

DEVELOPING ATCOS' SUPPORT SYSTEM: LOAD MANAGEMENT, INTEGRATED SENSORS AND EYE TRACKING

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Abstract

Nowadays, because the development of the highly automated systems, the role of operators is in transition from active to passive control. In case of active control, the operator deals with continuously situation awareness – decision making - control actions; while, in case of future automated systems, the operator monitors the operating system and only in abnormal, and emergency situation should initiate active control. The work quality of passive operators depends on their loads, namely information, task, work and mental loads. Especially, the information and mental load as physical - psycho-physiological condition plays much greater role in future systems.

This paper introduces the developed concept of future ATCOs' model, a working environment based on the model, enhanced with integrated sensors to collect information on ATCOS' activity, to increase situational awareness and reduce loads on the subject. Different methods and systems were tested to develop such a system. Researches led to the application of eye tracking and motion sensing systems in integrated way in the working environment. A concept of a system based on these sensors was developed and a test system was built which was presented by the HungaroControl in the World ATM Congress in 2015.

Keywords: *passive operator, ATCOs, highly automated systems, eye tracking, working environment*

1. Introduction

The revolution in information technology catalyzes to develop large highly automated systems, as future air traffic management (ATM) systems (see for example the European SESAR - Single European Sky ATM Research [1], the US NextGen - Next Generation Air Transportation System [2], Japanese CARATS - Collaborative Actions for Renovation of Air Traffic System [3]) or the Brazilian SIRIUS - Impulsionando o Desenvolvimento do ATM

Nacional [4]. In these systems the role of operators, namely air traffic controllers (ATCOs) will be changed from active to passive. In case of active control, the operator deals continuously with situation awareness – decision making - control actions; while, in case of future automated systems, the operator monitors the operating system and only in abnormal, and emergency situation should initiate active control. All the developing future ATM systems have a considerable influence [5, 6] on the air traffic controllers' (ATCOs) roles and responsibilities, too. There are two important changes partially delegation some roles and responsibilities from ground (ATCO) to on-board (pilot) and to an intensive automation [7]. Principally, the automation will not take over the whole task, trajectory management, it expands the ATCOs functional envelope [8]. The future terminal manoeuvring area (TMA) keeps operators in decision support systems because the human skills, adaptability, flexibility and problem-solving. According to a survey [8], most of ability requirements will be changed in future systems. For example, requirements in written comprehension, fluency of ideas, originality, memorization, number facility, mathematical reasoning, inductive reasoning, time sharing, hearing sensitivity, speech clarity will be considerable reduced, while roles of the other requirements as problem sensitivity, deductive reasoning, speed closure, flexibility of closure, perceptual speed, respond orientation, reaction time, visual color discrimination, resistance to premature closure, vigilance, impulse control will be increased, significantly.

The work quality of passive operators depends on their loads, namely information, task, work and mental loads [9]. Especially, the information and mental loads as physical - psychophysiological condition of the operators play much greater role in future systems, because the drowsy monotony of work calls inattention and fatigue. This paper deals with supporting the operators by actual and required information on their requirements and depending on their load conditions. The operator loads are measured by sensors integrated into the operator working environment. The eye tracking uses for recognition and identification the operator "attention targets" on the screen, i.e. point of regards. Depending on the measuring results, at the identified attention targets, windows are opening on the operators' screens in which the additional information appears. The system is developing for improving the ATCOs' working environment.

This paper deals with use of eye tracking system in ATCOs supporting systems. The developing method is integrated into the ATCOs' working environment. The project is supported by the HungaroControl - Hungarian Air Navigation Services.

2. Future ATCOs support systems

2.1 ATCOs model

The ATCOs model can be defined by two different approaches. On one hand, the situation awareness and decision making is the central element of the model. Figure 1. shows the model [9] developed by adaptation of the well-known and probably the most used model created by Endsley [10, 11]. The situation awareness is made at three different levels:

- level 1. - encompass and awareness of specific key elements of situation
- level 2. - comprehension of current situation, integration of that information in the light of operational goals,
- level 3. - ability to project future states of the systems.

In this model, the situation is evaluated from present situation instead of state of environment as defined by Endsley. The model is improved by including the actual (present) mental condition of operators into the individual factors, because in the highly automated systems the role of psycho-physiological condition of the operators is increasing.

