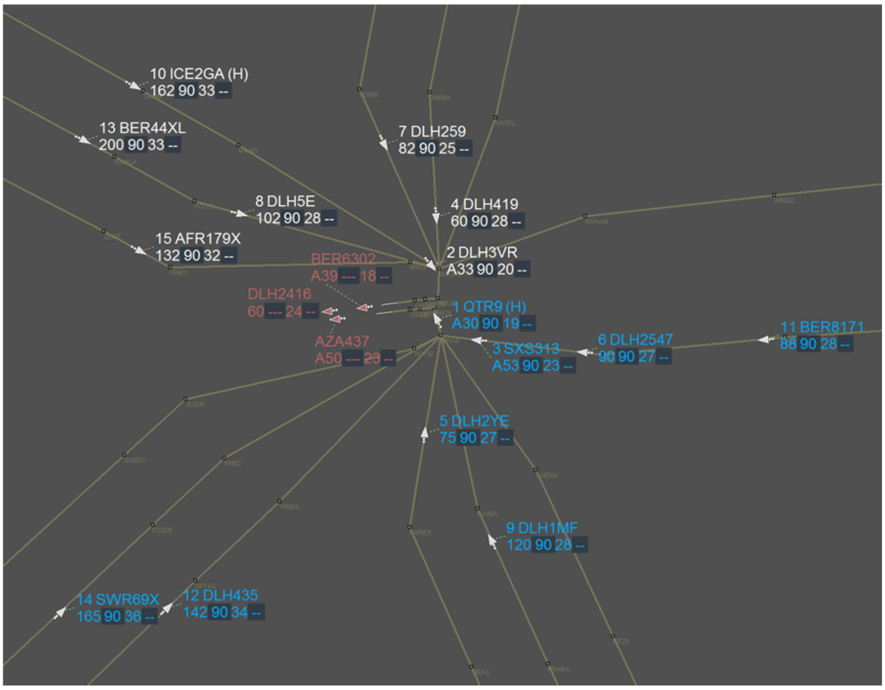


Fig. 9 Airspace structure with independent routes joining in merge points and various aircrafts (red=departures; blue=arrivals; white=arrivals under control of this ATCO)

Those independent arrival routes join in one merge point for each runway only a few nautical miles away from the airport. From 14 arrival routes that lead to the two merge points, three start in the north west, three in the north, and one in the north east to the northern merge point as well as three from the south west, three from the south, and one from the south east to the southern merge point. Departures fly westwards and may then turn north- or southwards in the extended TMA that has a radius of roughly 120 NM. The air traffic scenarios comprise almost 100 aircraft for these two runways during the simulation time. 10% of those aircrafts have the weight category "heavy", the others are medium; 40% of all aircrafts are departing. Callsigns are adapted to usual airlines and flight numbers approaching and departing from EDDM nowadays.

B. Air Traffic Scenarios

Five scenarios were set up for different purposes: three 45-minute scenarios for Training, Baseline, and MINIMA Solution as well as two 15-minute scenarios Relax and Stress. The latter two scenarios are used to calibrate the EEG-based VAC: controllers have to work with a low (Relax) and high (Stress) traffic load to measure 'relaxed' and 'stressed' (i.e. induced) vigilance and to extract subjective features, so taking into account inter-individual differences.

The Training scenario will be used to introduce the subject controllers to the MINIMA concept. It will serve two purposes. First, subjects will be given the necessary time to familiarize with the Integrated VAC and the TE. Second, this is expected to cause subjects to trust the system and therefore increase their will of using it during their work. The Baseline scenario is looking roughly 20 years into the future incorporating a highly automated environment. Controllers will mainly have to monitor so that the human operator's role is reduced to that of a mere observer. Such low levels of involvement are expected to cause low levels of vigilance, thus increasing the risk of the operator being unable to take over control of the system if automation fails. As automation is set to a high level throughout the scenario, controller vigilance is expected to decrease over time, ultimately resulting in OOTL occurrences.

In the Solution scenario, the VAC developed for MINIMA will actively adapt the level of automation within the TE, based on the subject's vigilance as measured via EEG data. When subjects show low levels of vigilance caused by their passive monitoring role, the level of automation is lowered and vice versa. Different levels of automation are provided through various automation and attention guidance systems featuring different operational modes.

