ATTENTION GUIDANCE PROTOTYPE FOR A SECTORLESS AIR TRAFFIC MANAGEMENT CONTROLLER WORKING POSITION

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Abstract

Facing flight centred air traffic control (ATC) and more monitoring tasks at future controller working positions (CWP), it becomes even more important that air traffic controllers (ATCo) always focus their attention at the relevant spots on their human machine interface (HMI). This paper outlines relevant literature about attention and attention guidance (AG) in different domains, explains the concept for an AG prototype for sectorless air traffic management (ATM) and the plan for its validation in the course of Single European Sky ATM Research (PJ.16-04-03, SESAR2020). The AG prototype considers three aspects. First, the desired area of attention: An assistance system calculates where the ATCo should look at depending on input data like radar and flight plan data. Second, an external system relying on eye tracking and user inputs determines where the current ATCo focus is. Third, if the desired and the actual area of attention are not the same, mechanisms to guide the ATCo's attention will be triggered taking a strategy of escalating visual cues into account. The latter comprises an intelligent display of action indicators with respect to time, position and appearance as well as pre-tactical inattention indicators. The AG prototype aims to increase controller productivity, improve situation awareness as well as reduce workload and stress level in a future flight centred ATC environment.

1. INTRODUCTION

Guiding air traffic controllers' attention can influence a number of key performance indicators in a positive way. An AG system should increase controller productivity, comprising improved situation awareness as well as reduced workload and stress level. The air traffic controller (ATCo) is a key factor to guarantee safe and efficient air traffic [1]. Currently ATCos are actively involved in communicating with aircraft pilots. However, the future role of an ATCo in air traffic control (ATC) will change [2].

Two examples of such changes are the increasing degree of automation and new air traffic management (ATM) concepts. First, ATCos will predominantly monitor traffic and intervene in seldom cases instead of actively guiding each flight through an airspace, which could lead to decreased situation awareness and vigilance. Second, the concept of sectorless ATM respectively Flight Centric/Centred ATC induces a different paradigm on how ATCos need to control air traffic. This goes along with a different type of shared situational awareness between controllers. Nowadays critically opponent flights often belong to the same airspace sector and thus the same responsible ATCo. When not being responsible for sectors anymore but for flights, the necessary awareness and actions have to adapt.

Despite these future modifications, it will still be important for safety, efficiency, and environmental friendliness that air traffic actions are performed in a timely and spatially accurate manner. Furthermore, the ATCo will remain as the final decision authority at a controller working position (CWP) by using the relevant human machine interface (HMI) functionalities mainly connected to a situation data display (SDD). If it is assumed that the ATCo's visual attention is, where he/she is currently looking at, this offers possibilities to detect and moreover influence his/her focus of attention.

Current CWP HMIs mostly offer discrete support actions such as the visualization of information in form of text and colours on a display or a beep tone depending on a certain trigger [3]. However, those triggers do hardly take the dynamic air traffic situation as a whole into account but mostly activate a display function whenever the corresponding event (e.g. a conflict) is active. Beyond that, dynamic psychophysiological measures are even further away from being considered in operational CWP HMIs.

Eye tracking is considered as a psychophysiological measure that could be beneficial as it is non-intrusive, lightweight, cheap, and has potential for different use cases in ATC. If an ATCo watches two possibly conflicting aircraft multiple times in a row in the last seconds, it may not make sense to bother the ATCo with highlighting those aircraft and presenting a warning. However, if an ATCo did not visually check a specific area of the SDD for a certain amount of time, it might be good to guide the ATCo's attention to this area to support him/her not to miss an incoming aircraft from an adjacent sector.

If the ATCo currently solves a short-term conflict, there should be no visual or auditory elements in the foreground for less prioritized tasks like reminding of a top of descent. In particular with respect to sectorless ATM there is the challenge to have the attention at the right spot when monitoring the whole SDD. The SDD shows e.g. the complete Hungarian airspace, however only concentrating on a limited number of its aircraft. All of those aspects are considered in DLR's SESAR2020 Wave 1 PJ.16-04-03 "CWP HMI – Controller Productivity" [4]: development of an Attention Guidance (AG) prototype for controllers. This prototype will be integrated and investigated in the sectorless ATM environment of PJ.10-01b [5].

The presented AG prototype regards three basic questions: 1. desired attention: "Where should the ATCo currently look at?"; 2. actual attention: "Where is the ATCo currently looking at?"; 3. attention guidance: "Is there a mismatch between the answers on questions 1 and 2, so that the ATCo's attention needs to be moved to the spot needed?". The desired area of attention is determined by an assistance system such as an arrival, departure, or en-route manager. This system may take into account radar, flight plan, and weather data. The assistance system considers e.g. potential conflicts, long absence of attention in a certain area, or demanded controller actions. The actual attention is measured via a monitor-mounted eye tracking system that provides the current spots of the HMI the ATCo's gaze focusses. In addition, mouse clicks and keyboard strokes are taken into account when determining the current attention. The attention guidance system then encompasses different escalation levels of AG HMI elements and the corresponding trigger mechanisms. It is no re-invention or improvement of existing short- or medium-term conflict alerts.

This paper outlines related work in the relevant fields for the AG prototype in sectorless ATM in section 2. Section 3 presents the AG concept for the implementation of the AG prototype that is described in section 4. The setup for the validation exercise is presented in section 5 followed by conclusions and a summary in section 6.