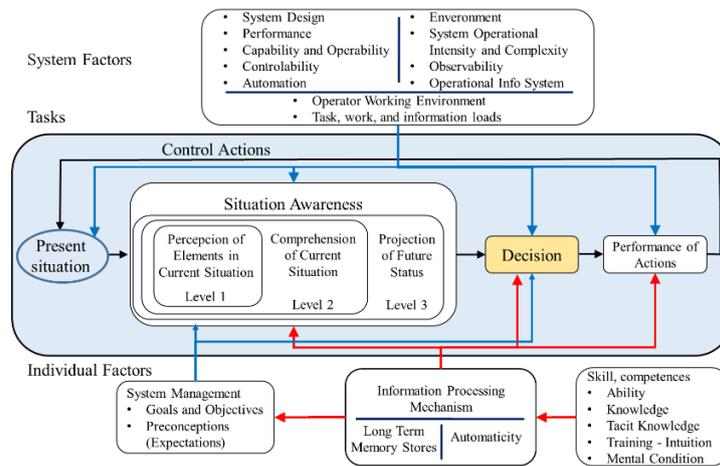


Figure 1. Model of situation awareness in future dynamic ATM environment

The (i) system functions, (ii) operational characteristics and (iii) operator - system interface (working environment) compose the system factors. The model includes some new system factors as (i) system operability (including interoperability), controlability and automation; (ii) system operational intensity and (traffic) complexity, observability and operational (flight) information system; (iii) developed working environment to increase the level of situation awareness.

The underlined new elements and incorporated into the traditionally applied situation awareness model adapt the model to future air transport system, to future air traffic management.

As it is investigated and well known, the success of situation awareness and decision making depends on human behavior (skill and performance), as well as on the task, work, information load and mental condition of the operators. As Rasmussen [12] 30 years ago defined, the situation awareness and decision making might be realized on three different levels. The first level, the so called skill-based control is applied by the operators (ATCOs) when the situation is normal and the operator can easily recognize the situations and can work 'automatically'. At the second level, the operators must recognize and identify the situation and apply the rule based solutions to reach the expected situations. In case of abnormal flight situations or possible flight conflicts, the operators must derive the solution with their knowledge and practice. This is the knowledge-based level.

It is clear, in future ATM system, the ATCOs role will change from active control to passive monitoring of the traffic, but in case of any situations required their assists, they must work on the knowledge based level. So, in a highly automated environment, the ATCOs need new type of support systems. The ATCOs support systems must be adapted to their actual working ability.

The second approach applying to description of the ATCOs model is based on the operator loads. The created model (Fig. 2.) contains the task information, work and mental loads [9, 13]. The task load is generated by the number and hardness of tasks to be solved. It depends on airspace demands, interface demands, traffic regulation, airspace design and traffic planning, etc. In case of highly automated systems, the changes in traffic intensity, abnormal and emergency situation may generate several extra tasks. Additionally, the task load depends on the weather condition and on other aspects, like unlawful actions.

The info (or information) load is applied for characterising a relatively new problem, initiated by supporting the operators with too many and partly not harmonized information from the different sources. For example, the weather forecast information and information about the real weather condition reported by pilots in the same sector.

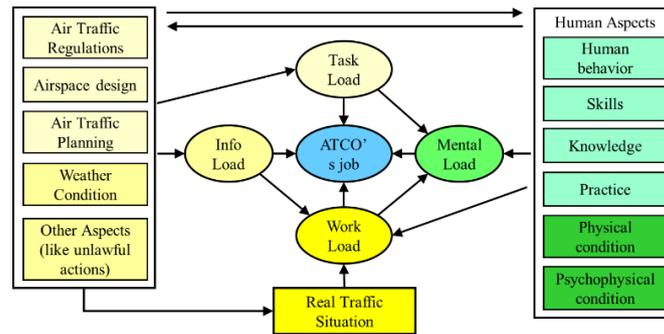


Figure 2. The ATCO model

The task and information loads together with real traffic complete the work load of the operators. This is the most known and applied merit. The first and since used load measurement methods were developed 25 – 30 years ago. For example, Endsley and Kiris [14] developed a special situation awareness global assessment technique (SAGAT) that is applied nowadays, too by NextGen and SESAR. Other well deployed measuring and evaluation methods are NASA Task Load Index (TLX) [15] and Situation Awareness Rating Technique (SART) [16]. These old methods are improved and combined by new technologies permitting to measure the human performance to evaluate the future ATM, or future automation concepts (see for example Automation Thrust Index (SATI) [17] or identifying the key human performance [18]).

