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MOTO

THE EMBODIED REMOTE TOWER

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Abstract

This document provides a summary of MOTO main accomplishments and outcomes. The main feedback obtained during the project, lessons learned in terms of technical content and for future R&D activities are hereby reported. This document also frames MOTO in the ATM Community and in the integration of Exploratory Research projects into the SESAR mainstream and future SESAR 2020 program.

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1 Executive Summary

This document provides an overview of the MOTO project context, work performed and main outcomes.

MOTO (the embodied remote Tower) was a Horizon 2020 project co-funded in the framework of the SESAR Research and Innovation Action (RIA), started in June 2016 and lasting 24 months (<http://www.moto-project.eu/>).

MOTO project explored the opportunity to enhance the human performance in a remote tower platforms from the perspective of embodied cognition (improving the sense of presence and immersion). The goal was to ultimately augmenting human-system interaction with multisensory feedback.

The project identified key multimodal stimuli in the current control tower operations and defined user requirements for a multimodal Remote Tower, to reconstruct multimodal perception in a remote tower simulation platform and enhance ATCOs sense of presence.

This document summarises the key project outcomes, namely:

- Virtual Reality Multimodal Platform for simulation of Tower operations.
- Neuro-physiological classifiers to monitor human performance in (Remote) Tower operations.
- Prototypes of augmented multimodal Remote Tower.
- Exploratory concepts for multimodal multiple Remote Tower.

The contribution of MOTO project to SESAR ATM Master Plan and the project maturity assessment are also included in the present document.

Finally, the document reports the main conclusions, lessons learnt and next steps for future related Research& Development (R&D) activities.

2 Project Overview

2.1 Operational/Technical Context

The overall MOTO concept is that Remote Tower (RT) platforms can be enhanced by considering human performance in control towers from the perspective of embodied cognition, with the goal of augmenting the human-system interaction with multimodal technologies.

The motivation for the project is that ATM Human Performance (HP) research has been traditionally focused on two senses: sight and hearing. Remote Tower Operations (RTO) make no exception, with many efforts and resources focused on acquisition of visual images, for instance by means of high-resolution cameras.

Moreover, the project addresses a research gap of the Remote Tower concepts there are currently different platforms available on the market or for research, but include limited use of multimodal and augmented information as the ones targeted by the MOTO project.

The HP assessment carried out in SESAR [1] briefly touches on the topic, mentioning two important points:

- ID 2.3.1.1 Controllers reported that it was difficult to judge wind and rain conditions,
- ID 2.3.7.7 Lack of external sound from aerodrome reduces controller situation awareness.

In general, controllers report as a frequent HP issue the low quality of the “real world view”.

From the state-of-the-art review performed during the initial phase of the project, it was concluded that there is a relatively good convergence in the type of technologies being used to implement the remote tower concept. As video sensors, HR cameras are used for daytime observation; IR cameras are used in low light conditions, and provided the typical weather does not occlude the vision. PTZ cameras are typically used to emulate the function of binoculars. The number of such cameras varies greatly depending on the actual airport setting, around an average of one up to two dozen cameras.

Audio sensors are, in comparison, far less developed. The typical set-up is to capture and render ambient audio, possibly in a stereo setting. More complex audio set-ups, e.g. multichannel audio captured from more sources, are rarely used. Finally, capturing and rendering vibrations is very rarely used. However, this option has a high potential of providing additional information to ATCOs in the RTO.

There are not sufficient details concerning the rendering of vibrations in the RTO context, so this option appears to be rarely used (if at all). Interaction uses the typical devices present in a physical tower, with the salient presence of e-stripping as an innovative element. However, little information is available to assess the potential differences in effectiveness, fatigue, stress, and/or attention between working in a physical and a remote tower. As such, work to be done in the current project to measure these factors is of clear added-value.

Currently there is also a very limited amount of innovative information visualization techniques being used to make operations in a RTO setting more effective. In general, the interaction and data visualization devices present in the RTC copy those being used in the actual physical tower, with small changes, e.g. to support switching contexts in the case of a multiple tower. Here as well, we see potential for improvement.

The project is structured in two key streams of work, one concerning the reproduction of a realistic Remote Tower environment (technology-driven innovation approach), the second concerning an Augmented Remote Tower environment (design-driven innovation approach).

1. **“Realistic” Remote Tower.** The full understanding of what it takes to reproduce “reality” in RTO and most importantly of the key aspects of reality that we need to reproduce, is a necessary building block to design how to augment reality in these platforms. Assuming that vision is the primary sense “naturally” leads to augmenting only vision, thus eliminating since the very beginning the possibility of exploiting other senses to render a more integrated (from the controllers’ point of view) augmented perception of reality. In more general terms, from a Human Factors (HF) point of view, it is reasonable to expect that a realistic setting will result in higher arousal and lower reaction times for controllers, as compared to a setting deprived of key perceptual aspects. This stream of work will follow a technology-driven innovation approach: An incremental improvement of the current RTO technologies, by integrating multimodal aspects to enhance ATCOs performance.
2. **Augmented Remote Tower.** A second related opportunity is to build new human-system interaction concepts on the understanding how multimodality and the sense of presence impacts certain aspects of ATM Human Performance. The end goal is to enhance human performance by augmenting multisensory stimuli, including but not limited to the already overloaded visual channel, but without increasing the ATCO workload due to the stimuli increase. The use of multimodal technologies is a promising avenue to maintain a high level of situation awareness and control, by partially off-loading the visual channel and relying on other channels (i.e. audio or haptic feedback) for monitoring out-of-the-current-view airports. This part of the work is more focused on a design-driven innovation approach: Re-thinking how control tower activities currently take place, by exploiting multimodal solutions for augmented interaction in (remote) tower operations.

The operational environment considered in MOTO project included single RTO (addressed during both first and second validations) and the Multiple RTO (addressed only during the second validation).

The contingency use of remote towers, facility to assure at least a basic level of service (be used when an airport tower is unserviceable for a short period), was out of the scope of the project.

2.2 Project Scope and Objectives

The main aim of the project is to explore the impact of multimodal perception and sense of presence experienced by ATCOs in RTO and to enhance ATCOs performance using augmented multimodal concepts and prototypes.

The detailed objectives are the following:

- **Objective 1:** assessment of the role of Embodied Cognition in control tower operations.
- **Objective 2:** definition of user requirements for a multimodal Remote Tower.

- **Objective 3:** definition of neuro-physiological indexes, customized for Remote Tower Operations, to monitor aspects of Human Performance like: workload and situation awareness
- **Objective 4:** validate the above results in realistic ATM operational conditions through simulation facilities.

The table below summarises all the MOTO objectives and corresponding lower level objectives.

Table 1. Overview table of the MOTO objectives.

Objective	Sub-objective
1. Assessment of the role of Embodied Cognition in control tower operations	Analysis of sensory information (with a specific focus on other senses than sight, but not excluding sight) normally considered by tower controllers.
	Analysis of how proprioception affects decision-making and performance in tower operations.
2. Definition of user requirements for a multimodal Remote Tower.	Gap analysis for multimodal information in Remote Tower platforms.
	Design of multimodal concepts of human-system interaction in Remote Tower platforms, integrating at least sight, hearing, and touch
3. Definition of neuro-physiological indexes, customized for RTO	Integrate existing knowledge on neurometrics with multimodal input in Remote Tower context.
	Derive a sense of presence and immersion index
4. Validate the above results in realistic ATM operational conditions through simulation facilities.	Assess the performance benefits by comparing the baseline Remote Tower with the Augmented Remote Tower.
	Assess the performance benefits of the Augmented Remote Tower in more innovative scenarios (including Multiple Remote Tower scenarios).

2.3 Work Performed

The main technical activities and work performed were organized under 4 main blocks. The diagrams below presents these activities organized in the key work packages and the related results.

The Baseline and Gap analysis (WP1) corresponds to an initial part of work that fed the two main streams of work that correspond to WP2 (Enhancing the Embodiment) and WP3 (The Augmented Remote Tower). The results from realistic remote tower part of work fed the augmented remote tower work. The Validation (WP4) consisted in the part of the work that allowed to gather the evidence by means of the preparation and execution of two validation experiments, one for each main stream of work, WP2 and WP3.

The interaction between the activities performed within each WP is summarized below:

- WP1 output feeds: WP2, WP3 and WP4
- WP2 output feeds: WP3 and WP4
- WP3 output feeds: WP4.
- WP4 output feeds: WP1, WP2 and WP3.

Table 2. Technical work packages structured

WP1. Baseline and Gap Analysis	
Baseline measurements in real towers and gap analysis with current RTO.	
Outcomes: <ul style="list-style-type: none"> ▪ Scenarios of embodied cognition in tower operation ▪ Requirements for realistic multimodal remote tower platforms 	
WP2. Enhancing the Embodiment (Realistic Remote Tower)	WP3. The Augmented Remote Tower (Augmented Remote Tower)
Definition of concepts for realistic remote tower platforms and perform measurements in VR environment and RTO platform.	Definition of augmented multimodal concepts for RTO and perform measurements in RTO platform.
Outcomes: <ul style="list-style-type: none"> ▪ Impact of multimodal input in RTO ▪ Requirements for a realistic remote tower ▪ Sense of presence and immersion index 	Outcomes: <ul style="list-style-type: none"> ▪ Augmented multimodal prototypes and concepts for the remote tower ▪ Recommendations for augmented remote tower platforms ▪ Final sense of presence and immersion index
WP4. Validation	
Two main validation experiments, the first in VR Environment and the second in Remote Tower Platform.	

The high level activities performed are described in order in the following listing and for each of them are reported the deliverables in which the work have been documented:

- **Baseline Measurements (WP1)** – Identify and select scenarios of tower operations where multimodal perception plays a role under low and high workload conditions. The scenarios were identified and selected based on literature review, interviews with experts and dedicated workshops. Some measurements in a real control tower environment were carried out to understand the real range of multimodal stimuli in a standard control tower.
- These activities are documented in D1.1 Baseline scenarios and measurements [2] and in D1.2 Requirements for realistic multisensory remote tower platforms [3].
- **The Embodied Remote Tower Setting (Realistic Remote Tower) (WP2)** – Reproduce multimodal stimuli in a VR environment with the help of Head Mounted Display. Definition of the

measurement of users' state, using EEG, and, other psychophysiological measures (e.g. heart activity, galvanic skin response), and subjective standard questionnaires. Analyse the output and to iteratively fine tune the technologies and produce the Realistic Remote Tower requirements.