2. RELATED WORK ON ATTENTION, ITS GUIDANCE AND FLIGHT CENTRED ATC

In order to provide effective attention guidance in highly complex operational environments such as sectorless ATM, it is important to consider the underlying mechanisms of attention and its interdependencies with other cognitive aspects as well as to explain the theoretical framework for the concept of AG in the following.

2.1. Attention

Attention can be viewed as a filter to the environment, that narrows down to decrease irrelevant input, and sometimes it broadens to take in parallel streams of environmental information for example for integration or multi-tasking [6]. The effective breadth of the filter depends on a variety of factors: our senses, more exactly, by their perceptual limits (e.g. foveal vision), task demands, the differences and similarities between stimulus channels. Also the strategies the human operator applies and his understanding of the situation impacts subsequent attention processes.

Of course the physiological state and circadian rhythm may impact the human operator's attention as well. The effects that "attention" causes at a human (operator) are perceiving, conceiving, distinguishing, remembering, and shortened 'reaction-time' [7].

2.1.1. Attention Models

One of the most recognized attention models is Broadbent's "Filter Model" [8] . Information from all of the stimuli presented at any given time enters a sensory buffer. However, only one of these entering inputs is then selected on the basis of its physical characteristics for further processing and is allowed to pass through a "selective filter" which prevents that the information processing system (i.e. the human's brain) becomes overloaded. Based upon Broadbent's "Filter Model" Treisman (1964) postulated a filter, that rather attenuates unattended material than eliminating or filtering it out [9]. After passing the "attenuation filter" the meaning of the extracted information is passed to the short term memory, ready for further processing. Treisman agreed with Broadbent that there was a "bottleneck" (filter), but disagreed that information is completely filtered out.

It is important to note, that the limited attentional resources due to the "bottleneck filter" present a major limit on situation awareness. According to Endsley [10], situation awareness (SA) is defined as "the perception of the elements in an environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the future". SA is very important to continuously maintain an overview in a highly complex task environment such as air traffic control. Because the supply of attention appears to be limited, improvements in SA on some elements may mean decrements in SA on others once the limit is reached. This limit may occur rather quickly in complex environments [11]. Considering the latter, attention guidance may be a promising measure which can help the human operator to free additional attention resources and to perceive more relevant elements within the environment. Altogether, this may result in improved situation awareness. The following section focusses on the aspect of visual attention, which is viewed as the most prominent modality for human attention processes and for the proposed attention guidance system.

2.1.2. Visual Attention

As the envisioned AG system primarily incorporates the guidance of the controller's visual attention, this paper focuses on attention processes related to this modality. Within the air traffic control environment, visual attention is engaged in several activities which are according to Wickens [6] as follows:

1) General Orientation and Scanning: e.g. ATCo looks at the radar screen (both undirected and goal-directed).
2) Supervisory Control: e.g. scan path of an ATCo's eyes on a radar screen, assuring that certain dynamic variables are within bounds. This task is highly goal directed.
3) Noticing: involves monitoring and responding to unexpected events (e.g. ATC emergency).

4) Searching: e.g. predefined targets such as aircraft that are about to receive a clearance.
5) Reading information: e.g. flight data within aircraft label.
6) Confirming: some control action has been carried out, e.g. input into electronic flight strips or smart radar label.

Many of the activities related to visual attention involve combinations of different activities, as for instance “searching and reading” or “orientation, monitoring and noticing”. Within our proposed AG system particularly the activity “noticing” plays a very important role. Certain physical characteristics of visual stimuli (e.g. motion or flashy colour) are easier to notice respectively to detect and facilitate the attentional capture than visual stimuli that do not change its physical properties strikingly.

However, the opposite may be the case when operators are under high task load and are engaged in attention-demanding tasks or when the stimuli are presented outside the center of fixation. The greater the visual angle between location of the change and the fovea (center of fixation), the less likely the change will be detected. Also the salience of a stimulus is a contributing factor to the capture of attention, e.g. alerts or warnings presented are more likely to be attended by the ATCo than non-salient information as for instance flight level changes within an aircraft label [6]. Those aspects for visual stimuli are also taken into account for the AG.

2.2. Theoretical Framework for Attention Guidance

The following subchapters provide empirical findings and theoretical considerations for our proposed AG system. A particular focus is put on cueing of attention, which is an important aspect of how an operator’s attention can be directed. Another aspect that is considered relevant for the design of the AG system relates to the concept of areas of interests (AOIs).

2.2.1. Cueing of Attention

Attention Guidance is typically performed by some kind of automation in which an intelligent assistance system assumes that the human operator should be informed of the location of a critical event [6]. This is also called “cueing of attention”. Cueing of attention frees some of the attentional resources for the perception of the target stimulus (e.g. an aircraft that has not been looked at for a certain time period), and those resources can be used to detect other targets or may be used for other tasks like decision making [6].

In dynamically changing and data-rich environments, the observer’s attention (here: the ATCo’s attention) needs to be guided to select a target that is relevant for the observer’s goals. Stimulus-driven factors can guide attention automatically for instance when an unexpected object suddenly appears, e.g. flashy colour of an alert indicating the necessity to direct attention to it. This can draw attention without the observer intending it. This stimulus-driven attention, also referred to as *exogenous cueing*, is based on the physical properties of the stimulus. Little higher cognitive processing in terms of voluntary perception, decision making and execution, is necessary in order to decide whether to attend the stimuli or not. In contrast to that, the attention can also be guided in a top-down manner, i.e. attention is goal driven. In this case the ATCo made an internal decision to attend to a stimulus beforehand (e.g. the ATCo is informed by another ATCo that an aircraft is about to be handed over thus plans in advance to focus on that particular aircraft).