Depending on the level of automation, controllers are either reallocated part of their manual tasks or are provided with additional information such as unmonitored aircraft and potential separation losses. This way, vigilance is expected to return to a normal level, which will prevent OOTL occurrences. Likewise, if controllers show high levels of vigilance from overextension, automation can be set back to a higher level. The results of the Solution scenario will be compared against the Baseline scenario after conducting the validation trials.

C. Controller Tasks during Simulation Runs

The controllers' task is to monitor the high-density traffic approaching to and departing from EDDM and assure the absence of conflicts respectively critical situations. During most of the scenario, the controllers do not need to intervene, as traffic should fly automatically and free of conflicts in this hypothetical future highly automated scenario. Conflict-freeness is guaranteed through the aircraft's coordination (respectively their Flight Management System (FMS)) and trajectory negotiation with an arrival management system on the ground taking into account the whole radar and flight plan based air situation.

The Arrival Manager (AMAN) Four-Dimensional Cooperative Arrival Manager (4D-CARMA) from DLR uses its modules Lateral Path Predictor, Arrival Interval Calculator, Scheduler, and Trajectory Generator to fulfill the role of the ground based system. Those trajectories and all other relevant scenario data are stored in a database. These data also help to enable other controller support functionalities that will be explained later. However, it is assumed that automation is not perfect and there will be some conflicts from time to time. To provoke such situations, we included two conflicts in each of the three 45-minute scenarios by purpose to be recognized by the controllers.

D. Situation Data Display with Aircraft Radar Labels

The situation data display (SDD) used for MINIMA is an enhanced version of the DLR prototypic radar display RadarVision (see Fig. 0).

Fig. 10 DLR situation data display RadarVision with a radar screen on the left and a timeline on the right (overview of whole screen; more details in the following figures)

The main area shows the TMA with airspace structures and waypoints as well as aircraft positions with their radar labels. On the right side, there is a timeline visualizing planned landing sequence with touchdown times and runways of each aircraft on one of the two used parallel runways. RadarVision also serves as the HMI between an ATCO and the ATC system, e.g. to initiate a clearance. The controllers' options to work with the HMI and support functionalities vary with the level of automation that is depending on the measured vigilance.

The RadarVision display presents the sequence number (e.g. 4) and callsign (e.g. DLH419) as well as potentially 'DEP' for departures and 'H' for weight category 'Heavy' of an aircraft in the first label line of each aircraft. Altitude (e.g.

60 for FL60 or 40 for 4000 ft), last cleared altitude (e.g. 90), speed (e.g. 28 for 280 knots ground speed), last cleared speed (e.g. 30 for 300 knots indicated airspeed or "--" if there was no former clearance) are shown in the second line. Aircraft type (e.g. A320) is presented in the third line as part of the extended mouse-over label (see Fig. 0).

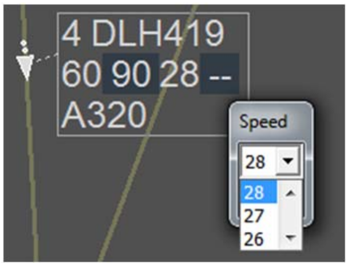


Fig. 11 Aircraft radar label with command drop-down menu

A timeline where each aircraft has a label dedicated to a certain time and runway is shown right of the SDD. All dynamic elements will move downwards as time goes on.

E. Automation Matrix and Automation Levels

The implemented TE's automation matrix consists of three automation levels for each of the nine adaptive functionalities. The less vigilant a controller is, the more work he/she should get to not fall OOTL. Thus, automation level 2 serves as the only available level for the Baseline simulation run consisting of a future highly automated scenario. Automation levels 1 and 0 are only available in the MINIMA Solution simulation run in case of low controllers' vigilance. The automation level changes only every five minutes in case the predominant vigilance level of the last 30 seconds differed from the current vigilance level. By switching the automation level, the respective functionalities in the automation matrix are switched on or off.

All of the following functions (Sections IV.F-IV.K) are triggered and adapted according to the automation level coming from the VAC.

F. Air Ground Communication

Commands can be entered into the system by clicking on the aircraft radar label's altitude or speed field (see Fig. 0). The controller choses a value from the opening drop-down menu and acknowledges it to be send to and executed by the aircraft via simulated datalink. However, in automation level 0, there is a "V" (for voice) at the end of the second label line (see left parts of Figs. 0 or 0) to remind the controller of uttering the clearance. The given command values find their way into the system via a special pseudo-pilot functionality.