- These activities are documented in D2.1 Measurements in the Virtual Cave setting and in the Remote Tower platform [4] and in the Remote Tower platform and in D2.2 Technology requirements for realistic multisensory remote tower platforms [5].
- **Realistic Remote Tower_ First Validation (WP4)** – The multimodal technologies were validated in a virtual reality environment reproducing a Control Tower, with professional Air Traffic Controllers' involvement. This activity provided feedback on the potential benefit of the introduction of multimodal support in remote control tower operations. Moreover, this study provided indication for the implementation of multimodal stimuli in the concepts being developed. The first validation exercise focused on Single remote tower scenarios, including low-high workload conditions and low visibility operations.
- These activities are documented in D 4.1 Validation strategy and plan [6] and the details of the first validation exercise are reported in D4.2 First validation report [7].
- **Augmented Multimodal Tower Setting (WP3)** – Enrich augmented prototypes and concepts with multimodal stimuli to enhance human performance. The design and develop of prototypes were supported by interviews and dedicated workshops with experts. A set of concepts were selected and developed to the level of working prototypes, while others only at the level of concept and described in a dedicated website.

These activities are documented in D3.1 Measurements in the Virtual CAVE setting [8], in D3.2 Measurements in the Remote Tower platform [9] and in D3.3 Technological concepts for augmented multisensory interfaces for tower platforms [10].

- **Augmented Remote Tower_ Second Validation (WP4)** – The augmented multimodal technologies were validated in a Remote Tower platform , with professional Air Traffic Controllers' involvement, measuring the users' state by EEG and other psychophysiological measures (e.g. heart activity, galvanic skin response), and subjective standard questionnaires. The final validation exercise simulated a more innovative scenarios, such as multiple RTO, with parallel operations. This study provided recommendations for the implementation of multimodal augmented solutions in RTO. The details of the second validation exercise are documented in D4.3 Second validation report [11].

The table below summarises the two main validation steps described above.

Table 3. MOTO validation activities overview

	Multimodal Remote Tower Validation experiment (T4.2)	Augmented Remote Tower Validation experiment (T4.3)
Objective	<ul style="list-style-type: none"> Impact of multimodal feedback in RTO Requirements for a realistic remote tower Sense of presence and immersion index 	<ul style="list-style-type: none"> Augmented multimodal concepts and prototypes for the remote tower platforms Final index of presence and immersion (behavioural and neurophysiological data) Recommendations for augmented remote tower platforms
Scenarios	Single remote tower scenarios	Single and Multiple remote tower scenarios
Validation platform	Virtual reality environment in Head Mounted Display (HMD)	Remote Tower platform
Where	SCN Laboratory (Rome, Italy)	ENAC (Toulouse, France)
When	September and October 2017	March 2018

2.4 Key Project Results

The main project results and outcomes can be mapped in the two MOTO main streams of work: (Stream 1) the Realistic Remote Tower, and (Stream 2) the Augmented Remote Tower.

- VR Multimodal Platform for simulation of Tower operations (Stream 1)**
 The VR tower platform developed in the first stream of work of the project explores the impact on ATCO of the innovative multimodal feedback for control tower (current and innovative).
- Neuro-physiological classifiers to monitor human performance in (Remote) Tower operations (Stream 1 and Stream2)**

Development of neuro-physiological classifiers to monitor human performance in (Remote) Tower operations, associating neurophysiologic conditions with established HF concepts like workload, situation awareness and sense of presence.

- **Augmented multimodal Remote Tower Prototypes (Stream 2)**

Prototypes of augmented multimodal support to enhance ATCOs performance in RTO. A set of augmented multimodal prototypes have been tested in a remote tower platform implementing spatialized auditory warning and vibration feedback.

- **Exploratory concepts for multimodal multiple Remote Tower (Stream 2)**

Exploratory concepts of augmented multimodal tools to enhance ATCOs performance in Multiple RTO. These exploratory concepts were derived disruptive design activities with ATM experts focusing on multiple remote tower settings (interviews, workshops and focus groups). These concepts were not subject to a formal validation moment during the duration of the project.

2.4.1 VR Multimodal Platform for simulation of Tower operations (Stream 1)

The present content is reported in more detail in D1.1 (Baseline scenarios and measurements) [2] and in D4.2 (First Validation Report) [7].

2.4.1.1 Data acquisition to integrate in the VR Remote Tower Platform

Hereafter are reported the detailed description of the methodology employed to acquire vibrations, sounds and visual signals in real tower environment:

- Vibrations have been recorded with a National Instruments 4-channels C series dynamic signal acquisition module (CompactDAQ systems with a NI 9234 module and 4 high sensitive accelerometers). This system permits high-accuracy audio and vibration frequency measurements from integrated electronic piezoelectric (IEPE) and non-IEPE sensors with NI CompactDAQ systems and LabView Express 2014 acquisition software. The NI 9234 delivers 102 dB of dynamic range and incorporates software-selectable AC/DC coupling and IEPE signal conditioning for accelerometers and microphones. The four input channels simultaneously digitize signals at rates up to 51.2 kHz per channel with built-in anti-aliasing filters. See the figure below for an example of the technology used.



Figure 1. CompactDAQ systems

- Sound information has been acquired by means of a customized free Space Binaural Microphone to record sounds signals from the environment. This system has the advantage to simulate the natural human ears. See the figure below for an example of the microphone.



Figure 2. Space Binaural Microphone

- Visual information has been recorded with a LG 360 cam. This cam has dual wide-angle 13 million pixel lenses that permit to acquire images with a visual angle of 360 degree. This configuration has permitted to record the visual information of the whole airfield.



Figure 3. LG 360 cam

In the baseline measurements, visual, acoustic and vibration information generated from airport environment have been recorded from Real Air Traffic Control Towers. Vibrations and sounds signals have been recorded from the perceptual space where air traffic controllers are working. It is expected that sixty different instances of the target operational scenarios will be recorded, in order to achieve representativeness of the various operating conditions and be able to reproduce them with the required high fidelity level in the experimental environment. The following requirements are fundamental to reproduce multimodal stimuli and enhance the sense of presence.

2.4.1.2 Virtual Reality Remote Tower platform

Initially, the two types of platform described below were considered to reproduce the VR environment, CAVE Virtual Environment and Head Mounted Display platform.

Technology has drastically improved in the recent years and the new virtual reality headsets are now available with valuable assets. The visualization latency is very low and head movement are accurately tracked. The screen resolution has drastically improved, and it is almost impossible to perceived single pixels. In this sense, these devices provide an infinite screen size around the user and thus leverage user visualization field of view. Finally, such device enable a much stronger user immersion into virtual environment compared to a CAVE.



Figure 4. Two different VR headsets: HTC Vive (on the left), and Oculus Rift (on the right).

The first validation was finally performed in the VR environment reproduced in the HMD because it proved to provide a highly immersive environment. The following paragraphs summarize the main characteristics of the tools and characteristics of those tools that helped render an immersive VR environment.

The TWR experimental platform consisted wooden vibrating base that was placed in a corner of the room with a chair on top. The vibrating base was connected to the main pc and there was also a Behringer audio amplifier plugged into the vibro-tactile transducer placed under the wooden base to render the scenarios that included the vibration conditions. There were two infrared cameras fixed on the upper part of the room's corners to track the virtual reality headset movements and position.

The experimental management platform consisted in the workstation that contained the main desktop computer a main screens. The main computer had a main monitor attached to it that allowed the VR management expert to control the events for each scenario in coordination with the pseudo-pilot. The secondary screens included a laptop with skype that allowed the pseudo-pilot and participant communications. There was respectively a screen with a stopwatch to help the pseudo-pilot to follow the experimental scenario transcript and an extra screen that rendered the participant actual HMD VR view that helped the pseudo-pilot keeping track of the scenario flow.

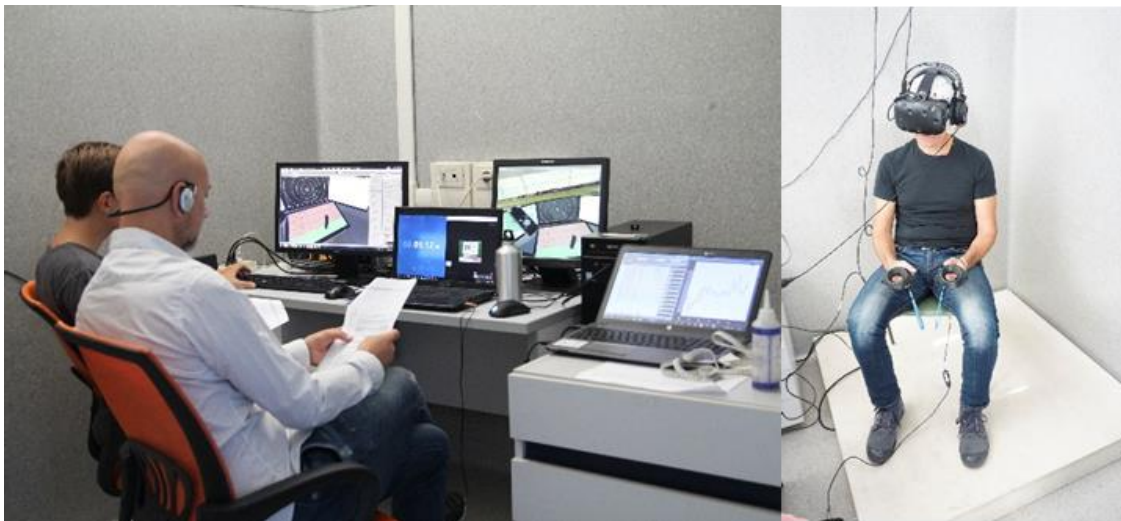


Figure 5. Experimental room setup (right- experimental management platform; left-TWR experimental platform)

The virtual scenario was partially designed in 3dsMax 2015 (Autodesk, Inc.) and implemented using Unity3d 5.6.0, a game developing platform used also for creating virtual reality environments. It consisted in a 3D reproduction of an air control tower (ATC) surrounded by a 180° image acquired in Ciampino from the ATC perspective.

Participants were immersed into the 3D tower thanks to a HTC VIVE head mounted display (HMD). This HMD has a resolution of 2160x1200 (1080x1200 per eye), a refresh rate of 90 Hz and about 110 degrees of field of view. The tracking of the device was carried out by the Lighthouse system, consisting in 2 HTC VIVE Base Stations emitting infrared lasers. The participants seated on a chair placed on a wooden vibrating platform built expressly for this experiment.

The platform used a Clark-Synthesis TST329 Platinum Tactile Sound Transducer powered by Behringer iNUKE NU1000DSP to reproduce the vibrations recorded from the ATC. The tower operators were asked also to wear a MSI DS502 GAMING VR Stereo Headset (msi.com) used for reproducing environmental sound and communicate via Skype with a pseudo-pilot).

In the end of the first validation experiment the platform was considered very realistic and immersive in order to simulate operational scenarios in which technologies or sensorial features could be tested. A similar setting can be not only for validation activities but also for training scenarios that can't actually be reproduced or are difficult to reproduce in real operational conditions.

2.4.1.3 Virtual Remote Tower Environment reproduced during the first validation experiment

During the first validation activity [7] the, using VIVE HMD, the participants were immersed in a virtual Tower environment simulating the airport environment and reproducing the ATC tools used to manage the traffic during the experimental tasks (see the figure below with a description of the tower virtual environment).

