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A Real Time Neurophysiological Framework for General Monitoring Awareness of Air Traffic Controllers

Rajamanickam Yuvaraj^{1*}, Sun Woh Lye¹, and Hong Jie Wee²

Abstract—With the increasing traffic volume, air traffic controllers (ATCos) highly efficient performance plays an essential part in ensuring the safety and managing within limited manpower and resources. To ensure the performance, one way is to perform situation awareness (SA) examination. However, the known SA methods (such as text query) are either subjective or inapplicable in a practical scenario. Therefore, the use of physiological signals is becoming popular. In this work, a real time monitoring approach is proposed to assess a general monitoring awareness while looking at the events happening at the radar display during air traffic control (ATC), using neurophysiological measures taken from electroencephalogram (EEG) signals along with eye-tracking metrics such as eye fixation count and duration. Seven university engineering students participated in the attentive and non-attentive radar monitoring activities. The preliminary experimental results revealed that the real-time data of EEG, average fixation count, and fixation duration highlight distinct differences in levels between attentive and non-attentive monitoring activities (individual and collective). Also, the cognitive resource required for air traffic management (ATM) monitoring is relatively high. Such measures can be used as complementary data sets to gauge and validate an ATCos general SA.

Index Terms—air traffic control, visual monitoring, eye-tracking, EEG, situational awareness.

I. INTRODUCTION

According to an International Civil Aviation Organization (ICAO) report, global air traffic is forecasted to increase by 4% annually to 2020 [1]. It is projected to grow at a compound annual growth rate (CAGR) of 4.3% and 3.9% for passenger and cargo aircraft, respectively [2]. Based on the existing approaches, Air Traffic Controllers (ATCos) are greatly challenged to handle this growth in air traffic. Various automated technologies and procedures have been developed to assist ATCos to better monitor air traffic and make decisions accordingly. Coupled with this increase and the push towards automation, this would affect the situation awareness (SA) of controllers in terms of managing and monitoring one's performance, ensuring air safety adherence and vigilance, as well as effective functioning of new air traffic operational systems and setups. Acquiring and maintaining appropriate levels of SA is critical in aviation environments as it affects all decisions and actions taking place in flights and air traffic control. Loss of SA is one of the main causes of air-traffic-related accidents, and it is essential to obtain suitable indices to assess SA. Current SA assessment tools

and measures tend to be performed offline during training, subjective in its assessment, and not well suited to system modifications and dynamic tactical display changes.

Over recent years, physiological signal measures have grown in popularity and adapted in SA assessment by many researchers for different applications [3]–[8]. Physiological measurement can be traced easily across time, as it can capture changes in bio-signals continuously [9]. This allows the evolution of how well an ATCos is able to perceive and comprehend to be studied while causing minimal disruption to their tasks [10], as well as enabling physiological measurements, which are highly sensitive to such changes over the entire experimental duration, to be made. Measuring the subject's eye movements during task execution is deemed to be the most direct and objective form of physiological measurement of a subject visual monitoring behavior [11]. Eye-tracking devices can be employed to determine situational elements the subject has fixated upon and evaluate how the subject's attention is allocated. Nevertheless, the process indices have an indirect nature, i.e., the 'look but do not see' phenomenon by which the subject may fixate upon a certain environmental element but does not accurately perceive it. Electroencephalogram (EEG) reflects the true cognitive activity of a person, which helps to understand whether a subject really watches and responds to what he sees. In the literature, eye tracking and EEG signal measurement technique have been deployed independently in many surveillance fields like aviation [12], [13], driving [14], [15], pilot assessment [8], [16], healthcare [17], as a method for monitoring and analyzing the viewing behavior. However, SA assessment based on the combination of eye-tracking and EEG in relation to radar monitoring is sparse.

This research work presents a real-time approach that seeks to assess general monitoring awareness while looking at the events happening at the radar display during air traffic control (ATC), using neurophysiological measures taken from EEG along with eye-tracking metrics such as eye fixation count and fixation duration. Our numerical results show that real-time data of EEG, average fixation Count, and fixation duration highlight distinct differences in levels between attentive and non-attentive monitoring activities.

The rest of the paper is organized as follows. Section II explains the materials used, including participants, equipment used, experimental design, and procedures. Section III presents the proposed methodology to evaluate general SA. Section IV presented the results and discussed in the same section. Finally, Section V concludes our findings and propose ideas for future research directions.