G. Eye-Tracking to Guide Attention

To realize the guidance of controllers' attention, one needs to know in advance, where the controller should look and compare it with where he/she is currently looking. The area of attention is determined with an eye-tracker system mounted on the bottom of the SDD monitor. On the one hand, the eye-tracker continuously checks the screen position where the controller is looking at. Furthermore, it is evaluated if there is an aircraft icon or label in the close vicinity of this spot. On the other hand, the AMAN calculates which ATC events or aircrafts are relevant to look at.

If there is a mismatch between the desired and the actual area of attention, the eye-tracker based attention guidance mechanisms will apply. Hence, there is visual highlighting on the radar display if the controller does not pay attention to aircraft for a specific amount of time. If current time minus the time needed to pass 1.5 NM with an aircraft's current ground speed is bigger than the data base time of last aircraft gaze, an aircraft is marked as unattended. Such aircrafts are highlighted via semitransparent circles around their icon or a text hint depending on the automation level (see Fig. 0).

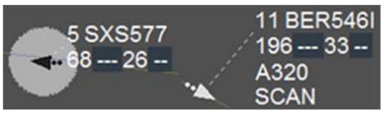


Fig. 12 Attention guidance elements for unattended aircraft (semi-transparent circle in automation level 0, "SCAN" in automation level 1)

The eye-tracking functionality and thus the attention focus detection with succeeding attention guidance is only active in case of automation levels 0 or 1.

As mentioned above automation level 2 serves as a baseline for monitoring a highly automated air traffic scenario without the MINIMA adaptive automation to avoid possible OOTL phenomena.

H. Guiding Attention to Special Air Traffic Situations

There are three other reasons for activating attention guidance mechanisms, i.e. if there is an upcoming or actual separation loss, or if there are deviations from the negotiated and agreed four-dimensional trajectory.

In case of loss of separation, a red non-filled circle is displayed immediately around an aircraft to draw the controllers' attention to the desired area (see Fig. 0).

Fig. 13 Attention guidance elements for conflicting aircraft (red circle around conflict partners in automation level 0, otherwise red alpha-numeric values)

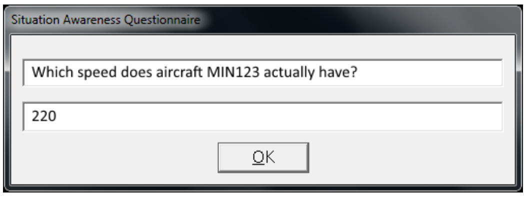
Fig. 14 Attention guidance elements for aircraft that have a short-term predicted conflict (orange circle around aircraft in automation level 0, orange alpha-numeric values in automation level 1)

Short-term flight prediction is calculated from radar data as well, using the AMAN's prediction module. Anticipated conflicts (30/60 seconds depending on automation level) are visualized by orange circles drawn around affected aircraft (see Fig. 0).

The AMAN prediction module uses current heading, altitude, and speed of all aircraft to predict such situations. Deviations from agreed target times are computed by comparing an aircraft's scheduled position as planned in its 4D-trajectory with its actual current position. Aircrafts whose current positions deviate from their scheduled positions are visually indicated by drawing a yellow circle around their icons.

I. Situation Awareness Questions

In the two lower automation levels, the controller needs to answer questions about task-relevant information. A question dialogue appears at the Graphical User Interface (see top right of Fig. 0) every few minutes. The time interval depends on the automation level (2/5 minutes in automation level 0/1). Three questions have to be answered in a row without feedback about the correctness of the answer. They relate to an aircraft's altitude, heading, speed, and position as well as the anticipation of positions in the future also with respect to other aircraft. They are chosen from 18 different questions and corresponding answer types. The values (callsigns, headings, durations, etc.) of the question text are randomly chosen for each single question. Therefore, the number of possible disjunctive questions is at least a great five-digit number due to selection of randomized aircraft callsigns, waypoint names, and other aircraft movement values such as speed and altitude. Two example questions would be "What is the current heading of DLH123 [°]?" and "Will AFR456 and BAW789 approach to less than 5 NM lateral distance within the next 30 seconds?" (see also Fig. 0).