Finally, the actual physical and psycho-physiological condition called as mental load might be defined and measured. This load depends on human behaviours, skills, knowledge and practice. The mental load plays a determining role on the so called subjective situation awareness and decision making of operators [9, 19, 20]

2.2 ATCOs support systems

ATCOs are working in large and very sophisticated environment supported by different systems:

- physical systems, technical, technological elements – chairs, tables, computers, displays, etc.,
- information systems providing all the available information – aircraft performances, flight information system, weather information system, information provided by other systems as surveillance etc.
- communication systems – between the ATCOs, ATCOs and pilots, communication between the service providers, etc.,

- monitoring, detecting and decision support systems, namely surveillance, conflict detection, conflict resolution, – that containing the technical equipment (as radars, sensors), principle of measurement analyses, i.e. situation awareness and decision support and software,
- load management – based on monitoring the ATCOs loads,
- special extra supporting systems – as safety and security risks evaluation and mitigation,
- rules, operational manuals synthesizing the supporting system into net centric general system.

The future ATM system that are being developed by several megaprojects (SESAR, NextGen) under rethinking, redesigning the existing system by use of latest results of sciences and technologies [1, 2, 21]. All the supporting system will be improved and a lot of new principles, solutions, tools will be developed (Fig. 3).



Figure 3. Some examples of new technology solutions were planned to develop and deploy by NASA Blueprint [21]

The new developments will generate systematic changes in future ATM (Figure 4.) as as it is evaluated by SESAR.

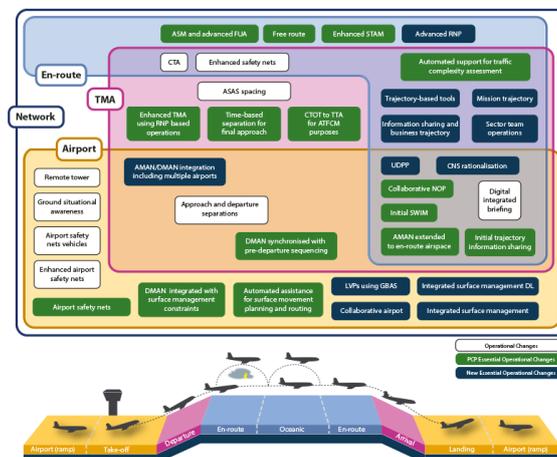


Figure 4. The essential operational changes caused by SESAR developments [22]

The planned use of eye tracking system for supporting ATCOs work will be integrated into the load management supporting system, but it will present the information about the objects look at by controllers. Therefore, it will be associated with information support systems, and with the monitoring, detecting and decision support systems, too.

2.3 ATCOs' future working environment

The future works and working environment of ATCOs might be characterized by following four major aspects:

- ATCOs will play role of passive operator in highly automated system – instead of active separation control management,
- ATCOs will have “greater” environment”, namely they will have several displays or large screens, several windows working parallel on their computers, etc.,
- they will be working on-line in an “off-line” environment, i.e. in remote tower environment equipped with large synthetic vision screens, etc.,
- they will have too much information that may confuse them.

In such an environment as developed at the HungaroControl (Fig. 5.) the controllers load management, especially, the mental and information load monitoring and management initiate new requirements to information processing.



Figure 5. Very large scale demonstration (VLD) test of the remote tower (rTWR) developing at the HungaroControl [23]

The major specific circumstances of HungaroControl and Budapest Airport met during planning the remote tower developments were the followings [23]:

- Two parallel and shifted runways, 6 km between the furthest thresholds
- A-SMGCS – an ability to control airport traffic even without any visual observation (radar is the main surveillance system, not human eyes)
- More than one simultaneous ATCO positions and specialized ATCO roles (ADC, CDC, GRC - apron, TPC, SV)
- Stripless operation; MATIAS TWR capability, ILS and AGL controls (partially integrated in A-SMGCS HMI)
- Medium size: 100.000 movements yearly

As Figure 5. shows, by use of original idea applying the eye tracking to information display management, the major problem will be met. The operators sometimes look at their displays on the table, sometimes screens on the wall. This means the eye tracking system must be able to detect the point of regards or look at points of operators even in case when they are walking in room.