This is called *endogenous cueing* of attention where the observer’s attention is guided by information held in his working memory. Jonides et al. [12] could show that endogenous attention cueing was slower than exogenous cueing. Studies on exogenous vs. endogenous attention cueing showed that guiding the attention to a target can be highly reflexive and fast, but only if the accuracy of the cues is perceived as high and reliable by the human [13]. This is an important implication when designing an AG system. With respect to the design of an AG system, three aspects of attention cueing have to be considered: the absolute threshold of stimulus detection, the cue location, and its reliability.

2.2.1.1. Absolute Threshold of Stimulus Detection

The type of stimuli (visual, auditory, haptic) and its features that have to be detected by the human operator can have a significant effect on attention guidance. Therefore, one essential factor is the absolute threshold of stimulus detection. The absolute threshold describes the minimum stimulus energy which is necessary in order to be detected [14]. If the stimulus is below that threshold, the operator will not detect the signal. Our proposed AG system targets at the design of visual HMI elements which reach the absolute threshold so that the ATCo is able to detect the attention guidance stimuli as fast and accurate but as less disturbing as possible.

2.2.1.2. Cue Location

The cue location, whether it is placed in the center of fixation or outside of it, is another important consideration. A *central cue* is positioned at or near the center of fixation (foveal vision) and is often presented as an arrow pointing in the direction of the target stimulus, e.g. an aircraft on the radar screen. A *peripheral cue* is usually placed at the target location and away from the center of fixation. It might be represented as a cone shaped flash light [6].

There are important differences between these two types of cues: central cues as for instance a pointing arrow are mainly cognitively driven, which means that the spatial orientation of the central cue has to be identified at first, followed by the target stimulus detection. This implies a little bit longer stimulus processing times, meaning central cues have to be presented earlier. Central cues are beneficial when they are correct, but produce information processing costs when they are wrong [6].

In contrast, peripheral cues seem to be more perceptually driven and are more or less automatically processed in orienting the person’s attention toward the location of their position. People tend to react faster on peripheral cues, which can be sometimes counterproductive when the target stimulus does not indicate the correct position.

The difference between peripheral and central cue is relevant when attentional guidance is developed for professional environments (e.g. guiding the ATCo's attention to a potential conflict aircraft). In this case, a central cue is placed near the "typical focus of fixation" (e.g. forward view). Peripheral cues also have some costs, if they are too far outside the fovea, i.e. too far in the visual periphery beyond 90 degrees of visual degree regardless how intense (big or bright) they are. Wickens and Rose [15] suggest making peripheral cues more salient such as using multiple onsets (flashing) rather than single onsets. Another issue with peripheral cues regards the masking of information that is non-salient but could be important. Central cues (e.g. arrows) are barely affected by masking, since they are separated from the target [6]. But central cues are less precise in designating target location and require more information processing (Yeh, Wickens, & Seagull, 1999 in [6]).

2.2.1.3. Cue Reliability

Cue reliability has several implications for human performance that have to be taken into account: if the cue is wrong and the person does not find anything displayed or an incorrect target, the person looks elsewhere in the future but using the aid. This may finally result in disuse of the AG system [6]. If the attention guidance system is nearly perfect (towards 100 percent reliability), the phenomenon of automation over-trust arises, i.e. the risk that the human operator insufficiently pays attention to automation output. This can lead to potentially dangerous situation because the automation is viewed as reliable although it is not.

Another side effect that can come along with increased reliability of spatial cueing is attentional tunneling [6]. This occurs when the cues correctly indicate the location of an important target and the person's automation trust rises. Then it may happen that the person neglects other areas outside the "cue target area". The observer neglects these other areas in case of attentional tunneling although they may sometimes contain critical information (Yeh et al., 2003 in [6]). Attentional guidance through cueing is closely related to the issues of highlighting. The highlighting placed on a subset of objects/items usually inferred by an agent (assistance system) may sometimes be erroneous and lead to degrading search of the human operator [6].

2.2.2. Areas of Interests

Within the framework of the proposed AG concept, the simplified assumption is made that the gaze fixations represent the current area of visual attention. Gaze fixations, in turn, are related to the concept of "areas of interests" (AOI). AOIs are a helpful concept for the determination of visual attention in control tasks as for instance monitoring aircraft on the radar screen.

An AOI is a physical location within a defined visual workspace such as the radar screen where task-specific information can be found (e.g. flight data within radar label) [6]. AOIs are used to link eye-movement measures such as gaze fixations to parts of the stimulus used (e.g. time spent looking at a particular aircraft within the radar screen) or in contrast identify whether an ATCo has not checked a relevant aircraft within an AOI for a certain period of time. Thus, AOIs can be used in order to assess visual attention or its absence. This is done within our proposed AG concept by means of an eye tracking system.

2.2.3. Guiding Attention

Some European projects already handled aspects of attention guidance. The SESAR2020 exploratory research project *Mitigating Negative Impacts of Monitoring high levels of Automation* (MINIMA) dealt with a vigilance and attention controller (VAC) to mitigate negative impacts of high automation [16]. The VAC used electroencephalography (EEG) and eye tracking (ET) data as input to enable and disable activation tasks for the controller [17]. Hence, it could be seen as adaptively automated functionalities. In case of high vigilance, ATCos could use a high degree of automation. In case of low vigilance, ATCos needed to perform more tasks to not suffer from any out-of-the-loop (OOTL) phenomenon [18].