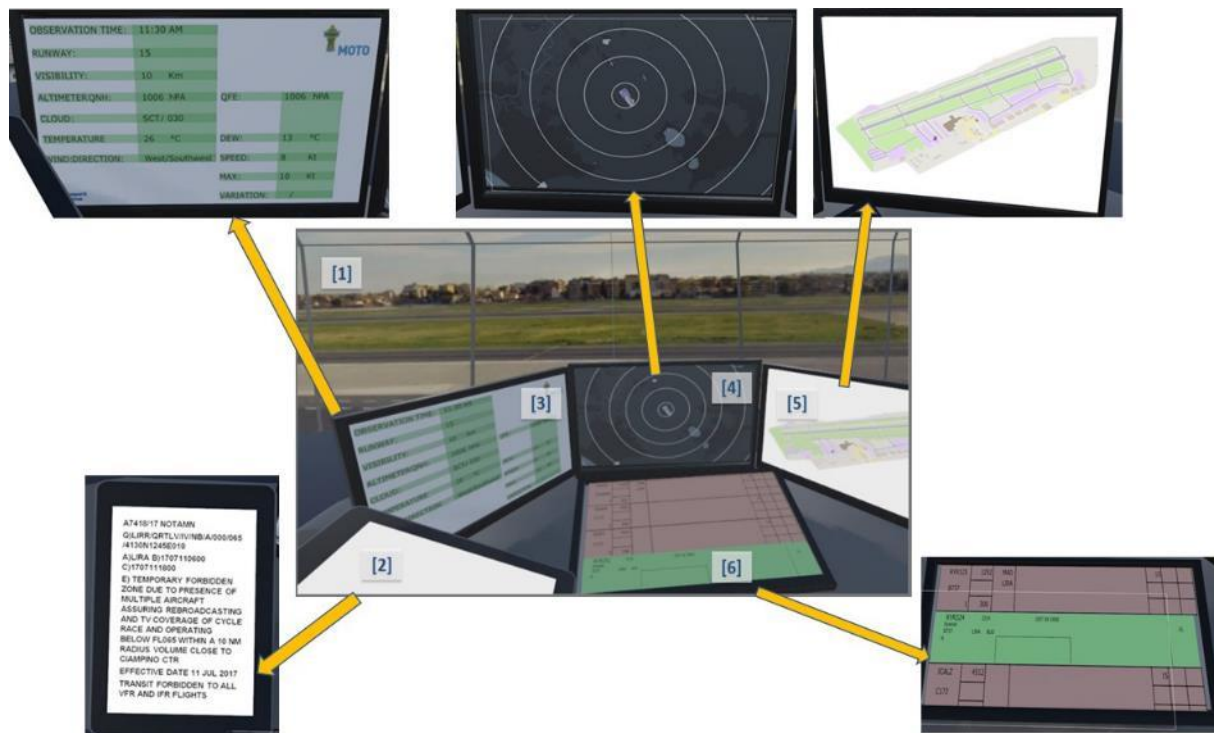


Figure 6. Virtual Reality (VR) environment. From the left to the right: airport environment.

The simulated ATC tools simulated in the VR Tower Environment were the following:

- Ciampino Tower out of the window view (1);
- NOTAM screen (2);
- ATIS Information screen (3);
- air radar (4);
- Surface Movement Radar (SMR) (5)

- Flight Progress Strips (FPS) screen (6).

2.4.2 Neuro-physiological classifiers to monitor human performance in (Remote) Tower operations (Stream 1 and Stream2)

The classifiers to monitor human performance were addressed in the frame of RTO but they can also be applied in current Air Traffic Management operations. The detailed description of the neuro-physiological classifiers for workload and sense of presence are reported more into detail in the project first [7] and second validation [11] deliverables.

2.4.2.1 Cognitive Workload

In the following section, all the steps to derive workload index starting from the EEG activity of the user (i.e. W_{EEG}) will be explained. Such analysis was employed to highlight overall workload experienced by the participants for each experimental modality (i.e. Augmentation ON/OFF) and condition (i.e. Multiple/Single remote tower). In this regard, most of the studies showed that the brain electrical activities mainly involved in the mental workload analysis are the theta and alpha brain rhythms typically gathered from the *Pre-Frontal Cortex* (PFC) and the *Posterior Parietal Cortex* (PPC) regions. Previous studies demonstrated as the EEG theta rhythm over the PFC presents a positive correlation with the mental workload [12]. Moreover, published literature stressed the inverse correlation between the EEG power in the alpha frequency band over the PPC and the mental workload [13]. Only few studies have reported significant results about the modulation of the EEG power in other frequency bands, i.e. the delta, beta and gamma [14]. More specifically, most of the studies are focused on the EEG power modulation occurring in theta (4 – 8 Hz) and alpha (8 – 12 Hz) frequency bands, usually associated with cognitive processes such as working memory and attention, typically involved in mental workload.

Mental workload is also known to suppress EEG alpha rhythm and to increase theta rhythm during activity of information encoding and retrieval [13]. Depending on such evidences, theta EEG rhythms over frontal sites, and alpha EEG rhythms over parietal sites have been used for such kind of analyses. In particular, for each ATCO, scalp EEG signals have been recorded by the digital monitoring BE Micro system (EBNeuro system) with a sampling frequency of 256 (Hz) by 13 Ag/AgCl passive wet electrodes covering frontal and parietal scalp sites (FPz, AFz, AF3, AF4, Fz, F3, F4, Pz, P3, P4, POz, PO3, PO4) referenced to both the earlobes and grounded to the right mastoid, according to the 10-20 standard [15].

In the following all the necessary steps to calculate the EEG-based workload index (W_{EEG}) have been reported.

First of all the EEG channels have been firstly band-pass filtered with a fifth-order Butterworth filter (low-pass filter cut-off frequency: 30 (Hz), high-pass filter cut-off frequency: 1 (Hz)). The Fpz channel has been used to remove eyes-blink artefacts from the EEG data by using the regression-based algorithm REBLINCA [16], that could affect the EEG frequency bands involved in workload assessment. With respect to other regressive algorithms (e.g. Gratton method,[17]) the REBLINCA algorithm has the advantages to preserve EEG information in blink-free signal segments by using a specific threshold criterion that recognize the occurrence of an eye-blink, and only in this case the method cleans the

EEG signals. If there is not any blink, the method has not any effect on the EEG signal. The band-pass filtered (1÷7 (Hz), 5th order Butterworth filter) Fpz signal has then been used as template to remove eye-blinks contribution from the EEG signal. For other sources of artifacts (e.g. bioamplifier saturation, muscular activity during the experimental task) specific procedures of the EEGLAB toolbox have been used [18]. In particular, three criteria have been applied:

- *Threshold criterion*: if the EEG signal amplitude exceed ± 100 (μV), the corresponding epoch would be marked as artifact;
- *Trend criterion*: each EEG epoch has been interpolated in order to check the slope of the trend within the considered epoch. If such slope was higher than 3 ($\mu\text{V/s}$) the considered epoch would be marked as artifact;
- *Sample-to-sample difference criterion*: if the amplitude difference between consecutive EEG samples was higher than 25 (μV), it meant that an abrupt variation (no-physiological) happened and the EEG epoch would be marked as artifact.

At the end, all the EEG epochs marked as artifact have been rejected from the EEG dataset with the aim to have an artifact-free EEG signal from which estimate the brain variations along the different conditions.

All the previous mentioned numeric values have been chosen following the guidelines reported in Delorme and Makeig [18].

At this point, the free of artifacts EEG signal has been segmented into epochs of 2 seconds, shifted of 0.125 seconds. The *Power Spectral Density* (PSD) was calculated for each EEG epoch using a Hanning window of the same length of the considered epoch (2 seconds length (that means 0.5 (Hz) of frequency resolution). Then, the EEG frequency bands of interest have been defined for each subject by the estimation of the *Individual Alpha Frequency* (IAF) value [19]. In order to have a precise estimation of the alpha peak and, hence of the IAF, as stated before the participants have been asked to keep the eyes closed for a minute before starting with the experiments.

Finally, a spectral features matrix (EEG channels x Frequency bins) has been obtained in the frequency bands directly correlated to the mental workload. In particular, only the theta rhythm (IAF-6 ÷ IAF-2), over the EEG frontal channels and the alpha rhythm (IAF-2 ÷ IAF+2), over the EEG parietal channels have been considered as variables for the mental workload evaluation.

At this point, a linear classification algorithm (*automatic stop StepWise Linear Discriminant Analysis* – as SWLDA, [20] has been used to select the subjective discriminant EEG spectral features related to the workload. Once trained with specific “calibration data”, the algorithm can be used to compute a workload index (i.e. W_{EEG} index) on other data by combining the selected EEG features with specific *weights* in output from the model itself. In particular, the algorithm has been calibrated by using the two “Easy” and “Hard” difficulty level scenarios, in order to extract for each subject the spectral features related mental workload. At this point, an EEG-based workload index (W_{EEG}) has been calculated for each modality (i.e. Augmented ON/OFF) and condition (Multiple/Single remote tower), by combining weights in output from the classification model and the PSD data. In conclusion, z-score transformation [21] has been used to compute a normalization of index distribution (Figure 7).

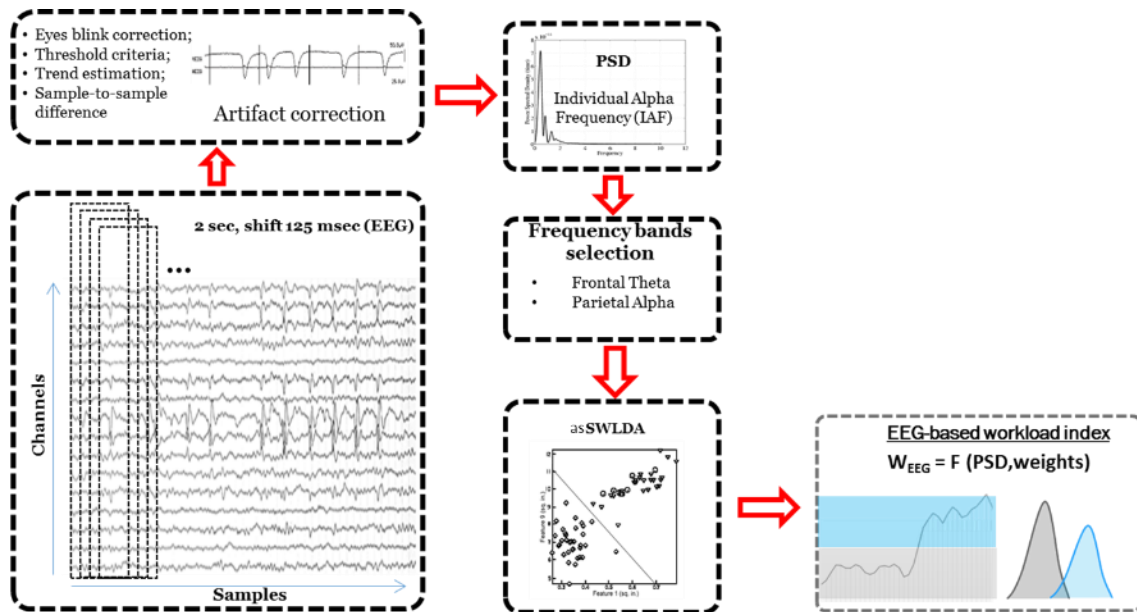


Figure 7. Technical steps description to calculate the index

2.4.2.2 Embodiment Index (Sense of Presence Index)

The sense of presence is a human response to immersion, defined as technology’s ability to create a convincing, engaging environment with which users can interact. The sense of presence can be measured through objective and subjective measures. In this project, we collected both subjective and neurophysiological indexes. These measures were acquired continuously during the experiment (i.e., the neurophysiological measures), and at the end of each experimental session or at the end of the experiment. Moreover, we developed a novel and original experimental paradigm, the task of the aircraft, consisting of a virtual airplane suddenly approaching the control tower thus increasing the collision risk, that it was performed at the end of the whole experiment, in each participant. One of the objectives of this task was to test if immersive virtual environment generates a sufficient sense of presence to make controllers’ perception in the RTO as real as reality, and thus able to induce neurophysiological reactions similar to those obtained in natural and ecological environments.