3. Eye tracking systems

3.1 Cameras, eye tracking headgear

Eye tracking has been gaining in popularity around for over a hundred years [24]. Several researches have been carried out for developing eye tracking systems such as in reading [25, 26], human computer interaction [27,28], psychoanalysis [29] and over- learned task such as hand washing, tea making or even how people compose photographs with digital cameras [27].

In aeronautics, the first eye tracking measurements were realized in flight and ATC simulations. Optical measurements were used, namely video recorded by cameras mounted into the working environment in the front of the operators, and /or on the headband. The head positions were measured by wearing special items by operators (pilots, ATCOs). The headband as usually, held eye and screen cameras. The measurements resulted to aggregated metrics like fixation duration, dwell times, and moving average time windows (MAW) introduced by Anders [28]. Such simplified measurements are applied even nowadays (see for example [29, 30, 31]). The results give information not directly about the eye movements, only, but discover some special peculiarities of ATCOs. The MSc thesis, made at Linköping University [29] shows that

- in case of single tower, for every investigated episodes, the ATCO clears the aircraft to continue approach; the first thing the ATCO does when a pilot is contacting the tower for the first time is to look at the air radar, etc.;
- in case of multiple remote tower, in all episodes the ATCO looks at the information for the specific aircraft just before or while speaking to the pilot; the ATCO looks at the radio screen before contacting an aircraft, etc.

The eye tracking can be applied into three major tasks:

- training of operators – pilots, ATCOs, (even maintenance staff) for supporting their self-learning and evaluate their working qualities [32],
- monitoring the operators’ activity and mental conditions [33] and
- use of eye tracking in control [34].

There are several devices that eye trackers can build on to capture the eyes’ movements, simply by moving eyes up-down or left-right, at different purposes. One of the well-known measurement technique is using the eye-tracking head gear (Figure 6). It is also important to note that using the head gear is a low-cost way to do eye tracking and it is a lightweight eye-tracking device with a wearable system which is a marketable and accessible product [27].

Mainly with utilizing the eye tracing glasses in flight simulator, three different measurements can be made, (i) measuring how different flight modes can be realized (during landing, take off or so on), (ii) Don’t understand this sentence, the time dependence of the process can be measured. For example, if the pilots’ mental load reduces, how is the change in the system, (iii) critical information can be collected about the pilots and we can compare this information with others which are monitored by micro sensors.

On the other hand, utilizing the eye tracing glasses can be introduced into the pilots’ learning and trainings processes. Especially this device would be useful in the student pilots’ learning process. For example, Flight instructors can help student pilots to learn more quickly and adopting more easily to make special processes, as landing and take-off.

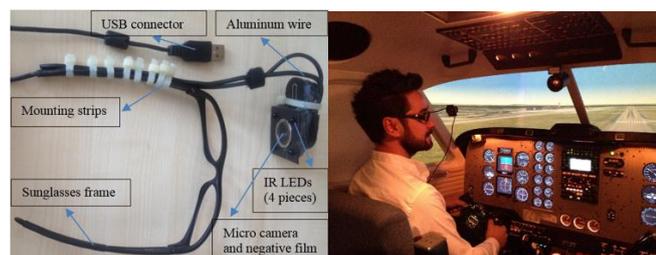


Figure 6. Eye tracking glasses (left side) and its usage into the flight simulator at BME (right side)

The construction of the head gear has built in micro lens video cameras with image resolution of at least 640x480, safety goggles and infrared emitters. Miniature camera is optimally located just above the eye to improve resolution and is used to capture the scene from the subject's perspective.

It seems it is really lightweight solution, simple to wear and can be used in many different working environments. The accuracy of attention target measurements is adequately good [34]. However, this accuracy may not be enough for reaching the objectives defined by this study. Detecting the point of regards of the operators (ATCOs and pilots) moving in virtual tower. The eye tracking headgear more usable in case of relatively small distance between the operator and attention target point on the screen.

3.2 Use of binoculars

Binoculars are used by tower controllers since the beginning of air traffic control. It is a simple tool to collect information or extra information from large distances that cannot be acquired by other methods. In a situation like this, simple eye tracking methods are not applicable. Other methods can be used to determine the position of equipment i.e. motion tracking. A motion tracking system can provide information about the activity of the subject and with information provided by the system, the point of regards can be determined.