Which speed does aircraft MIN123 actually have?

220

Fig. 15 Situation awareness question example

Thus, the controller will not be able to learn the right answers, but always has to check visualized data. Nevertheless, the types of questions do not vary too much for comparison reasons. By scanning the situation data display to look for the right answers, the controller has to interact with the current situation displayed. This is intended to help increasing the situation awareness during monitoring tasks. The more frequent the controller has to deal with the current situation, the less he/she should run into OOTL effects.

J. Centerline Separation Range and Advisories

The Centerline Separation Range system (CSR) is a visual hypothetical aircraft final approach visualization. It supports the ATCO by visualizing the order in which aircrafts are reaching final approach, their callsigns and weight classes (by color) as well as the horizontal distance between adjacent aircraft (see Fig. 0). Also, advisories for controller commands are shown in an advisory stack (Fig. 0). Those advisories are executed automatically by the automation and are presented to the controller for information depending on the automation level.

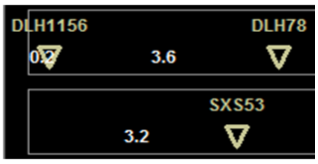


Fig. 16 Centerline Separation Range for two parallel runways with distances to preceding aircraft respectively touchdown

+4	DLH009	Descend	Alt 4000
+17	DLH005	Reduce	KT 170
+23	DLH006	Descend	FL 110

Fig. 17 Advisory stack lists "controller commands" that will be executed automatically

K. Adaptation of Sector Size

The different modes concerning the sector size for which an ATCO is responsible differ by combination of two factors: number of runways used and normal vs. early handovers. Number of runways can be varied, so the ATCO is responsible for air traffic of either one or two runways. Normal vs. early handovers relate to the distance at which responsibility for aircraft is given to the ATCO. In default mode, ATCOs handle aircraft within the TMA but only in the range of 80 NM (see central circle line at radar screen in Fig. 0) approaching one runway. To increase the ATCOs' task involvement, the remaining modes cover two of the remaining factor combinations described above. First, the ATCO is assigned responsibility for a second runway. Second, the responsibility range is extended to 100 NM along with the ATCO being responsible for two runways.

V. THE MINIMA VIGILANCE AND ATTENTION CONTROLLER

In MINIMA, the task of the VAC is to measure the current vigilance level and the attention focus of the human operator with the aim to detect or anticipate typical OOTL performance issues, such as:

a) the operator fails to observe system changes and to intervene when necessary (vigilance decrements);
b) human over-trust in automation (complacency);
c) the operator loses overall situation awareness.

Therefore, the VAC has been developed in order to be able to measure both vigilance aspects, which refer to the alertness component of attention, and the selective aspects, which refer to the capacity of controlling the focus [8]. Following a detailed state of the art study carried out by the MINIMA research team, the vigilance component of the controller attention is measured through the classification based on the EEG data made by the EEG-Recorder software (see Section V.A), while the control of the attention focus is measured through the gathering and elaboration of gazes captured by an eye-tracking device (see Section V.B).

A. The Vigilance Observer

The Vigilance Observer (Fig. 0) is based on the EEG-recorder, which is a software developed by BrainSigns s.r.l.

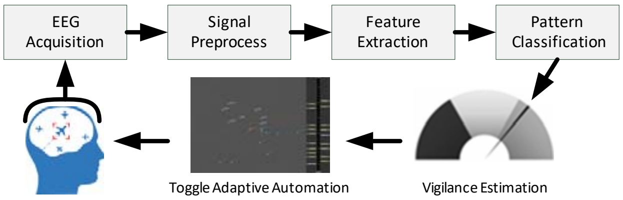


Fig. 18 Vigilance observer cycle

It allows recording, processing, and visualizing biosignals, in particular EEG. Moreover, the computation and online classification of neuro-indexes of the investigated mental state and its dispatching (i.e. the online index) through a specific network protocol (TCP/IP) are also implemented [21].

The vigilance monitor device is based on the operator's EEG power spectral density (PSD) estimation. It encompasses five functions: EEG Acquisition, Signal Preprocess, Feature Extraction, Pattern Classification, and Vigilance Estimation, as shown in Fig. 0.