From a subjective point of view, our data demonstrated that participants perceived a high degree of being present and immerse in the virtual environment. In other words, at least at awareness level, they believe to be placed in the virtual tower and forgot the reality of the laboratory. The use of questionnaires however might produce a methodological circularity. By asking questions about ‘presence’ or ‘immersion’ might bring about the very phenomenon that the questionnaire is supposed to be measuring. For this reason, the aim of this project was to support this evidence by using objective, neurophysiological indexes. Neurophysiological assessment performed during the whole experimental activity indicates that, despite participants’ experienced high sense of presence across all experimental

conditions and regardless of the task difficulty, significant differences were detected between the visual modality and VA (Visual + audio) and VAV (Visual + audio + vibrotactile) conditions (V condition reports lower GSR than VA and VAV). In other words, when the virtual environment was characterized only by the visual input, the sense of presence in the virtual remote tower is reduced. Accordingly, the enrichment of the virtual environment with the audio information increases the sense of presence and immersion. These results are notable because participants were unaware of the fact that they earned sense of presence/immersion when a multimodal stimulation occurred. It is worth noting, also, that these results were consistent with those obtained from the neurophysiological - EEG analysis where the integration of the audio information with the visual modality increase the ATCO performance and reduce the workload.

The embodiment index has been developed as an objective measure of the sense of presence and it results as crucial to test if immersive virtual environment generates a sufficient sense of presence to make controllers' perception in the RTO as real as reality. Our results indicate that the sense of presence can be quantified from the possible modulations of the GSR responses induced by a stressful experience. This index aimed to test for each participant his/her sense of presence engaged from an emotionally salient virtual context in RTO environment. Despite participants might be aware that the aircraft and its collision with the tower was unreal, the stressful event, i.e., the collision risk, elicited an increasing of the level of arousal. It is worth noting that this objective measure can also be useful to discern those individuals with high aptitude to experience the synthetic virtual environment as real, and this is particularly important to test the emotional engagement of the ATCOs, even if they are several kilometres away from the place in which the event is really happening. In other words, these individuals will have the same emotional reaction to a potential danger as they were physically located on the place of the event. Finally, the results sense of index outcomes support the idea that physiological variables can be used as reliable, valid, and objective measures of presence. This is a great advantage especially in light of the development of future user requirements for realistic multimodal remote tower platforms.

2.4.3 Augmented multimodal Remote Tower prototypes (Stream 2)

The following prototypes of augmented multimodal Remote Tower are described in more detail in D3.3 [10]. These prototypes were validated both in Single remote tower and also Multiple remote tower scenarios during the human-in-the-loop experiment. The outcomes of this validation highlighted a clear advantage in the used of the Augmented multimodal prototypes on specific operational conditions and for certain events (i.e. Spatial and Runway incursion alerts), since the related reaction time values were significantly shortened (on 3 times on average) once Augmented multimodal prototypes were active.

The perception of the overall performance across the different conditions and modalities, by both the experimental subjects and the SME, was significantly decreased if the augmented solutions were activated. The same trend was confirmed by the workload measures, both subjective and neurophysiological, suggesting an increase of experienced workload if augmented solutions were activated. Such behaviour could be interpreted as need for a longer familiarization of experimental subjects in enriched sensorial operational environments (which is not the case in current tower

operational environments). The detailed results can be reported in D4.3 Second Validation Report [11].

1. Spatial alert

The spatial alert is a “general purpose” alert, which aims to inform the ATCO that an emergency occurs in one of the monitored airports.

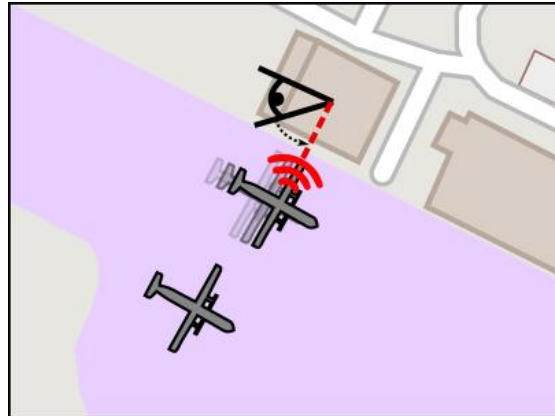


Figure 8. Alert given once there is an unauthorized aircraft movement. The alert is spatialized, attracting the ATCO attention to this situation.

This augmentation can be used alone to catch the attention of the controller on an abnormal situation, or be combined with a specific alert to increase its saliency.

The augmentation should increase the situation awareness. The intervention of the ATCOs is expected to be quicker than without the augmentation as an unauthorized movement is hard to notify on a ground radar (if any) due to the refresh time.

Sensorial Modalities

Spatial alert uses the audio modality. A distinctive enough sound is played in order to unequivocally attract the ATCO.

To avoid creating doubt in case the ATCO would have anticipated the situation and is already focused on, the alert is not activated if the gaze of the ATCO is already in direction of the abnormal situation.

2. Radio Saliency Alert

Radio is a mandatory tool, which ease to use should be kept. Introducing multiple remote tower, without radio coupling to avoid potential misunderstanding from the pilot (pilot from an airport facility taking into account the information about another traffic in another airport surrounding), can potentially overload the controller. Indeed, the ATCO has to determine from which airport the message is coming from, “load” the mental map of the right airport and then take a decision.



Figure 9. Vibration of the seat of the chair to indicate to the ATCO, that the call is coming from a secondary airport.

The Radio saliency aims at shorten the overall process by helping to determine from which airport the call is coming.

This tool is expected to improve conscience awareness and decrease the workload of the ATCO by indicating the location of the call, which instantly provides the situation’s context.

Sensorial Modalities

The information is provided using vibration, which modality does not disturb sight, used to monitor the traffic, neither audio, used at that moment by the radio.

3. Runway Incursion Alert

Runway incursion is defined as

“Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft”, ICAO, Doc 444 – PANS-ATM.

Runway incursions increase risks of collision in the aerodrome surrounding. Moreover, in accidents occurring on the runway, at least one of the aircraft involved will often be travelling at considerable speed, which increases the risk of significant damage and the severity of the consequences.



Figure 10. Left: Runway incursion due to a holding point crossing w/o authorization. Right: Runway incursion due to an aircraft lined up. Center: Vibration alarming the ATCO that a runway incursion has been detected.

To prevent this kind of incidents on the runway, a specific alert is risen when an aircraft crosses the holding point, or is present on the runway threshold while another aircraft is in final approach.

This augmentation has been designed to decrease the reaction time of the ATCO. It should increase the situation awareness and help the ATCO to manage such situation without increasing too much the workload.

Sensorial Modalities

Given the seriousness of the event, the trigger has been chosen uncomfortable. To do so, we use the vibration modality with a strong and distinctive signal.

4. Audio focus

To take decision, ATCOs need to have an up to date mental map of the airport. They need to know where aircrafts are at every moment. In case of good visibility, the mental map mostly relies on vision. In case of bad visibility, the visual perception loss should be compensated by a tool not affected by the bad condition.

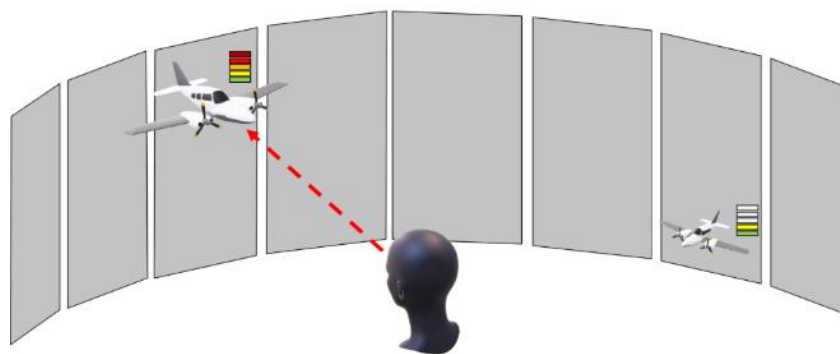


Figure 11. The audio focus augmentation aims at helping the ATCO to detect the aircraft by increasing the sound of the ones in front of her/his gaze.

The head of the ATCO is tracked, allowing to increase the sound of aircrafts situated in a cone circumscribing.

Sensorial modalities

By facilitating the discovery and the tracking of aircraft in low visibility, Audio focus is expected to increase the situation awareness and decrease the workload.

The audio focus is a tool similar to spyglass but for the audio modality.

2.4.4 Exploratory concepts for multimodal multiple Remote Tower (Stream 2)

The set of exploratory concepts presented here below are a preliminary outcome from series design-oriented innovation activities focused on re-thinking control remote tower activities by exploiting multimodal concept in a multiple remote tower setting. The concepts were developed to the level of maturity corresponding to a Technology Readiness Level (TRL) 1 (Feasibility) but were not formally validated during the second validation experiment. The detailed design-related activities and methodological approach followed are reported in D3.3 Technological concepts for augmented multisensory interfaces for remote tower platforms [10].

1. Airport transition function



Figure 12. Airport transition function (demonstration with 3 airport CWP).

The airport transition function enables the ATCO to switch the airport visualization mode from one (main or secondary) screen to another, when a specific airport requires the operator's attention.

The concept foresees the implementation of a movement tracker and a device (e.g. wearable bracelet(s) able to identify the operator's arm and hand movement in the air when changing the primary screen visualization with a secondary one (and vice versa).

The screens system gives the ATCO the possibility to always have at his/her disposal the environments to be controlled and, when necessary, to switch from one aerodrome environment to another with a directional gesture control (from the right to left side and vice versa).

Sensorial modalities

The sensorial modalities which this concept explores are visual and proprioception.

Human-machine interaction

The interaction between the ATCO and the system is enabled by the ATCO's hand and arm movements that allow him/her to change the airport visualization.