The SESAR1 WP-E project *Neurometrics INdicators for ATM* (NINA) considered neurophysiological measurements in order to distinguish between cognitive states. There were also some adaptive support functionalities with regards to information processing. The four adaptive functions that were used for validation included different amounts and designs of HMI alerts to adapt situation awareness in monitoring, a reduced visual HMI load in general and highlighting of communicating stations on the HMI by speech recognition [19].

2.2.4. Implications for the Attention Guidance Concept

Based up on the empirical findings, for the design of an attention guidance system that primarily addresses the visual modality the following theoretical considerations can briefly be summarized:

- Use of exogenous cues instead of endogenous cues, since they are processed faster and responses tend to be more accurate then to endogenous cues. However, only if exogenous cues are viewed as highly accurate and reliable.

- Use of peripheral cues which are typically placed right next to the target stimulus if the attention guidance system mainly triggers the support when the focus of the ATCo is not directed towards a target aircraft.

- Peripheral cues should be made salient enough using multiple onsets (flashing or radiant) rather than single onsets especially when they are too far in the visual periphery from the current fixation of the ATCo.

- If peripheral cues are used, there is potential risk of masking relevant targets which are not salient. Thus peripheral cues must not be made too intense so that they do not mask a non-salient target.

- Highlighting of targets should be done carefully and not be presented for too long as they might lead to attention tunneling and distract the ATCo from other relevant targets.

- Cue reliability should be as high as possible (close to 100 percent) in order to avoid disuse of the attention guidance system.

- Integration of both sensor data and model-based attention guidance to enhance reliability of the AG system. Thus avoiding “single point of failure design”. This is important when sensor data is not highly reliable or erroneous.

2.3. Flight Centred Air Traffic Control

Flight Centred ATC is a concept mainly for en-route traffic where controllers are no longer in charge of geographic sectors but are assigned individual aircraft anywhere in the airspace. Controllers are responsible for the assigned aircraft from their entry into the sectorless airspace until their exit. This also called “sectorless air traffic management” has been researched at the German Aerospace Center DLR in close cooperation with the German ANSP DFS Deutsche Flugsicherung GmbH (DFS) since 2008 [20]. Previous publications have investigated various aspects of the sectorless ATM concept: General feasibility of the concept for upper airspace was proven in 2011 [21]. The compatibility of sectorless ATM with SESAR has also been analysed and discussed [22].

The sectorless ATM concept is part of SESAR2020 under the name of Flight Centred ATC (PJ.10-01b) as described in the multi-annual work programme [23]. Further research covered a first set of priority rules [24], assignment strategies [25], the controller’s mental model [26], controller tasks [27], a safety net [28], a safety assessment [29], transition strategies [30], and colour schemata for the CWP [31]. A research report [32] summarizes DLR research on sectorless ATM between 2009 and 2014.

Validations have been run on DLR’s TrafficSim, an aircraft flight management system based simulator which is capable of fast-time and real-time simulations [21]. In real-time simulations, the simulator can be equipped with as many CWPs as needed; traffic which is not assigned to simulation controllers can be guided by the simulator. The design of the CWPs has been controversially discussed among experts and simulation participants. Initial CWP design supports a method of working where one controller is responsible for six aircraft at the same time. Therefore the CWP SDD comprises six different radar tiles – one per aircraft (see FIGURE 1).

However, for the first trials using the Hungarian airspace, it was decided to have just one conventional but huge radar tile to display the complete country’s air traffic. Hungary’s geography consists of a great east-west extension compared to the north-south dimension (see FIGURE 2). Thus, the horizontally broader monitor (than vertically) works fine. Furthermore, the size of the country makes it feasible to be displayed with a reasonable zoom factor. These aspects might not be true for other airspaces.

FIGURE 1. Sectorless Controller Working Position Prototype in the “Six Tiles” Design

FIGURE 2. Sectorless Controller Working Position Prototype in the “Complete Airspace” Design

Besides, there is a significant change especially in the weighting of typical controller tasks when comparing sectorless with sectorised air traffic management. In sectorised control, ATCos perform monitoring, conflict detection, radio telephony, conflict solution, clearances, and coordination [32]. In the sectorless environment much more time is used for planning because of higher levels of automation. Conflict detection and planning tools support controllers in their decisions [32]. For those reasons, the decision to have just one sectorless controller instead of a team of executive and planner [26] has been another topic of many discussions [28]. For the Hungarian airspace trials, there are single controllers responsible for a number of flights. A sufficient number of single controllers are responsible for the whole sectorless airspace in the end.

2.4. Attention Guidance embedded in SESAR

The attention guidance (AG) concept of this paper was developed connected to the work of SESAR2020’s PJ.16-04 solution that focuses on the Human Machine Interface (HMI) of the Controller Working Position (CWP). 23 partners from Europe representing the most important Air

Navigation Service Providers (ANSP) and ATM system providers as well as research, development, and consulting affiliations are part of PJ.16-04 solution. The solution comprises six different activities and develops amongst other things new user interface technologies such as automatic speech recognition, multi-touch inputs and attention guidance. It also derives requirements towards the operationalisation of those technologies in future operational CWPs.

The AG activity will be validated with two different exercises. Exercise 1 considers an AG prototype in a sectorless ATM environment (part of this paper) driven by DLR and supported by HungaroControl. Exercise 2 – driven by SKYSOFT-ATM and Skyguide – validates the improvement of medium term conflict alert forecast quality which is one of the input data for AG. A first screening and prototype ideas for AG designs and methods have been analysed before [33].