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II. MATERIALS USED

A. Study Participants

Participants were seven university students (2 females, 5 males) with a mean age of 24.71 ± 2.87 years. Most of the participants did not have prior experience with air traffic control (ATC), and they were given training and guidance beforehand. One male participant had few years of ATC experience. The inclusion criteria for the participant included normal or corrected-to-normal vision, able to communicate in English, and basic comprehension skill (e.g., able to understand the ATC process). All participants provided written informed consent prior to the experiment and this research was ethically approved by the Institutional Review board (approval no. IRB-2020-05-021-01).

B. Experimental Setup

The equipment used to perform this study is a real-time air traffic control simulator, NARSIM Interface, the remote eye tracker, Tobii X2-30, and EEG recording device, Emotive. A post-processing tool, TopSky-HF, is used to record and post-process the eye-tracking data. Fig. 1 shows the complete experiment setup. NARSIM is a powerful human-in-the-loop simulator for ATC radar and tower simulations developed by the Netherlands Aerospace Centre. The radar data containing information about the aircraft's location on the radar screen display different time frames throughout the simulation. The radar simulation, the aircraft's positions, updates every 9.8 seconds, which corresponds to the time taken for one radar revolution. Therefore, the radar data displayed in each of these 9.8 seconds intervals is called a frame. The eye tracker tracks the participant's eye-fixations on the radar display. The eye-tracker was positioned 55 cm from the participants' eyes and 18 cm from the radar screen. The eye movement data was captured from the eye tracker at the rate of 30 Hz [11]. Emotive EPOC is the 14-channel wireless EEG recording neuroheadset (sampling rate of 128 Hz). The EEG signals were recorded from AF3, AF4, F8, F3, F4, FC5, FC6, T7, T8, P7, P8, O1, and O2 sites of the international 10-20 system, and the linked ear was used as a reference [18], [19].

Fig. 1. Experiment setup: Participant working position with equipment required.

C. Experiment Design

The experiment was designed to collect three sets of data, namely radar data, eye tracking metrics, and EEG synchronously during real-time ATC simulation. An illustrated representation of the experimental protocol is shown in Fig. 2. Each participant completed two independent sessions (same scenario), namely general attentive monitoring and non-attentive monitoring. During the attentive monitoring session, the participants were required to give full attention and concentration in monitoring the air traffic. In the second session, they were required to monitor the air traffic partially. Participants were instructed to look partially away from the screen or engage in other activities (such as playing with handphones, resting, not paying attention) during non-attention monitoring sessions. There was a break of 10-15 minutes between the session. Each session took approximately 60 minutes, i.e., the study participant approximately monitors 366 frames ($9.8 \times 366 = 60$ min). The participants were allowed to relax during the break since the continuous assessment would have been too exhausting. The radar data, eye tracking metrics and EEG signals were recorded for each session separately.

D. Procedure

Before the experiment, each participant in a session underwent an initial 9-point eye-tracker calibration exercise. Calibration was repeated until a satisfactory calibration was obtained. The purpose of the study was clearly explained to the participants before initiating the experiment and followed by instructions on how to use the equipment. The participant playing the role of the ATCos is further advised to sit comfortably and to calibrate his eyes to the center of the screen. This helps to ensure that the eye-tracking collected is consistent.

III. METHODS

In this study, eye tracking metrics, namely, eye-fixation count (count of the number of fixations) and fixation duration (longer fixation duration indicates the longer processing time is needed to extract information), are chosen as dependent variables. These eye metrics are chosen as they are deemed to be suitable measures in capturing the monitoring behavior [3], [4], [11]. A fixation is computed from the eye data using the velocity threshold fixation identification (I-VT) algorithm [4], [11], [20]. The I-VT fixation detection algorithm classifies the eye movements based on the velocity of the directional shifts of the eye. The readers can read [21] to know more details about eye-tracking metrics computation. The eye-tracking metrics were computed for every 9.8 seconds. In total, 366 eye-fixation counts, and fixation duration were obtained from each one-hour session.

EEG analysis was performed offline in the MATLAB (version 9.3.0.71, R2017b) environment. After data acquisition, the EEG signals were subjected to filtering. Frequencies below 1 Hz and above 49 Hz are removed by a zero-phase 4th order Butterworth bandpass filter. Later the EEG signals were segmented into 9.8 seconds ($9.8 \times 128 = 1254$ samples)

Fig. 2. Illustration of experiment protocol.

TABLE I
SUMMARY OF NEUROPHYSIOLOGICAL MEASURE VALUES DURING ATTENTIVE MONITORING ACTIVITIES.