When the ATCO needs to manage the traffic at a secondary airport, in order to visualize the secondary environment on the main screen, through a gesture movement (arm/hand) performed from the left to the right (if the secondary screen to visualize as primary is on the left) and vice versa, as output of

the movement s/he will receive the switch of the two environments; the secondary becomes the primary one and vice versa.

The movement could be also supported by one (or two) wearable bracelet(s) able to add precision to the recognition of the ATCO's arm movements in the air.



Figure 13. Airport transition function interaction demonstration

2. Secondary airport preview function



Figure 14. Secondary airport preview function.

The secondary airport preview function is implemented in the secondary screens system. The secondary screens system is composed of a number of screen (one for each aerodrome) and it could be implemented in the future Multiple Remote Tower Controller Working Position (CWP), in order to give the ATCO the possibility to maintain the visual control of all the airports under his/her control.

In the case of one ATCO managing 3 airports, two screens show the activity occurring on the runway and taxiways of two remote aerodromes, while one of them reproduces the Surface Movement Radar of the main airport on the primary screen.

This function would allow the ATCO to give a quick look to one of the secondary airport, enlarging the image of a secondary aerodrome to a small area on the biggest screen with the visualisation of the primary aerodrome.

Sensorial modalities

The sensorial modalities which this concept explores are visual and proprioception.

Human-machine interaction

Two optional interactive modalities were foreseen for this concept:

1st option:

The interaction between the ATCO and this function consists in an arm gesture movement in the air in front of the secondary screen the ATCO needs a preview of during a specific moment of his work. Through the arm movement, s/he is able to drag the secondary visualisation to a small area in the master display, in order to have a preview of the secondary screen. The projection is reproduced in the area of the biggest screen immediately adjacent to the secondary one. For instance, if the secondary screen is located on the left, its preview will be on the bottom left angle of the primary screen.

The arm movement could be hold until it is necessary for the operator; the airport goes back to the initial configuration when the user moves the arm toward the secondary screen.



Figure 15. Interaction 1 with the secondary airport preview function.

2nd option:

The same interaction could be performed through a touch interaction, tapping directly on the secondary screen to highlight the area the ATCO wants to check with the preview function.



Figure 16. Interaction 2 with the secondary airport preview function

In both cases, when the operator activates this function, that means when the operator is looking at the secondary environment overview, s/he is able to hear the environmental sounds (e.g. wind, rain, storm, engine sound, birds flying in the vicinity and etc.).

The main change introduced by this concept is related in the possibility to directly manipulate the interface, both in the case of the drag movement and in the touch interaction.

3. Runway inspection lock-up function



Figure 17. Runway inspection lock-up function

The runway inspection lock-up function that allows the system to activate the “inspection modality” when the ATCO authorizes it through the radio frequency.

The function is enabled by the following systems:

Founding Members



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- Head tracking that detects the direction of the ATCO head movements;
- Directional microphone, which is located on the secondary screens and detects the ATCO's voice when speaking toward its direction;
- Display with overlaid information represented by the primary and the secondary screens.

In addition, the system applies a coloured filter on the screen related to the airport with the inspection and the filter remains active on the screen, both in case it is the primary airport under control and in case it is moved to the corresponding secondary screen, when another airdrome requires the ATCO's attention.

When the airport interested by the inspection is on the foreground (secondary screen), the system highlights the presence of a vehicle on the runway with an icon (or other visual element) identifying the exact position of the inspection car.

Sensory modalities

The sensorial modality which this concept explores is visual.

Human-machine interaction

The function is activated by the recognition of the ATCO instructions that authorise the inspection on the runway. When the system recognises the authorisation, a timer and an icon of a lock appear on the screen, together with a coloured cover identifying the inspection in progress. If (and when) the ATCO needs to move the airport with the inspection to the secondary screen, with a gesture movement of the hand and arm s/he changes the main airport visualization (supported by a wearable bracelet).

The coloured filter and the timer with the icon remain active if (and when) the inspected airport is moved to the secondary screen, in order to allow the ATCO to see the car on the runway.

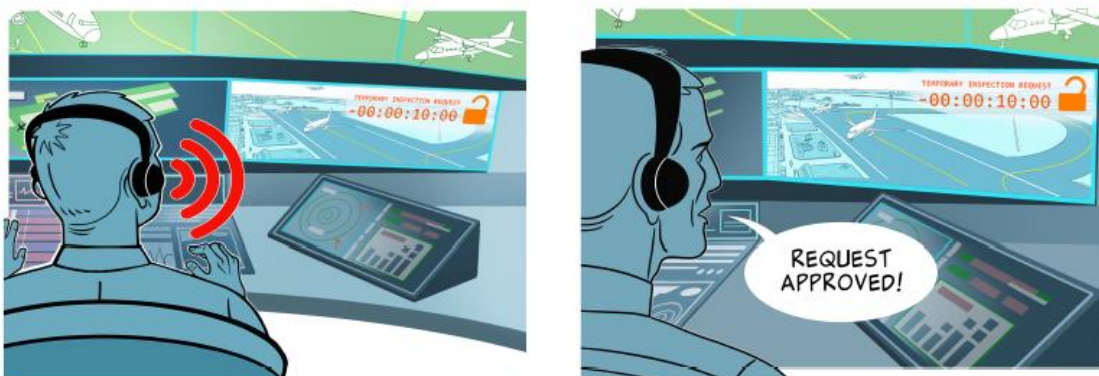


Figure 18. Runway inspection lock-up function interaction

4. Weather status alert



Figure 19. Weather status alert

The Weather status alert aims to inform the ATCO about unexpected weather changes and information. In order to do that, the system is able to detect an unexpected change in the environment (e.g. if it is expected the fog in a specific moment of the day, it starts raining) and to inform the ATCO of the change in progress. The technical elements involved in the system are the following ones:

- Dashboard with overlaid weather information;
- Wearable bracelets (or other kind of device) providing a vibrotactile input when the change occurs. The kind and intensity of vibration can vary based on the unexpected changes impact on the operations (e.g. two options: reduced or suspended operations)
- Headphones reproducing the environmental sound.

Sensory modality

The sensorial modalities which this concept explores are visual, auditory and vibrotactile.

Human-machine interaction

The dashboard with the timeline of the strips bar provides the operator with the weather information (e.g. an icon indicating a strong wind from 14pm to 17pm is displayed).

When an unexpected change in the environment is occurring (e.g. instead of a strong wind, it starts raining), a vibration from the wearable bracelet warns the operator. At the same time, on the primary screen a visual alert reinforces the message and, as the ATCO is already listening to the environmental sound through the headphones, s/he perceives also the rain sound.

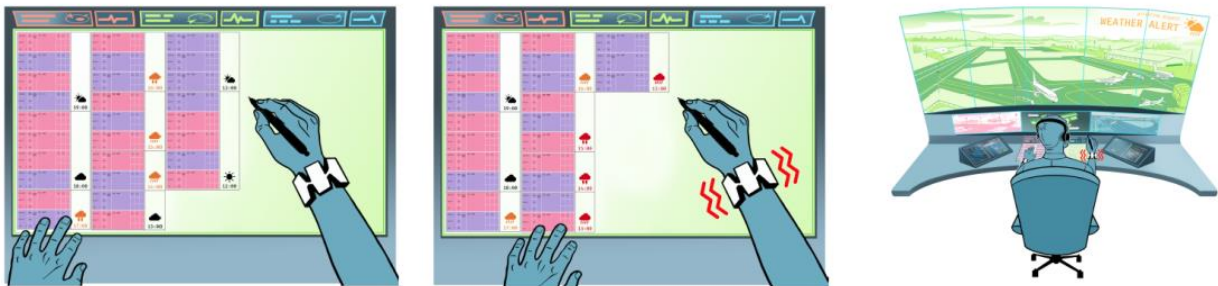


Figure 20. Weather status alert interaction

5. Emergency alert



Figure 21. Emergency alert

The Emergency alert aim is to inform the ATCO that there is an emergency occurring at one of the secondary airports. This information is gradually provided by two different kinds of stimuli: i) two visual inputs, namely a change in the brightness intensity of the airport display and a red icon notifying the situation; ii) vibrotactile input that can be provided by wearable bracelets or other kind of device.

Considering that, the elements of the system that support these functions are:

- A display with changing brightness;
- Wearable bracelets or other tools able to provide a vibrotactile stimulus to the operator.

Sensory modalities

The sensorial modalities which this concept explores are visual and vibrotactile.

Human-machine interaction

When at one of the secondary airport an emergency occurs, the brightness intensity increases (T1) and if the ATCO's time of reaction is low, an additional moving red icon is activated (T2); a vibration coming from the wearable bracelet (or other devices) is activated when the ATCO does not take any decision for a long period of time (T3).

T1, T2 and T3 represent the increase of the level of situation severity (growing intensity).

With respect to the current situation, the operator will have additional stimuli (visual and vibrotactile) to support his/her awareness of the emergency in progress; while the communication modalities between the actors involved (e.g. the ATCO and the pilot) will not change.



Figure 22. Emergency alert interaction

6. Sound spatialisation



Figure 23. Sound Spatialisation

The sound spatialisation function allows the ATCO to identify and recognise the specific airport requiring their attention among those under his/her control.

The system that activates this function comprehends the following elements:

- A radio frequency for the communication with the aerodromes that reproduces the sound of the incoming call. The principal active frequency is that of the primary airport, while those of the secondary ones are in a sort of standby. In addition, the sound of the incoming call is reproduced in the right or left side of the headphones depending on which of the secondary airports it corresponds to. The sound of the call is combined with a voice (e.g. high-low tone, woman/man voice) notifying the incoming call to the operator;
- Head-tracker system recognising the operator's head movements toward the airport interested by the call;

An icon on the screen of the airport with the incoming call that notifies that someone is speaking (e.g. sound waves); the icon is synchronised with the pilot's and controller's voice movement and if there are disturbances in the frequency or unintelligible words, the colour of the sound waves can change from green to red, depending on the level of frequency interference.

Sensory modalities

The sensorial modalities which this concept explores are visual and auditory.

Human-machine interaction

The function is activated when the operator starts a new communication with a secondary airport and/or receives an incoming call.

When there is an incoming call, the system provides the operator with auditory information reproduced in the right or left side of the headphones depending on which of the secondary airports it corresponds to. In addition to the auditory info, an icon appears at the top of the display notifying that someone is speaking (i.e. sound waves).

When the operator starts a new communication with a secondary airport, s/he has to rotate his head and to speak directly looking at the specific secondary display. The system catches the head movement and a directional microphone catches the message. At the same time, an icon (the same of the previous point) follows his/her speech.

If the system does not catch the message clearly, the colour of the icon and its movement will change (e.g. red); while when the message is clear the icon will be coloured differently (e.g. green).

In regard to the current situation, this function doesn't change the sequence of communication exchanges between the actors involved (e.g. the ATCO and the pilot), thus meaning that the ATCO's task is unvaried. What may change is the modality of interaction with the system, as the operator's interaction and movement to execute the communication task is guided and influenced by directional stimuli (i.e. sound coming from the secondary aerodrome to the right or left side of the headphone) that in the current situation don't exist.