3. CONCEPT FOR ATTENTION GUIDANCE

As addition to the above described sectorless controller working position, an attention guidance concept was developed to ensure controllers' situational awareness as well as safe and efficient operation using the new ATM concept. This section will introduce the key features of the developed attention guidance concept. In general, it comprises of adequate visual stimuli in order to guide the operator's attention to the most important information on the radar screen (areas of interest), if the ATCo does not notice the relevant data initially.

For air traffic controllers, situations of high workload as well as situations of multiple warning messages and alerts on screen are quite common. In combination with the increased screen size that is applied for the sectorless controller working position, controllers might not perceive important information immediately. Therefore, the presented AG concept incorporates the introductory stated steps of evaluating the desired attentional focus of the controller (i.e. AOIs the controller should notice), the determination of his/her actual attentional focus and the resulting application of AG measures to reduce the gap in between.

As mentioned, the current area of the controller's attention will be detected by an eye tracking system. The captured eye tracking data is consecutively analysed together with information of the current air traffic situation (e.g. radar, flight plan, and airspace data, assistance data for conflict detection) by an algorithm that is called the trigger logic. When the trigger logic assesses the demand of an attention-shift, visual stimuli of various escalation levels can be displayed on the radar screen to direct the controller's attention to important information.

3.1. Attention Guidance Trigger Logic

The trigger logic reflects the core part of the concept, as it defines under which conditions the AG methods are needed and to which extent visual stimuli are generated. We divided the trigger logic into two hierarchical but interacting levels: the global and the local trigger logic.

Firstly, the global trigger logic prioritizes the currently active events, whereas the following events are considered: short and medium term conflict alerts (STCA and MTCA), emergencies indicated via squawk, conflicts with restricted airspaces and upcoming changes in controller responsibility for a given aircraft. These events will be computed by the sectorless CWP prototype and consecutively sent to the AG software. The prioritization algorithm then takes the importance of the event into account and performs a weighting between different events regarding time criticality (see TAB 1).

Furthermore, the expected need of attention guidance for the controller, i.e. the expected unawareness of the controller regarding respective event is influencing the priority. That means that although high importance and time criticalness of an exemplary event is given, the visual representation is not escalated if the controller has focused the respective area or aircraft label recently, i.e. has noticed the event already.

Importance	Event	Time Factor
Very High (5)	STCA	Estimated time remaining before minimum separation is violated
High (4)	Emergency Squawk	Immediate action
Medium (3)	Restricted Airspace Conflict	Estimated time remaining before reaching the minimal separation to the restricted airspace
Medium (3)	MTCA: No right of way	Estimated time remaining until STCA is triggered
Low (2)	MTCA: right of way	Estimated time remaining until STCA is triggered
Very Low (1)	Change in controller responsibi-lity	Assume: time to Top of Descent / next Conflict Resolution, Airspace Conflict / Handover Handover: Estimated time remaining before reaching the minimal separation to the neighbour airspace

TAB 1. Ranking of Events in the AG Concept

On the basis of the priority estimation, the global trigger logic decides which of the currently active events should be displayed on the radar screen or shall disappear. The local trigger logic then determines the appropriate escalation level on a per-event basis. For each display element, the priority and time of non-observance are considered. If the event-specific time threshold is exceeded, the escalation level is increased in order to attract the operator's attention quickly. If the eye tracking system detected the operator's focus on the considered element, the escalation level can be lowered to the first applicable escalation level.

3.2. Escalation Levels of Visual Cues

As mentioned above, the AG concept provides different escalation levels for each event. The attention guidance elements for the controller are different characteristics of action indicators. Starting with escalation level zero, the controller will be presented information about the event in the aircraft label. In higher escalation levels, additional attention guidance means will intensify the visual cue for the respecting event, e.g. displaying elements with higher degree of salience by colouring, flashing, or motion.

Furthermore, there are pre-tactical inattention indicators. This means that the ATCo did not look on an aircraft or area for a certain amount of time independent of any concrete upcoming necessary action. The inattention indicators use the same visual cues than the action indicators in escalations levels 2 and 3 as shown by FIGURE 3 to FIGURE 6. In the following, examples are given for some events and the respective action indicators considered by the AG concept.

3.2.1. Medium Term Conflict Alert (MTCA)

As a very common alert example, the medium term conflict alert is considered firstly. When the trajectory calculation detects a conflict within the medium term threshold for two aircraft, a yellow “MTC” is displayed in the label of the sectorless ATM base system without AG as indication to the controller (escalation level 0). As visible in FIGURE 3, the intensity of the graphical representation is increased by peripheral cues, when the event stays unnoticed by the controller. At first a yellow border is drawn around the aircraft label, but only for the aircraft under control of the respective ATCo (aircraft with blue coloured label font). If the eye tracking system does not register a fixation on the aircraft, the salience is increased further by displaying circles of brighter background colour around the conflicting aircraft.