By knowing the position of controller and the point of regard, relevant or in special cases, extra information can be provided to the subject

Unnecessary to use binoculars in remote tower environment, but in such a large room, determination of position the subjects and detection of movement of their will not be less important. A system using a method that can follow and determine the position of the binocular can follow the controller's movement in the control room and can determine the direction ATCOs' head. Application of such a system can collect appropriate data on controllers' activity that can be used by the load management and supporting system.

3.3 General system

A concept was developed for future ATCOs' working environment. The advanced ATCO working environment has three major novelties [9, 13]:

Three-layer information displays. High resolution interactive displays are applied for (i) visualization of the live (real active) situation based on the radar, flight information and ground service data, (ii), displaying the available further information automatically on requirements of ATCOs that initiated by the visual attention detection, while (iii) the third layer is used for situation awareness and analysis.

Load monitoring system: it shows the continuously measuring individual task-, information, work- and mental loads of individual ATCOs. Generally, this information is available for the given ATCOs, however, in case of overloads, the system is reporting to the control managers.

Decision support system: This system assists the ATCOs to perform their job as requested. The system has three subsystems. The first one is the load monitoring system calling attention of the ATCOs on their load conditions and may advise the required actions. The second subsystem is the situation awareness - situation analysis - and decision support process with a developed subjective decision model. Finally, the third subsystem works as emergency alert.

The developed ATCOs' working environment concept (Fig.7) has the following features:

- tower-less, augmented reality or/and large display systems (for individual solutions),
- three-layer information including,
- live (active) radar and ground service information,
- information from automatic flight information system,
- other information packages (weather forecast, regulatory requirements),
- monitoring system and sensors to measure the ATCOs' condition.

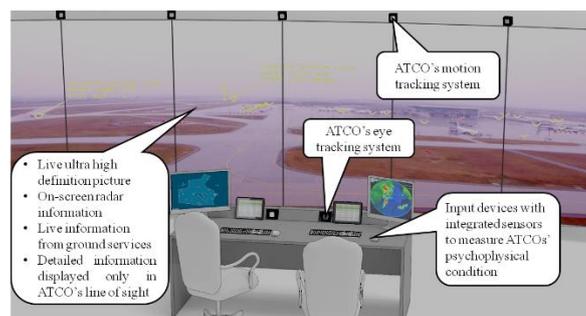


Figure 7. The basic set-up of the overall system.

As Figure 7 demonstrates the motion of ATCOS in the room, namely positioning their head will be realized by use of motion and head tracking system based on video cameras mounted on the wall at top of the screen. This system will be applied for eye tracking, too. In case, when the ATCOs are sitting in their chairs, the cameras on the front of the operators will be used for eye-tracking.

4. System developments

4.1 Preliminary studies

The Department of Aeronautics, Naval Architecture and Railway Vehicles at Budapest University of Technology and Economics has a long-term program developing skills and competence in operators working simulation, their load management and developing their working environments. The Department has two flight simulators and one ATC/ATM simulation laboratory. There are investigated systems for reducing the operator workloads. A Full Authority Digital Electronic Control (FADEC) was developed for the fault tolerant behavior to reduce the workload on pilots [workload of pilots by using digital control systems, [33]. Several motion simulations were created [35,41,38]. Special recommendation was elaborated for developing a training ship [34]. A flight simulator was developed and applied to investigation of the pilots' loads [40,43.]. Methods of subjective analysis were applied to pilots' and ATCOs' decision support [9, 13, 19, 20, 42]

For monitoring operator loads, special sensors were applied that were integrated into the working environment. For example,

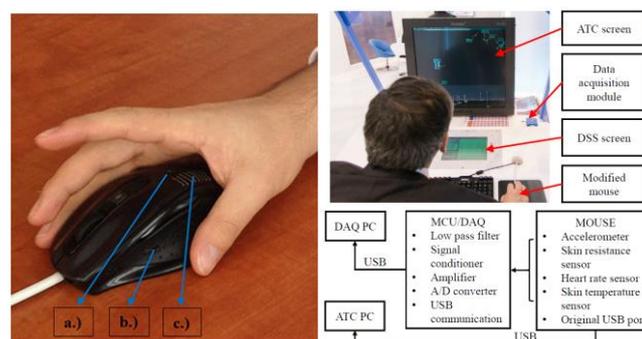


Figure 8. The principle of prepared mouse for ATCOs, on the right side of the figure; a.) skin resistance sensor, b.) heart rate sensor, c.) skin temperature sensor and also there is an integrated accelerometer into the mouse

The eye motion of pilots were measured in two seats fix based flight simulator of a medium size passenger aircraft as Boeing 737. There were invited simulations to pilots having

large practice, and beginners, so called less skilled pilots. The pilots realized different tasks. The measured eye motions and visual attentions were rather different depending on the tasks and skill of the pilots (Figure 9).