2.5 Technical Deliverables

Table 4. MOTO technical deliverables list

Reference	Title	Delivery Date ¹	Dissemination Level ²
Description			
D1.1	Baseline scenarios and measurements	05/12/2016	PU
This deliverable documents the reference scenarios in tower operations, selecting events where embodied cognition is expected to play a role. It also encloses the high-accuracy sound and vibration signals acquisition from real control tower(s) by means of dedicated hardware and software, to reproduce them with the required high fidelity level in the experimental environment.			

¹ Delivery data of latest edition

² Public or Confidential

D1.2	Requirements for realistic multisensory remote tower platforms	13/02/2017	CO
This deliverable includes the selection of technologies for the Virtual Reality, covering user requirements for visual, audio and vibration signals. It also presents the initial refinements coming from the first steps of the HMD (previously Virtual CAVE) implementation, the of perceptual framework and interaction modalities.			
D2.1	Measurements in the Virtual Cave setting and in the Remote Tower platform	02/07/2017	CO
This deliverable documents the data collection methods, the experimental protocol and the analysis of the recorded data (physiological, electro-neurophysiological, direct and indirect indices of embodiment).			
D2.2	Technology requirements for realistic multisensory remote tower platforms	18/05/2018	CO
This deliverable documents the user requirements and specifications for reproducing visual, audio and vibration signals in the target settings. It also traces the state of development of the embodiment index at the end of WP2.			
D3.1	Measurements in the Virtual Cave setting	23/02/2018	CO
This deliverable documents a pilot exercise to prepare the second validation exercise, where the operator states is measured during realistic tower operations in the Remote Tower platform. Measurements under evaluation enclosed physiological (heart activity and galvanic skin response) and electrophysiological data (brain cortical activity). Behavioural correlates of Embodied Cognition are also evaluated by a standardized questionnaires.			
D3.2	Measurements in the Remote Tower platform	30/01/2018	CO
This deliverables reports a pilot exercise to finalising the proposed application of embodied cognition to augmented interfaces for towers operations. The document describes the measuring of the operator states during realistic tower operations in the ROT platform, the calibration and integration of sensors and the data analysis conducted.			
D3.3	Technological concepts for augmented multisensory interfaces for tower platforms	22/06/2018	PU
This deliverable documents the results of the second validation exercise and delivered the final set of concepts, user requirements, and specifications for augmented multimodal interfaces in remote tower platforms. It also encloses the design of the technological concepts for the augmented Remote Tower platform, detailing the technologies to be used, the target operational scenarios, typical use cases, benefits expected. The concepts will include techniques and tools for (a) analysis and (b) visual exploration and presentation of multivariate multimodal data.			
D4.1	Validation strategy and plan	13/02/2017	PU
This deliverable documents the validation strategy and plan and the overall validation approach for the two steps of the validation process. It also encloses the high level validation objectives, the detailed objectives, corresponding indicators and metrics, the workplan for both validation exercises.			
D4.2	First validation report	15/12/2017	PU

<p>This deliverable documents the first step of the MOTO validation process reporting the data collection and analysis to assess if the selected technologies can reproduce a realistic experience of visual, audio and vibration signals in ROT, via VR technology. This step mostly targeted Single remote tower scenarios. The document details the scenario definition, the preparation and execution of the different validation exercises, the data analysis and results reporting. Main outcomes from the first validation suggested that ATCOs awareness and workload could be improve by using the multimodal feedback and enhancing the sense of presence through the integration of the visual channel with one sensory modality at a time (either audio or haptic)</p>			
D4.3	Second validation report	22/06/2018	PU
<p>This deliverable reports preparation, execution and results of the MOTO second validation experiment. The human-in-the-loop Remote Tower Simulation aimed at assessing the proposed Augmented prototypes for Remote Tower platform. This validation targeted single remote tower scenarios and the more innovative Multiple Remote Tower scenarios, featured by parallel operations in a low density remote aerodrome. Results showed an advantage in terms of performance for the augmented concepts providing spatialized auditory warning and vibration feedback. Further studies are recommended to verify that performance benefits could be extended to the whole set of proposed augmented prototypes.</p>			
D5.1	Dissemination, Exploitation, and Communication report	22/06/2018	PU
<p>This document presents the MOTO Dissemination Exploitation, and Communication plan developed to promote the project and its results properly. The document illustrates the dissemination and exploitation goals, the overall communication strategy and the needed dissemination activities. It also identifies the dissemination and exploitation actions planned for the near future.</p>			
D6.1	PMP: Project Management Plan	19/10/2016	CO
<p>This document presents the Project Management Plan (PMP) that complements the project information provided in the Grant Agreement and its Annex I - Description of Action, integrating in particular more detailed procedures, briefly describing the Communication and Dissemination Plans, addressing the Ethics Requirements and implementing any additional refinement agreed at the Kick-off meeting.</p>			
D6.2	Projects Results final report	30/04/2018	PU
<p>This report is the final publishable report, the current document, which synthesizes the objectives and outcomes of MOYO, while relating our achievements to the operational context and to the SESAR programme.</p>			
D7.1	POPD – Requirement No. 8	27/02/2017	CO
D7.2	POPD – Requirement No. 3	27/02/2017	CO
D7.3	M - Requirement No. 2	27/02/2017	CO
D7.4	H - Requirement No. 1	27/02/2017	CO
D7.5	POPD – Requirement No. 7	27/02/2017	CO
D7.6	POPD – Requirement No. 6	27/02/2017	CO
D7.7	H - Requirement No. 5	27/02/2017	CO



D7.8	H - Requirement No. 4	27/02/2017	CO
<p>These deliverables present the procedures followed by MOTO Consortium to ensure compliance with the 'ethics requirements' set out in WP7. Detailed information is provided on the procedures that will be implemented for data collection, storage, protection, retention and destruction and confirmation that they comply with national and EU legislation.</p>			

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

The work performed in MOTO project address the concept of Remote Tower Platform.

This topic is targeted by different SESAR projects within the OFA 06.03.01 Remote Tower. Remote and Virtual Tower was first proposed for development and assessment in SESAR P06.09.03, alongside system projects P12.04.06, 12.04.07, 12.04.08 and 12.04.09. The aim of P06.09.03 was to define and then mature the Remote Provision of ATS against the three identified modes (Single, Multiple, Contingency). At the time, the project was largely focused on the north European environment where the main driver was cost efficiency for low complexity, low traffic aerodromes.

Starting from this initial assessment, many aspects of the concept have been matured through learning and validation, and additional Operational Improvement (OI) have been proposed to complement original definition and classification of the concept.

MOTO, investigated the innovative concept of the integration into the RTO of the multimodal feedback to support ATCO performance and sense of presence. Ideally, both single and multiple remote tower environments might in the future benefit of this findings (if further consolidated in additional studies).

As exploratory project, MOTO outcomes in its future development, it might be contribute to the OIs targeting single remote tower as well as the ones addressing the multiple remote tower concept. However, in the current status, the initial achievements of the project do not allow to propose any new OIs.

It is possible to identify a list of current OIs that in the future might benefits of the insights of the MOTO project (see Table 5).

The maturity of these MOTO outcomes are differentiated according to the two main streams of work:

- **“Realistic” Remote Tower:** referring to the exploration of the potential benefit of the multimodal feedback in the remote tower environment. This activity provided initial promising results mainly detailed in D4.2 First Validation Report [7]. This stream of work achieved TRL2 at the end of the project.
- **Augmented Remote Tower:** referring to both to the prototypes of augmented multimodal prototypes (TRL2) and to the exploratory concepts for multimodal multiple Remote Tower (TRL1). Only the augmented multimodal prototypes were formally validated and the results achieved include performance benefits in specific operational scenarios detailed in D4.3 detailed in the Second Validation Report [11].

The neurophysiological classifiers to monitor human performance in (Remote) Tower are mapped on both streams of work and, in this framework, were considered as a relevant for the implementation of a multimodal remote tower. This outcome achieved TRL2 at the end of the project.

In both operational scenarios –single and multiple remote tower- the augmented multimodal concepts increased ATCOS cognitive workload, but this not negatively affect the performance did not induce an overload situation (i.e. high workload that affects negatively performance) (see [7]). These results might be explained by the fact that most control towers are sound proof, and vibration are generally not felt. Even if the use of these two sensory channels (i.e. hearing and touch) could be seen as natural,

the novelty of these interaction modalities and the information provided consequently need a longer appropriation time, implying a that ATCOs need a longer familiarization process in order to be able benefit from other sensorial modalities without perceiving it as disturbance.

However, the implementation of innovative features such as the ones studied by MOTO shall privilege a step by step approach to provide a more solid results and shall provide to the ATCOs a dedicated familiarization with the concept and technical features of the solutions to maximize the potential benefits. Further research should be carried out.

As detailed in chapter 4.3, further research are recommended in order to:

- Increase the TRL of the augmented solutions in order to deploy them in operations. Particularly, considering the TRL achieved at the end of the project as an initial TRL 2, further human in the loop simulations in a realistic environment (multiple remote tower environment; medium density aerodrome; contingency scenarios) are needed.; as well as execution of trials in operations.
- Increase the TRL of the neuro-physiological classifiers in order to make them easily usable in operations. Further work needed to progress in Industrial Research & Validation (TRL 2-6).

Table 5. Project Maturity

OI Code	Name	Future Project contribution	Maturity at project end
SDM0201 SDM0205 SDM-0207 SDM-0211	Remotely Provided Air Traffic Service for Single Aerodrome	MOTO project in the future might contribute to enhance ATCOs performance and awareness in a single Remote Tower environment by exploiting multimodal feedback support	<ul style="list-style-type: none"> • VR Multimodal Platform for simulation Tower Operations (TRL2). • Neuro-physiological classifiers to monitor human performance in (Remote) Tower operations (TRL2). • Prototypes of augmented multimodal Remote Tower solutions (TRL2).
SDM-0207	Remotely Provided Air Traffic Service for Multiple Aerodromes	MOTO project shall provide solutions to enhance ATCOs performance and awareness in a multiple remote tower environment	<ul style="list-style-type: none"> • Exploratory concepts for multimodal multiple Remote Tower (TRL1).

SDM-0211	Air Traffic Service Provided to Two Airports, One Local and One Remote	MOTO project shall provide solutions to enhance ATCOs performance and awareness in controlling two low density aerodromes from a Remote control tower exploiting multimodal feedback support	<ul style="list-style-type: none"> • Prototypes of augmented multimodal Remote Tower solutions (TRL2). • Exploratory concepts for multimodal multiple Remote Tower (TRL1).
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3.2 Maturity Assessment

The MOTO project outcomes described in chapter 2.4 were positioned between TRL1 and TRL2. The maturity of each of the outcomes is presented below:

- VR Multimodal Platform for simulation of Tower operations (TRL2).
- Neuro-physiological classifiers to monitor human performance in (Remote) Tower operations (TRL2).
- Prototypes of augmented multimodal Remote Tower (TRL2).
- Exploratory concepts for multimodal multiple Remote Tower (TRL1).