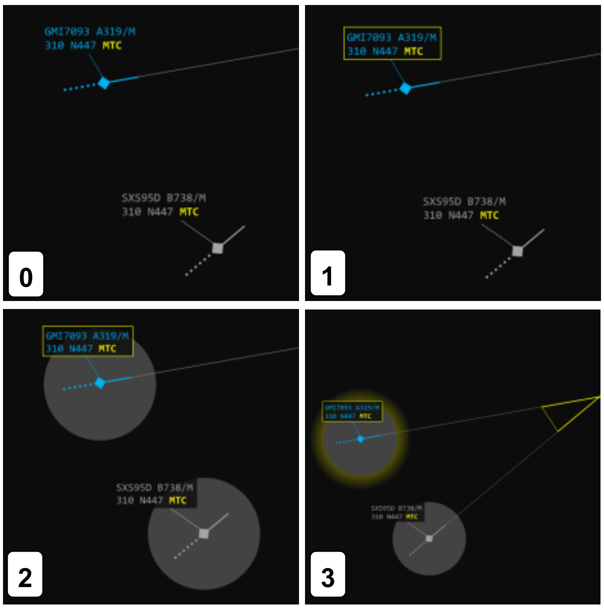

FIGURE 3. Escalation Levels 0-3 and Action Indicators for MTCAs

In analogy to a flashlight that enlightens the most important area of the visual field, this effect shall attract controllers’ attention quickly. In this case, i.e. if the controller fixates both conflicting aircraft, the system assumes that he/she is aware of the event and subsequently reduces the escalation level to level 0 again.

In case that the attention guidance measures presented so far did not result in a fixation of the event, escalation level 3 provides a yellow “glowing” effect around the flashlight circle of the aircraft under control and the display of the conflict area where separation minima are calculated to be underrun.

3.2.2. Short Term Conflict Alert (STCA)

The STCA is the event with the highest rated importance. It occurs if the sectorless ATM prototype detects an urgent conflict, i.e. according to the current trajectories there will be a minimum separation violation within the short time threshold. If the controller does not take action in time, a collision of two aircraft might be unavoidable. As escalation increased with time but the event is very time-critical, the escalation levels are designed to start already at level 1. Then, visual elements in line with the ones introduced for MTCAs are used to increase the visual salience (see FIGURE 4).

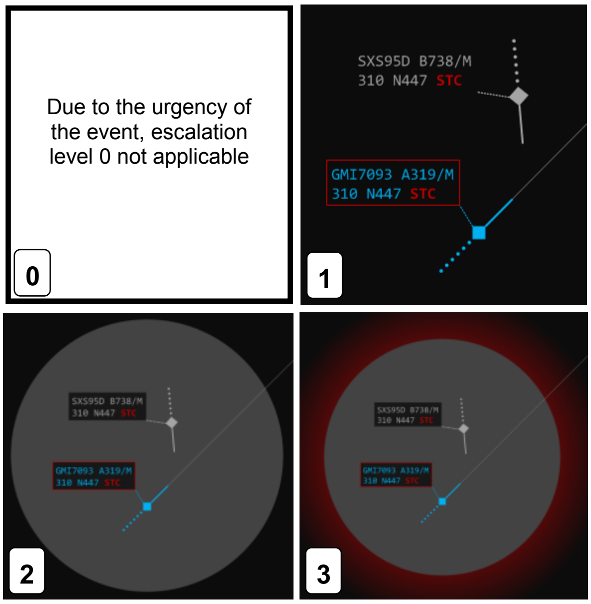

FIGURE 4. Escalation Levels 0-3 and Action Indicators for STCAs

For the colour coding of the increased importance, red is used for the elements instead of yellow. For the flashlight effect, both conflicting aircraft are displayed within one circle of salience to furthermore emphasize the timely urgency of the conflict. We generally apply in the last escalation level a glowing flashlight which is supposed to draw attention even if the aircraft is too far outside the fovea. The flashlight cues are consistently used in all use cases and are designed to capture the user’s attention under higher urgency.

3.2.3. Emergency Squawk Event

In case of an aircraft sending an emergency squawk, the controller needs to follow the corresponding procedure immediately, e.g. enabling a safe landing as quickly as possible or keeping the affected area clear of crossing traffic. The event therefore is assigned with very high priority. The colouring of visual elements again is set to red as for the STCA event (see FIGURE 5). Consistently, escalation level 1 is the first stage for this time critical event; other visual cues are also used in analogous manner. For the label entry, a red landing symbol is used.

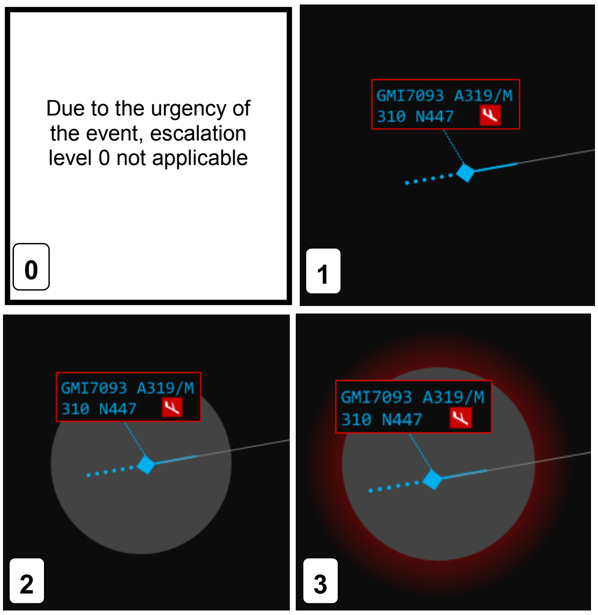

FIGURE 5. Escalation Levels 0-3 and Action Indicators for Emergency Squawks Events

3.2.4. Change in Controller Responsibility

To keep track of incoming aircraft that were assigned to the sectorless controller by the management system, the points of entry for those aircraft are highlighted in blue (see FIGURE 6).