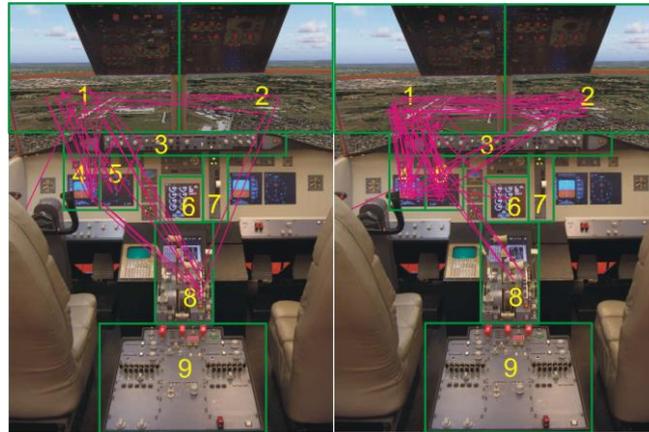


Figure 9. Eye movements and visual attention measured in flight simulator during take-off (left side) and final approach (right side).

Studies have led to generating an idea of using the eye tracking in decision support systems. The first developments had been focused on the accuracy of visual attention measurements and developing the supporting ideas. Therefore, a special binocular was developed and applied.

4.2 Concept validation by use of binocular system

To validate the concept of application of motion tracking system, a test set up was built in the simulator laboratory of the Department. Motion tracking cameras were placed above the test area to ensure the unobstructed view on the target. In the test area a binocular was placed which was followed by the motion tracking system. The system followed the motion of the binocular and from the position and orientation a self-developed algorithm determined the point of gaze. An information providing system was also developed to test the applicability of augmented reality and to develop methods load and information management methods to this concept.

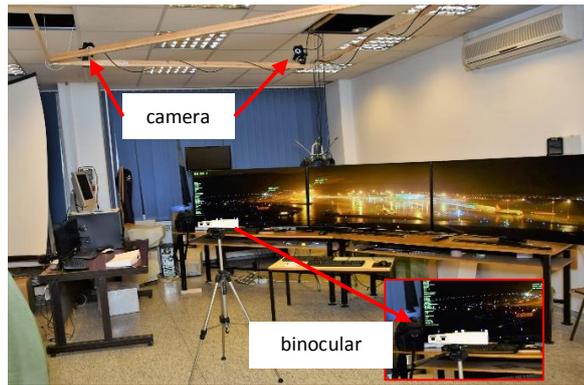


Figure 10. Laboratory test of the binocular used in detection of the point of regards

Tests showed that the developed test system is accurate enough to support the work of controllers in a classical tower and a more modern remote tower environment in the future. The test system based on the developed concept was presented by the HungaroControl in the world ATM Congress in 2015.



Figure 11. The dedicated displays with augmented reality features, as presented in the World ATM Congress in 2015.

5. Conclusions

Development and rapid spread of highly automated systems in air traffic control, the role of operators, mostly the role of air traffic controller's changes. Nowadays, ATCOs are an active element of the system, but in the near future they will be transformed to be a passive element. Operators will monitor the operation of automatic systems and will have active role only in abnormal and emergency situations. This change in working conditions and loads requires new management methods, support systems, etc.

In this changing environment, the old ATCO model had to be redefined hence the concept of future ATCO model was developed and introduced in this paper. Management of mental and information load are going to have a greater role in the new working environment, which requires more advanced supporting system. These systems need input about the ATCO.

Research was made on developing a working environment enhanced with integrated sensors to collect information on ATCOS' activity, to increase situational awareness and reduce loads on the subject. Different methods and systems were tested to develop such a system. Researches led to the application of eye tracking and motion sensing systems in an integrated way in the working environment. A concept of a system based on these sensors was developed and a test system was built which was presented by the HungaroControl in the World ATM Congress in 2015.

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