Table 6 ER Fund / AO Research Maturity Assessment (MOTO project)

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Partial – Non Blocking	<p>Currently among the different remote tower platforms available on the market or for research, none of them includes multisensory information sources as the ones targeted by the MOTO project.</p> <p>MOTO project aimed to improve the concept of multimodal Remote Tower platforms enhanced by considering all human senses in remote control towers from the perspective of embodied cognition, with the goal of augmenting the human-system interaction with multimodal technologies.</p>
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	Partial – Non Blocking	<p>The impact of the multimodal stimuli in RTO has been analysed and encouraging results have been found (see D4.2 [7]). Outcomes from the first validation, executed in a realistic remote tower environment (supported by VR technology) suggested that ATCOs awareness and workload could be improve by using the multimodal feedback and enhancing the sense of presence through the integration of the visual channel with one sensory modality at a time (either audio or haptic)</p> <p>A selection of the proposed multimodal solutions have been tested in a realistic remote tower platform in the second streams of work (see D4.3[11]). Results showed an advantage in terms of performance for the spatialized auditory warning and for the vibration feedback (ATCO showed faster reaction times in detecting abnormal situation such as an unauthorized clearance in the apron area or an on-going runway incursion). However, further studies are</p>

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			recommended to verify that performance benefits could be extended to the whole set of proposed solutions.
TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.	Achieved	The following main limitations have been identified during the second validation: <ul style="list-style-type: none"> ▪ The Multiple Remote Tower setting was not completely integrated in the platform. This likely prevented to identify clear advantages in the multiple tower scenario under evaluation. ▪ The participants lacked familiarity with the augmented solutions concept that were tested. These aspects need to be carefully consider in the interpretation of the results linked to the augmented solutions.
TRL-1.4	Has the concept/technology under research defined, described, analysed and reported?	Achieved	The augmented remote tower concepts were identified literature review and experts' advice. MOTO augmented concepts and prototypes design activities and implementations were reported D3.3 [10]. The outcomes of augmented remote tower platforms and the description of the validation activity are described in D4.3 [11].
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Partial – Non Blocking	MOTO project contributed to the remotely provision of ATS Operational Improvements (OIs) in single and multiple remote tower scenarios (see MAT for the detailed OI). The outcomes highlight specific outcomes and recommendations for augmented remote towers platforms implementations.





			However, augmented remote tower platforms still require further investigation.
TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	Achieved	<p>MOTO showed that providing the RTO with multimodal support may enhance the ATCO performance in managing traffic remotely in a low/medium density airport. This finding has been verified according to an incremental approach; in a VR environment replicating a realistic remote tower and successively in a RTO platform, in both single and multiple remote tower scenario.</p> <p>Particularly, WP2 and WP3 outcomes identified technical requirements of realistic multisensory remote tower platforms for image sound and vibration acquisition and reproduction. Within the WP3 and WP4 activities MOTO delivered a set of prototypes augmented multimodal solutions to support ATCO in remote tower and multiple remote tower environment.</p> <p>A list of augmented remote tower platform implementation recommendations. A set of exploratory concepts augmented multiple remote tower has been proposed but the outcomes of the set of design activities was not formally validated. Further investigation must be performed concerning this part of the work. This part of the work is documented in D3.3 [10].</p>
TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	Not applicable	
TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential	Achieved	<p><u>Strengths:</u></p> <ul style="list-style-type: none"> ▪ MOTO project shown evidences that providing a RTO with multimodal support may enhance the ATCO performance in managing traffic remotely in a low density airport.





	<p>benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.</p>		<p>The combination of sensorial modalities which improve human performance in RTO was identified during the validation experiments. Particularly, ATCOs performance could be enhanced by integrating visual channel with one sensory modality at a time (either audio or haptic). Workload assessment showed that by integrating only Audio channel to the Video one induced a decreasing in ATCO' experienced workload.</p> <ul style="list-style-type: none"> ▪ ATCO reported faster reaction time in detecting abnormal situation such as an unauthorized clearance in the apron area or an on-going runway incursion (in this latter a vibration feedback was reinforced by an auditory spatialized warning). <p><u>Limitations:</u></p> <ul style="list-style-type: none"> ▪ Results also showed that workload experienced by the ATCOs was significantly higher when audio and vibrotactile stimuli were provided at the same time, becoming more distracting than of helping. Of course, it has to be stressed that these are just possible explanations of why the workload was higher if the augmented solutions were activated. Further research and human-in-the-loop simulations should be performed on the impact of augmented solutions for single/multiple remote towers. ▪ The participants lacked familiarity with the augmented tower environment and the sensorial enriched environment. This impacted the obtained workload of ATCOs and the perceived benefits of the augmented prototypes. To compensate, future studies should include a longer training phase training in order to compensate the fact that ATCOs are not really familiar with audio and vibrotactile feedback in the operational environment. ▪ The Multiple Remote Tower operational setting was not fully investigated. Due to limiting time constraints the multiple remote tower setting in the platform had some limitations, namely: the secondary airport in the Multiple
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			Remote Tower condition did not include a ground radar and the out of the window view was provided in an extra screen that was not connected to the primary one.
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	Achieved	The scientific activities carried out in the project have been reported and disseminate in papers and conferences (see Chapter 5.3).
TRL-1.10	Have the research hypothesis been formulated and documented?	Achieved	<p>The MOTO main research hypothesis (namely, to explore the potential benefit of the use of multimodal feedback in the remote tower operational environment) was documented in the first project deliverables (see D1.1[2] and D1.2[3]). In line with the proposed research hypothesis, a gap analysis has been conducted in D1.2 in order to investigate the existing needs in the current state-of-the-art in Remote Towers Control. None of them includes multisensory information sources as the ones targeted by the MOTO project.</p> <p>Potential benefits of the implementation in a RTO of multimodal feedback have been tested during the WP4 activities, in two validation campaigns: the first validation executed in a VR environment and the second validation where multimodal augmented solutions were tested in single and multiple remote tower scenario. The results are documented respectively in D4.2[7] and D4.3 [11].</p>





<p>TRL-1.11</p>	<p>Is there further scientific research possible and necessary in the future?</p>	<p>Achieved</p>	<p>Further work concerning augmented multisensory prototypes and exploratory concepts for remote tower platforms:</p> <ul style="list-style-type: none"> ▪ Further R&D steps should consider a multiple remote tower platform where the interface and tools are fully integrated into realistic platform (including EFPS, surface radars, air radar and airport outside view visualization switching interface). ▪ Future activities should test the augmented multisensory prototypes as stand-alone tool (due to time constrains in the second validation they were tested integrated in two of four experimental conditions, namely Single Augmented Remote Tower condition-SART; Multiple Augmented Remote Tower condition- MART). This should allow to further discriminate the qualitative/quantitative evidences of each concept. ▪ Further human-in-the-loop simulations in a realistic environment (e.g. medium density aerodrome; contingency scenarios). ▪ Trials in operations. <p>Further work concerning neuro-physiological classifiers in order to make them easily usable in operations.</p> <ul style="list-style-type: none"> ▪ Sensors should be simplified: less invasive and more portable and easy to use caps (e.g. dry sensors).
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			<ul style="list-style-type: none"> Scalability of sensors complexity according to the level of detail of the needed information should be investigated. <p>The VR tower platform may help to further explore the impact on ATCO of the innovative multimodal feedback for control tower looking at potential impact on training needs and personnel selection for remote provision of air traffic service for single and multiple aerodromes.</p>
TRL-1.12	Are stakeholder's interested about the technology (customer, funding source, etc.)?	Achieved	<p>The following stakeholders, mainly from the ATM industry, shown interest at different level for the outcomes of MOTO project.</p> <p><u>ATM industry:</u></p> <ul style="list-style-type: none"> AEROPORT De PARIS Ingénierie HUNGARO CONTROL SEARIDGE TECHNOLOGIES, Inc.: expressed interest in the results. AIRBUS GROUP: interest in the results & in applying the MOTO approach to other aviation segments, e.g. multimodal interaction in cockpit, or ground stations for RPAS IDS - Ingegneria Dei Sistemi with which DBL is currently developing a standardized HMI for RPAS ground station ALENIA (IT), THALES ITALIA (IT), CIRA (IT), NATS (UK), HANGZHOU UNIVERSITY AND AVIATION SCHOOL (CHINA): interest in real-time monitoring of the ATCOs' state via developing neurophysiological indicators.



4 Conclusion and Lessons Learned

4.1 Conclusions

MOTO project explored the concept of the Remote Tower platforms enhanced by considering human performance in control towers from the perspective of “embodied cognition”, with the goal of augmenting the human-system interaction using multimodal feedback.

Not only considered single tower operational scenarios but also looked at how augmented multimodal feedback could contribute to improve human performance in multiple remote Tower scenarios.

The outcomes revealed that of multimodal technologies integrated in remote tower platforms are promising feature to maintain/improve a good situation awareness and attention levels, by partially off-loading the visual channel and relying on other sensory channels (i.e. audio or haptic feedback) for monitoring out-of-the-current-view airports. MOTO project was a starting point to consider these aspects but further research must be carried out in order to better understand the real operational impact of enriching the sensorial feedback from the airport during operations.

The first stream of work performed in MOTO, ‘**Realistic Remote Tower**’, was explored through the **virtual reality platform** using the HTC Vive Head Mounted Display (instead of the Virtual CAVE platform initially considered in the project proposal). The virtual setting reproduced a realistic virtual tower, allowing via HMD a better “immersion” into virtual TWR environment of professional ATCOs.

The outcomes of this stream of work showed that ATCOs performance could be enhanced by integrating visual channel with one sensory modality at a time (either audio or haptic). In line with this finding, workload assessment showed that by integrating only Audio channel to the Video one induced a decreasing in ATCO’ experienced workload.

However, attention should pay to not “overload” ATCOs providing visual and both Audio and Vibrotactile stimuli. Results seem to suggest that the full combination may induce a degradation of performance, likely due to distracting stimuli contribution that is higher than their informative content. Finally, results suggest that in the ‘Visual + Auditory’ condition ATCOs sense of presence was improved, consistently with performance and workload improvement. These results are detailed in D4.2 (First Validation Report) [7].

The second stream of work, ‘**Augmented Remote Tower**’, exploited the possibilities offered by the multimodal stimuli, translating them into a technologies to enhance human performance, for instance by augmenting perception. The second step involved a rethinking of how control tower activities currently take place, for instance by exploiting the haptic and sound channel to give awareness of a second airport, to be managed in parallel to the one currently controlled (via sight).