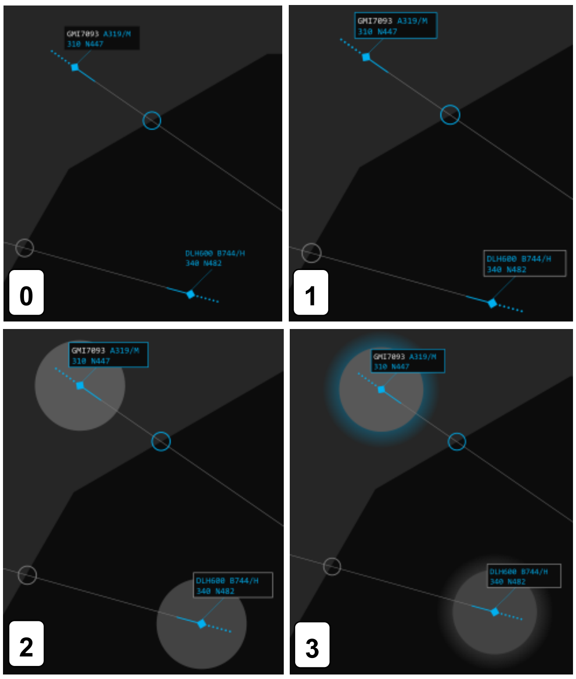

FIGURE 6. Escalation Levels 0-3 and Action Indicators for Changes of Controller Responsibility

This colouring scheme is consistent with the existing scheme of the sectorless prototype, where aircraft under control are marked by labels with blue font and other aircraft are labelled with light grey font. Incoming aircraft have light grey callsigns but already blue values to indicate the upcoming change in controller responsibility. For aircraft leaving the control zone, the point of exit is coloured grey to indicate the aircraft has to be transferred soon to another ATC unit. With increasing escalation levels, label highlighting, flashlight and glowing effect are applied analogous to the events presented before with blue/grey colour coding for sector entries respectively exits (see FIGURE 6).

4. IMPLEMENTATION OF AG PROTOTYPE

For the implementation and subsequent validation of the attention guidance concept, the sectorless ATM prototypic controller working position is used as a basis and extended by the eye tracking hardware and attention guidance software. A consumer eye tracking device is used for gaze input. This device is a screen mounted eye tracker that does not require the operator to wear any tracking markers or glasses. All traffic simulations for the validation exercise, including communication infrastructure and trajectory/alert calculation is provided by the sectorless CWP prototype. For the display of the presented escalation levels for the various events, the prototype was adapted to be able to increase or decrease the visual intensity of HMI elements in reaction to external commands.

The external HMI commands are computed by the AG software that uses eye tracking input (via an eye tracking application programming interface) and traffic situation data received via socket connections from the sectorless CWP to perform the priority ranking and trigger logic. The activation or deactivation of certain AG measures is then sent to the sectorless CWP. The attention guidance software is developed using the C++ programming language. The interface to the other components uses TCP (Transmission Control Protocol) network connections to ensure a platform independent distribution of the components. A brief overview about the infrastructure is given by FIGURE 7.

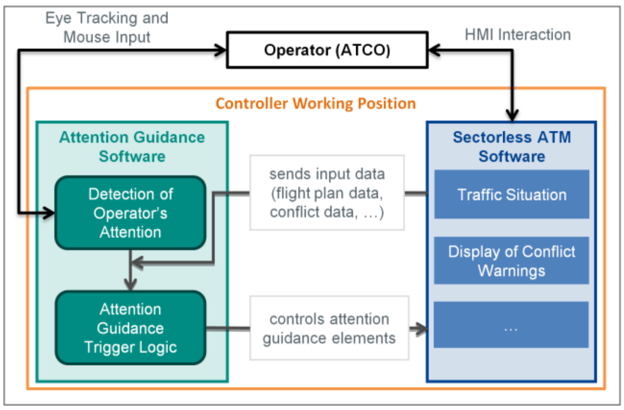

FIGURE 7. Schematic Workflow of the Attention Guidance Components for Validation Exercise

5. ATTENTION GUIDANCE VALIDATION EXERCISE

The DLR AG human-in-the-loop validation exercise (EXE-16.04-TRL4-TVALP-310) is connected to the PJ.10-01b Flight Centred ATC platform of DLR. This PJ.10-01b platform will be developed and tested until autumn 2018 at DLR in Braunschweig. This also comprises the development and integration of the PJ.16-04 AG prototype into the platform. Afterwards, the whole platform and validation environment is shipped to Budapest (Hungary), installed and tested at HungaroControl ANSP. The complete validation trials of both SESAR2020 solutions are planned for January 15-17, 2019 with an open day on January 16. The afternoon of the third validation day is reserved for the AG trials.

The main goal of the validation is to assess human performance and system usability when using the attention guidance prototype at the sectorless CWP. The most important performance benefits are improved situational awareness, reduced workload also regarding the HMI itself, faster detection of critical and non-critical events and thus improved flight efficiency, and enhanced system usability.

Five controllers and a sufficient number of simulation pilots – all of them have experience with Flight Centred ATC from connected validation exercises – will be there for the AG trials. The environment used for the validation exercise is ICAO (International Civil Aviation Organization) class C en-route airspace in Hungary. The relevant free-route airspace between FL325 and FL660 is divided in five Area Control Center (ACC) sectors for the baseline simulation run for Area Control Services by the ATC operational unit in the area of Budapest responsibility. In the solution run there are no sub-divided ACC sectors. All aircraft operate under IFR (Instrument Flight Rules) with a typical mix of aircraft types, capabilities and routes. The majority of flights are scheduled airline traffic. There are no specific requirements, terrain features (due to upper airspace), communication, navigation and surveillance aids, or separation minima applicable.