If vigilance decreases, more tasks will be assigned to the ATCO to raise vigilance again. As there are rare conflicts in the automated scenarios, overtrust and thus complacency should not be fostered. A possible loss of situation awareness is hopefully mitigated by asking situation dependent question to force ATCOs to identify with the current air traffic situation.

B. The Attention Controller

The visual attention measurement is provided by an infrared eye-tracking device. It is assumed that the spot where the controller is looking at equals the area of his/her attention. The eye-tracking device implemented in MINIMA is the Tobii EyeX Controller, gathering eye movements, fixations, and gaze point data of a user. The device provides data at a time resolution of 60 Hz and can capture human gazes pointing at a screen point up to a dimension of 27" (Fig. 0).

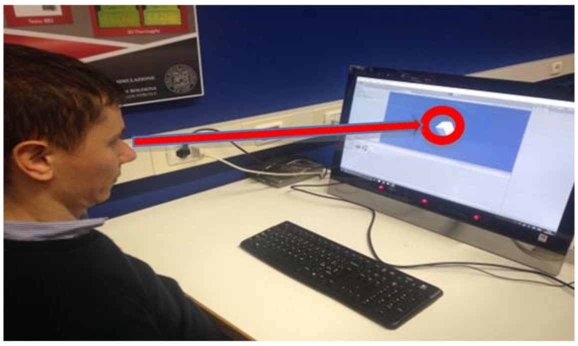


Fig. 19 Set-up of eye-tracking for validation trials

The Tobii EyeX Controller has been installed in the Virtual Reality Laboratory of the University of Bologna and is managed by the Tobii EyeX functions. These functions are based on the computation of Number of Fixations (NF) and time spent on a specific Area Of Interest (AOI), in particular:

- AOI are user-defined sub-regions of a displayed stimulus;
- NF is the number of times a subject stopped on an AOI;
- "Time spent" quantifies the amount of time that subjects have spent on an AOI;
- "Time of last fixation" quantifies the time from the last fixation of an AOI;
- Time to First Fixation (TTFF) indicates the amount of time it takes a subject to look at a specific AOI from stimulus onset; TTFF is a basic yet very valuable metric in eye-tracking. It could be relevant when important event appears in the simulation.

The attention guidance mechanisms as described in Section IV.G can be fulfilled with the eye-tracking data presented above.

C. Full Rehearsal (Third Phase) to Prepare Final Validation Trials (Fourth Phase)

The third phase comprised a full rehearsal using the implemented final VAC and TE as shown in Sections IV and V. This test focusing on technical aspects and the planned schedule was successfully passed prior to the fourth phase. During this last phase, 15 ATCOs from ENAV used the full-scale experimental set-up in the final validation trials.

VI. SUMMARY AND OUTLOOK

An increase of automation in air traffic control can have negative effects on the ATCO's performance. The effects are known as OOTL phenomenon. The MINIMA project developed a VAC to mitigate these effects. Particularly, psychophysiological measurements like EEG will be used to identify the state of the ATCO and combined with adaptive task activation. In this paper, we have introduced the concept developed to detect and compensate the negative impact of this phenomenon. This tool consists of two components: the VAC and the TE.

The MINIMA TE consists of a situation data display with special automation functionalities, air traffic scenarios, and a database supported arrival management system. Especially, adaptive functionalities have been selected and implemented to compensate the negative impact of OOTL phenomenon. These functionalities covering different fields of ATCO's work – Air Ground Communication, Attention Guidance to important air traffic situation and with eye-tracking, Situation Awareness Questions, Centerline Separation Range and Advisories, and Adaptation of Sector Size – are carefully described in this paper.

In order to trigger these support functionalities, the VAC aims at detecting OOTL occurrence using EEG signals. Using a PVT, a set of preliminary experiments has been conducted to develop and calibrate the Vigilance Observer in laboratory settings with traditional equipment. These preliminary experiments enabled identification of brain activity characteristics, i.e. EEG features, directly related to human vigilance. Particularly, vigilance failure is characterized by significantly lower values of PSDs of the Theta rhythms over central, parietal, and occipital sites as well as Beta rhythms over central and parietal sites. In the next steps, we aimed to test the robustness of these signals in a real environment, where the subject is free to move and to act, and to evaluate the efficiency of our supporting tools to mitigate the OOTL phenomenon.

The further results of the four experimental steps and especially from the final validation trials with the full-scale experimental set-up will be reported in a future paper.

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