A set of **augmented multimodal Remote Tower concepts** (TRL2) were designed and a subset were actually tested during the second MOTO validation providing an initial insight of the potential benefits in terms of performance. The augmented multimodal concepts validated in the second MOTO validation showed performance advantage using a spatialized auditory warning: ATCO reported faster reaction time in detecting abnormal situation such as an unauthorized clearance in the apron or an on-

going runway incursion (in this latter a vibration feedback was reinforced by an auditory spatialized warning). However, both subjective and neurophysiological results suggested an increase of experienced workload if augmented solutions were activated. Such perception could also be attributed to the fact that ATCOs needed a longer familiarization process with a more enriched sensorial environment for tower operations, since they are usually used to work only with information provided by the visual sensory channel.

Further studies are then recommended to verify that performance benefits could be extended to the whole set of proposed solutions.

A set of **exploratory concepts for multimodal multiple Remote Tower** featured by augmented interactions have been also defined at lower TRL1. These concepts derived by the study of the range of possible multimodal interactions and their association to a simple “meaning”. The output of this process was a wide assortment of simple augmented interactions. With the operational expert support, human-machine interaction, uses cases and envisaged benefits and drawback. These concept are described in detail in D3.3 [10].

A dedicated website is currently being produced to present the exploratory concepts developed for augmented multimodal remote tower. The aim, human-machine interaction modality and the envisaged benefits of the augmented concepts are demonstrated alongside their graphical representation. The website will also be used to collect further feedback on the presented exploratory concepts. The website the following: www.moto.dblue.it.

Another outcome of the project was the **neurophysiological classifiers were developed to monitor cognitive workload and sense of presence**. These classifiers were used in both validation experiments to measure the impact of a new environment on ATCOs mental states during the execution of air traffic control tasks, in a simulation environment reproducing the complexity of future scenarios and highly automated systems able to carry out decision making and action implementation tasks.

The Sense of Presence Index was explored more into detailed during the first validation. This index is intended as an objective measure of the sense of presence in an immersive remote environment (in this case also virtual). The index was quantified from the possible modulations of the GSR responses induced by an emotionally salient virtual context in RTO environment, and results from GSR and EEG were consistent along the whole activity.

These classifiers are a very relevant contribution to monitor training needs and validate innovative operational tools and environments in ATM.

Finally, it can be concluded that MOTO outcomes in terms of requirements and solutions for multimodal Remote Towers represents a good first step to integrate “realistic” multimodal feedback in current industrial solutions and to drive further R&D activities.

The project limited duration proved to be a limitation for the second stream of activity. This part of the work represents an initial contribution to the ‘Augmented Remote Tower’ topic and that needs to be further investigated. Some limitations have been identified mainly referring to the second validation:

- The Multiple Remote Tower setting was not completely integrated in the platform. This likely prevented to identify clear advantages in the multiple tower scenario under evaluation.
- The participants lacked familiarity with the augmented solutions concept that were tested.

The previously mentioned aspects need to be carefully considered in the interpretation of the results and likely prevented to obtain clear advantage in terms of human performance for the whole set of the solutions under evaluation.

4.2 Technical Lessons Learned

In the baseline measurements, visual, acoustic and vibrotactile information generated from airport environment have been recorded from real air traffic control towers. Vibrations and sounds signals have been recorded from the perceptual space where air traffic controllers are working in. It is expected that sixty different instances of the target operational scenarios will be recorded, in order to achieve representativeness of the various operating conditions and to be able to reproduce them with the required high fidelity level required for the experimental environment.

The technical lessons learnt during the augmented remote tower validation experiment were the following:

A multimodal Remote Tower platform aiming at providing a realistic sound rendering shall privilege either a high-quality set of speakers with high bandwidth and system 3D capable. The feedback received ATCOs during the first pilot exercise showed that poor audio installation (not accurate 3D audio rendering) can cause fatigue since the perception of the origin of the sound does not correspond to the actual position of the aircraft. During the second validation exercise the audio feedback was more accurate, therefore better accepted by ATCOs.

The haptic rendering shall privilege high quality vibrotactile sound transducers. Two different types of devices are available to reproduce vibration. Shakers creates vibrations by moving a mass like in mobile phones, while tactile sound transducers use “linear actuators” like speakers. The amplitude of the signal which can be produced is dependent of the technology used, and is higher with tactile sound transducers. The quality of the used transducers impacts on the ATCOs acceptability of technologies.

4.3 Recommendations for future R&D activities (Next steps)

Further research is recommended to achieve two main purposes, to increase the TRL level of the augmented prototypes and concepts and to increase the TRL of the neurophysiological classifiers.

1. **Increase the TRL of the augmented multisensory prototypes and exploratory concepts for remote tower platforms** in order to deploy them in operations.

Further work needed to reach Industrial Research & Validation (TRL 2-6):



- Further R&D steps should consider a multiple remote tower platform where the interface and tools are fully integrated into realistic platform (including EFPS, surface radars, air radar and airport outside view visualization switching interface).
 - Future activities should test the augmented multisensory prototypes as stand-alone tool (due to time constraints in the second validation they were tested integrated in two of four experimental conditions, namely Single Augmented Remote Tower condition-SART; Multiple Augmented Remote Tower condition- MART). This should allow to further discriminate the qualitative/quantitative evidences of each concept.
 - Further human-in-the-loop simulations in a realistic environment (e.g. medium density aerodrome; contingency scenarios).
 - Trials in operations.
2. **Increase the TRL of the neuro-physiological classifiers** in order to make them easily usable in operations. Further carry out in Industrial Research & Validation (TRL 2-6):
- Sensors should be simplified: less invasive and more portable and easy to use caps (e.g. dry sensors).
 - Scalability of sensors complexity according to the level of detail of the needed information should be investigated.

Finally, future R&D activities should investigate the impact on ATCO of the innovative multimodal feedback for control tower looking at potential impact on training needs and personnel selection for remote provision of air traffic service for single and multiple aerodromes.

5 References

5.1 Project Deliverables

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5.3 Project Publications

Authors	Title	Journal
Matteo Marucci , Viviana Betti, Piero Aricò , Gianluca Borghini , Gianluca Di Flumeri , Nicolina Sciaraffa , Fabio Babiloni , Enea F. Pavone	Towards immersive and multisensory remote operations: a virtual reality and EEG study	Publication in Conference proceedings of XXV Congresso della Società Italiana di Psicofisiologia e Neuroscienze Cognitive 2017.
Rosa De Piano, Ana Ferreira, Michela Terenzi, Simone Pozzi, Pietro Aricò, Gianluca Borghini, Gianluca Di Flumeri, Nicolina Sciaraffa, Fabio Babiloni, Matteo Marrucci, Viviana Betti, Enea Pavone, Salvatore Maria Aglioti, Christophe Hurter, Railane Benhacène, Charles Clercq, Maxime Reynal, Alexandru Telea and Han Kruijger	Virtual Reality platform to assess air traffic controllers' performance in Control Tower Operations	Publication in Conference proceedings/Workshop. 23rd International Conference on Virtual Systems and Multimedia. 2017.
Pietro Arico, Maxime Reynal, Jean-Paul Imbert, Christophe Hurter, Gianluca Borghini, Gianluca Di Flumeri, Nicolina Sciaraffa, Antonio Di Florio, Michela Terenzi, Ana Ferreira, simone pozzi, Viviana Betti, Marucci Matteo, Enea Pavone, Alexandru C. Telea, Fabio Babiloni	Human-Machine Interaction Assessment by Neurophysiological Measures: A Study on Professional Air Traffic Controllers	Accepted for presentation at 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2017.

Project related publications

Authors	Title	Journal
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Jose Matute, Alexandru C. Telea, Lars Linsen	Skeleton-based Scagnostics	IEEE Transactions on Visualization and Computer Graphic. 10772626. 2017
Lhuillier, C. Hurter, A. Telea	State of the Art in Edge and Trail Bundling Techniques	Computer Graphics Forum, vol. 36, no. 3, pages 619-645. 2017.
J. Kruiger, C. Hurter, A. Telea	Projection Navigation in Extremely Large Datasets (PNIELD)	Proceedings of the EuroVis 2017 conference on data visualization (12-16 June 2017, Barcelona), editors A. Puig and T. Isenberg
R. Martins, J. Kruiger, R. Minghim, A. Telea, A. Kerren	MVN-Reduce: Dimensionality Reduction for the Visual Analysis of Multivariate Networks	Proceedings of the EuroVis 2017 conference on data visualization (12-16 June 2017, Barcelona), editors B. Kozlikova, T. Schreck, T. Wischgoll)
J. Kruiger, R. Martins, A. Kerren, S. Kobourov, A. Telea	Graph Layouts by t-SNE	Computer Graphics Forum, vol. 36, no. 3, pages 943-955, DOI: 10.1111/cgf.13187
Christophe Hurter, Stephane Puechmorel, Florence Nicol, Alexandru Telea	Functional Decomposition for Bundled Simplification of Trail Sets	IEEE Transactions on Visualization and Computer Graphics. 2017.
Johannes Kruiger, Almoctar Hassoumi, Hans-Jörg Schulz, AlexandruC Telea, Christophe Hurter	Multidimensional Data Exploration by Explicitly Controlled Animation	Informatics. 4/3. 22279709. 2017.
Nicolina Sciaraffa, Gianluca Borghini, Pietro Aricò, Gianluca Di Flumeri, Alfredo Colosimo, Anastasios Bezerianos, Nitish Thakor, Fabio Babiloni	Brain Interaction during Cooperation: Evaluating Local Properties of Multiple-Brain Network	Article in Journal Brain Sciences. Multidisciplinary Digital Publishing Institute (MDPI)
Pietro Arico, Gianluca Borghini, Gianluca Di Flumeri, Nicolina Sciaraffa, Alfredo Colosimo, Fabio Babiloni	Passive BCI in Operational Environments: Insights, Recent Advances, and Future Trends	Article in Journal IEEE Transactions on Biomedical Engineering. ISSN: 00189294. 2017.
Nicolina Sciaraffa, Gianluca Borghini, Pietro Arico, Gianluca Di Flumeri, Jlenia Toppi, Alfredo Colosimo, Anastatios	How the workload impacts on cognitive cooperation: A pilot study	Publication in Conference proceedings 39th Annual International Conference of the IEEE Engineering in



Bezerianos, Nitish V. Thakor, Fabio Babiloni		Medicine and Biology Society (EMBC). 2017
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Appendix A

A.1 Acronym List

Term	Definition
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Services
CAVE	Cave Automatic Virtual Environment
CWP	Controller Working Position
EEG	Electroencephalogram
GSR	Galvanic Skin Response
HF	Human Factors
HMD	Head Mounted Display
HP	Human Performance
OI	Operational Improvement
PMP	Project Management Plan
PFC	Pre-frontal Cortex
PPC	Posterior Parietal Cortex
R&D	Research & Development
RT	Remote Tower
RTO	Remote Tower Operations
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking
SWLDA	StepWise Linear Discriminant Analysis
SME	Subject Matter Expert

TWR	Tower
TRL	Technology Readiness Level
VR	Virtual Reality
VA	Visual and audio experimental condition
VAV	Visual, audio and vibrotactile experimental condition
VR	Virtual Reality
VV	Visual and vibrotactile experimental condition

Table 7. Acronym list