The AG trials will start with a briefing about the AG prototype followed by a training run including calibration of the ET system. As the controllers are already trained with the sectorless concepts from the two days before, the training run will be short and focus on the visual AG elements that might appear later on. A medium density sectorless traffic scenario is used. However, some critical air traffic situations are included to let the AG elements appear. Then there is a baseline and a solution run of roughly one hour each.

The solution run equals a high density sectorless traffic scenario with the AG functionality switched on. At the baseline run, the scenario is very comparable, but without AG functions at the HMI. For those two runs 10 CWPs are needed to cover the whole Hungarian airspace. Five of them will be automated using an auto-controller with up-and down-data links commands and confirmations. The five controllers will work on the remaining five non-automated CWPs. In one validation run three of those CWPs offer AG-functions while two do not. In the other run only two of those CWPs offer AG-functions while three do not. Hence, three controllers undergo the solution run in the first run, the other two controllers in the second run and vice versa for the baseline run. With this, the order of baseline/solution for the controllers is randomized in order to avoid sequencing or learning effects. Finally, there will be a debriefing with two questionnaires.

The first general human performance (HP) questionnaire comprises six different parts. It is broadly used throughout the whole PJ.16-04 CWP HMI solution. This will allow for comparability of benefits of the different new HMI interaction technologies. Part one of the HP questionnaire consists of demographics including age, years of controller experience, ANSP, and sector. Part two is about workload. Data is gathered via the Bedford Workload Scale [34] on peak and average workload as well as on a ten point Likert answer scale [35]. The latter one concerns multitasking, planning, decision making, team awareness, process information, information attention, problem handling, memory, and situation awareness. Part three encompasses situation awareness via the China Lakes Scale [36]. Part four concentrates on usability and controlling tasks. Part five on user acceptance presents the Controller Acceptance Rating Scale (CARS) [37]. Part six evaluates the user confidence with four statements to be rated.

A second questionnaire concentrates on the specific aspects of the concrete AG prototype and exercise. The improved situation awareness will be assessed via 3D-Situation Awareness Rating Technique (SART). The usability is evaluated with the System Usability Score (SUS).

The objective measures to be compared between solution and baseline run are average flight lengths and flight times of aircraft, reaction times of the controller, and number of commands by the controller.

Furthermore, several objectives have been defined in order to evaluate the AG prototype. The SESAR2020 PJ.16-04-03 technical validation plan contains objectives with success criteria that will be assessed. These objectives are again linked to functional requirements that are detailed in a dedicated document also comprising relevant use cases.

The objectives comprise reliable detection of controllers' attention focus as well as a reset function to switch off/on the AG elements e.g. in case of un-reliable eye-tracking. In addition, the correct displaying of AG elements for STCA/MTCA, Squawk Event, Sector Entry/Exit, and the visual highlighting at higher escalation levels will be tested.

The above mentioned objectives will be analysed with respect to the defined use cases to guide the ATCo's attention via perceptional cues in case of critical ATC situations, potentially missed command actions, and supposed inaccurate situation awareness.

6. SUMMARY AND OUTLOOK

The concept of the attention guidance prototype gives answers on the three questions where a controller should look at, where the controller is currently looking at, and the determination of a mismatch of the respective gaze positions with following mechanisms to guide the attention if necessary (action indicators). These mechanisms comprise a trigger logic using different escalation levels. The AG concept has been documented, implemented and tested. The benefits of the action indicators will be examined by the SESAR validation exercise in January 2019. All results will be presented in the technical validation report of PJ.16-04's Technology Readiness Level 4 (TRL) documents. As our AG mechanism influences the Functional Block "Controller Human Machine Interaction Management for En-Route and Approach" of the European Air Traffic Management Architecture (EATMA), a new AG function will be introduced in the next dataset version of EATMA.

Besides DLR, other important players in the European ATC community participate in the AG research and development activities such as the ANSPs NATS, DFS, Enaire, Skyguide, LFV/COOPANS, Romatsa, and AvinorANS as well as the ATM system providers Thales, INDRA, and Skysoft-ATM (Skysoft-ATM/Skyguide also have an own AG exercise in PJ.16-04). It is planned to further continue the AG topic for increased TRLs in two different (candidate) solutions in SESAR2020's Wave 2 phase starting in 2020. Furthermore, the topic 'attention guidance' is foreseen to be a civil air traffic technology around the year 2040 in the German aerospace industry association (BDLI) roadmap [38]. Hence, the AG prototype presented in this paper and its upcoming validation results will influence further ATC research and developments with respect to visual and to some extent also auditory attention guidance.

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8. ABBREVIATIONS

ACC	Area Control Center
AG	Attention Guidance
ANSP	Air Navigation Service Provider
AOI	Area of Interest
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATM	Air Traffic Management
BDLI	German aerospace industry association
CARS	Controller Acceptance Rating Scale
CWP	Controller Working Position
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)
EATMA	European Air Traffic Management Architecture
EEG	Electroencephalography
ET	Eye Tracking
FH	University of Applied Sciences (Fachhochschule)
HMI	Human Machine Interface
HP	Human Performance
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
MTCA	Medium Term Conflict Alert
MINIMA	Mitigating Negative Impacts of Monitoring high levels of Automation
NINA	Neurometrics INdicators for ATM
OOTL	Out-Of-The-Loop
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SDD	Situation Data Display
SESAR	Single European Sky ATM Research
STCA	Short Term Conflict Alert
SUS	System Usability Score
TCP	Transmission Control Protocol
TRL	Technology Readiness Level
VAC	Vigilance and Attention Controller

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