Subject No.	Fixation count			Fixation duration (ms)			Normalized spectral power		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Minimum	Maximum
1	7.027	17	0	7565.027	16177	0	0.720	0.997	0.098
2	6.902	17	0	5262.005	11977	0	0.538	0.943	0.082
3	5.286	16	0	4233.556	11122	0	0.726	0.996	0.030
4	8.638	18	0	6966.583	14517	0	0.869	0.999	0.600
5	6.845	15	0	5455.041	15426	0	0.787	0.999	0.079
6	4.910	13	0	3886.619	11378	0	0.755	0.997	0.108
7	7.302	20	2	6444.409	13064	1055	0.667	0.927	0.343

TABLE II
SUMMARY OF NEUROPHYSIOLOGICAL MEASURE VALUES DURING NON-ATTENTIVE MONITORING ACTIVITIES.

Subject No.	Fixation count			Fixation duration (ms)			Normalized spectral power		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Minimum	Maximum
1	1.640	18	0	2196.417	17589	0	0.302	0.502	0.055
2	0.580	11	0	440.747	13976	0	0.214	0.832	0.006
3	1.357	7	0	1083.894	13922	0	0.310	0.823	0.047
4	1.117	14	0	688.605	9203	0	0.242	0.496	0.100
5	0	0	0	0	0	0	0.232	0.445	0.184
6	0.223	6	0	114.052	3137	0	0.246	0.584	0.086
7	1.054	11	0	1240.725	11522	0	0.226	0.465	0.001

epochs corresponding to the duration of time taken for one radar revolution. Finally, 366 epochs were obtained from each session to compute the spectral power. The EEG spectral power was computed using Welch's average periodogram method (MATLAB's 'pwelch' function) with an NFFT of 1,024 (with the resolution of 0.125 Hz) and a Hanning window length of 256. Later the spectral power values were normalized to 0–1 for each channel, and then the values were standardized by removing the mean and scaling to unit variance. The normalized spectral power values (attentive EEG Vs non-attentive EEG) were analyzed by the t-test. Statistical significance was defined as $p < 0.05$.

IV. RESULTS AND DISCUSSION

The proposed real-time neurophysiological-based general monitoring awareness during ATC can successfully capture the eye metrics and EEG signals of participants operating on the radar display. Table I and Table II show the average, minimum, and maximum fixation count, fixation duration, and normalized EEG spectral power values of each participant during attentive and non-attentive when monitoring radar

display. It can be seen that there are more fixation counts and longer fixation duration were registered during attentive monitoring activities as compared to non-attentive activities. This is consistent with the findings of other literature [20]–[22]. It was found that all the participants spent more than 3000 ms (on average) on radar display during monitoring activities. Such suggests that they are more attentive during radar monitoring activity. This was not in the case of non-attentive activity. One subject did not fixate on display at all (see Table II). A plausible explanation would be the loss of monitoring behavior due to continuous monitoring activity. This correlation shows that a shorter fixation duration may lead to a lower cognitive resource.

A similar observation can be seen from the mean value of EEG spectral power. More attentive represents more monitoring of aircraft on the radar screen, which adds more cognitive resources to the participant. This supports that increase in monitoring activities will cause an increase in the visual monitoring and cognitive resource of the participant. It is further noted that the cognitive resource required for

Fig. 3. Boxplot of EEG spectral power between attentive and non-attentive radar monitoring.

ATC monitoring is relatively high. The t-test results indicated that the EEG spectral values showed statistically significant ($p < 0.05$) changes among the attentive and non-attentive activities for all the subjects. Fig. 3 shows the boxplot of EEG spectral power between attentive and non-attentive activities. This also ensures the distinct cognitive activity between attentive and non-attentive monitoring activities.

V. CONCLUSION

In this study, a real-time radar monitoring approach is proposed to assess a general monitoring awareness while looking at the events happening at the radar display during ATC. Physiological measures such as EEG and eye metrics were captured for this purpose. The results showed the proposed approach highlighted significant differences in radar monitoring with regards to fixation count, fixation duration, and EEG signal during attentive and non-attentive activities. Furthermore, it is also highlighted the participant required larger brain activity to process visual information. The proposed neurophysiological measures-based approach could provide a better interpretation of a radar monitoring performance and strategy. The future development of this research will be focused on increasing sample size, assessing cognitive state level using other EEG features (e.g., time-frequency domain features), and utilizing machine learning algorithms for adoption.

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