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SOFTWARE SOLUTION FOR MONITORING THE LEVEL OF FATIGUE OF AIR TRAFFIC CONTROLLERS

Volodymyr POLISHCHUK[1,2*], Martin KELEMEN Jr.[2], Yurii FEDELESH[1], Bohdan BORYSENKO[1], Emilian HERASHCHENKOV[1]
[1] Uzhhorod National University, 88000, Narodna Square 3, Uzhhorod, Ukraine
[2] Technical University of Kosice, 04121, Rampova 7, Kosice, Slovak republic
*Corresponding author. E-mail: volodymyr.polishchuk@uzhnu.edu.ua

Abstract. The work developed a software solution for monitoring the level of fatigue of air traffic controllers using expert opinion. For constructing a software solution, a nine-step algorithm for hybrid assessment of the air traffic controllers' fatigue level was developed for the first time. For the first time, a software solution for monitoring air traffic controllers' fatigue levels was constructed using the TypeScript programming language and the React library. At the output, a generalized quantitative assessment and linguistic complex level of fatigue of air traffic controllers is obtained. If significant fatigue is detected, the software solution automatically notifies the decision-making person (DM), allowing timely action, such as suspending the dispatcher from work and replacing him. Algorithmic support and software were tested and configured based on accurate data, where the participants of the experiments were students of the Aviation Faculty of the Technical University in Košice. The study uses modern methods such as fuzzy set theory, expert evaluation, intelligent data analysis, and pattern recognition, which improves the accuracy of determining air traffic controllers' fatigue level. The advantage of the development lies in the combination of technical data from video surveillance and expert assessments. With the ability to adjust the settings levels, the software is suitable for both civil and military aviation, making it versatile in application.

Keywords: air traffic controllers, software, fatigue level, expert opinions, flight safety, fuzzy modeling.

1. INTRODUCTION

To prevent incidents at airports, the effectiveness of the air traffic control team plays a key role, as they are responsible for flight coordination and air traffic control. The high accuracy of their decisions and promptness of reactions guarantee safety both on the ground and in the air. Insufficient concentration or fatigue of dispatchers can lead to errors, which increases the risk of emergency situations. Therefore, it is important to develop and implement information technologies to monitor their condition, particularly the level of fatigue, to ensure uninterrupted and reliable work [1].

Video surveillance allows you to constantly monitor the condition and behavior of air traffic controllers in real-time, which is important for maintaining a high level of safety at the workplace. The use of video recordings makes it possible to detect early signs of fatigue, such as slow reactions, frequent blinking, or decreased attention. This allows timely measures to be taken to remove the dispatcher from his duties and replace him with others, which significantly reduces the risks of possible incidents at airports.

The analysis of video surveillance images regarding the fatigue of air traffic controllers based on the criterion of the percentage of closed eyes requires the development of specialized software that can process video data in real-time. This software should provide an accurate determination of the state of the dispatcher's eyes (open or closed), which will allow us to automatically assess the level of his fatigue. In addition, the use of video analysis in combination with expert evaluations allows you to dynamically monitor the level of fatigue in real-time and make proactive decisions. Technical means can collect and process large amounts of information, while expert opinions contribute to the interpretation of this data and its understanding in the context of specific situations. Therefore, such an assessment is not possible without a specially designed software solution that will ensure flight safety and prevent incidents at airports.

To date, there is no comprehensive study of monitoring the level of fatigue of air traffic controllers, which uses the analysis of quantitative information about the human condition and expert opinions. The study [2] examines the use of video surveillance to determine the level of human fatigue based on an indicator that determines the percentage of closed eyes. This indicator is considered the most effective for fatigue monitoring, and its effectiveness in real-time has been confirmed by numerous experiments and studies [3, 4]. A manual has guided fatigue management for air traffic service providers since 2016 [5]. It provides guidance for air traffic controllers in addressing this issue. Visual approval of the recommendations was carried out in the control tower of the International Airport of Taiwan [6]. The productivity of air traffic controllers is affected by physical fatigue and stress [7, 8]. The impact of mental fatigue is studied in [9]. It has been proven that the fatigue of an air traffic controller in real work conditions is greater than in training centers [10]. Many factors affecting the fatigue of dispatchers are outlined for the construction of management models [11]. It has been proven that fatigue affects aeronautical events [12], so it is suggested that indicators of fatigue efficiency be used to improve operational safety. More and more attention are paid to the use of machine learning methods for monitoring the physical fatigue of operators [13, 14]. An approach to detect the mental fatigue of motion controllers based on a machine learning algorithm used for regression and classification was proposed [15]. Fatigue occurs due to the prolonged sitting and constant concentration required of air traffic controllers. This can cause muscle pain [16], cognitive overload, and decreased activity and attention. Thus, air traffic controllers often face simultaneous physical and mental exhaustion, or combined fatigue [17]. In contrast, no study has also considered expert ratings of air traffic controllers' fatigue and various physiological measures.

Therefore, developing a software solution for monitoring the level of fatigue of air traffic controllers can timely detect signs of fatigue and allow taking the necessary measures to ensure safety in the airspace.

The study aims to develop a software solution for monitoring air traffic controllers' fatigue levels using expert opinion.

2. MATERIALS AND METHODS

The main goal of software support is to derive a quantitative (α_{ATC}) and linguistic (LF) fatigue assessment of air traffic controllers $A = \{a_1; a_2; \dots; a_n\}$. Such a quantitative assessment is obtained based on dynamic assessment in a certain period ($t_1, t_2, \dots, t_m$) and video surveillance, using expert opinion (e_a). The software will work based on the developed algorithm of the hybrid assessment of the air traffic controllers' fatigue level – $HATC$. Formally, the operation of the algorithm can be represented in the form of an operator:

$$HATC(A, t, e_a) \to \alpha_{ATC}. \quad (1)$$

Based on the input data A, t, e_a the operator outputs a quantitative (α_{ATC}) fatigue estimate of the air traffic controller A, which is mapped to the linguistic level LF. The initial assessment will include information obtained using air traffic control image analysis and expert opinion.

The software solution's structural diagram for monitoring air traffic controllers' fatigue levels is presented as a step-by-step algorithm, fig. 1.

Next, a detailed step-by-step algorithm for the hybrid air traffic controller fatigue level – $HATC$ assessment is given.

1st step. *Data collection using video surveillance*

The eye image is fixed in the specified period $t_j, j = \overline{1, m}$ based on the camera video. The resulting video is processed in the image processing software module.

2nd step. *Image processing from video surveillance*

The processing of such an image is processed according to the logic of determining the percentage of the closed eye [2]:

$$v_{a(t_j)}(a_i) = 1 - \frac{r_3 - r_2}{r_4 - r_1}, i = \overline{1, n}, j = \overline{1, m}. \quad (2)$$

Here r_1 is the time from the moment the eye is fully opened to 20% of its closure; r_2 – the time from full opening of the eye to 80% of its closure; r_3 is the time from full opening to full closing of the eye, after which it opens by 20%; r_4 is the time from the initial position, due to the complete closure of the eye, to its opening by 80%. When ε approaches 0, this indicates maximum human fatigue. On the contrary, when ε approached 1, it indicates that a person feels energetic, rested, and ready for active actions [2]. In the next step, normalized estimates $v_{a(t_j)}(a_i) \in [0; 1]$ are submitted. Such estimates are calculated programmatically, and the result is displayed to the user.

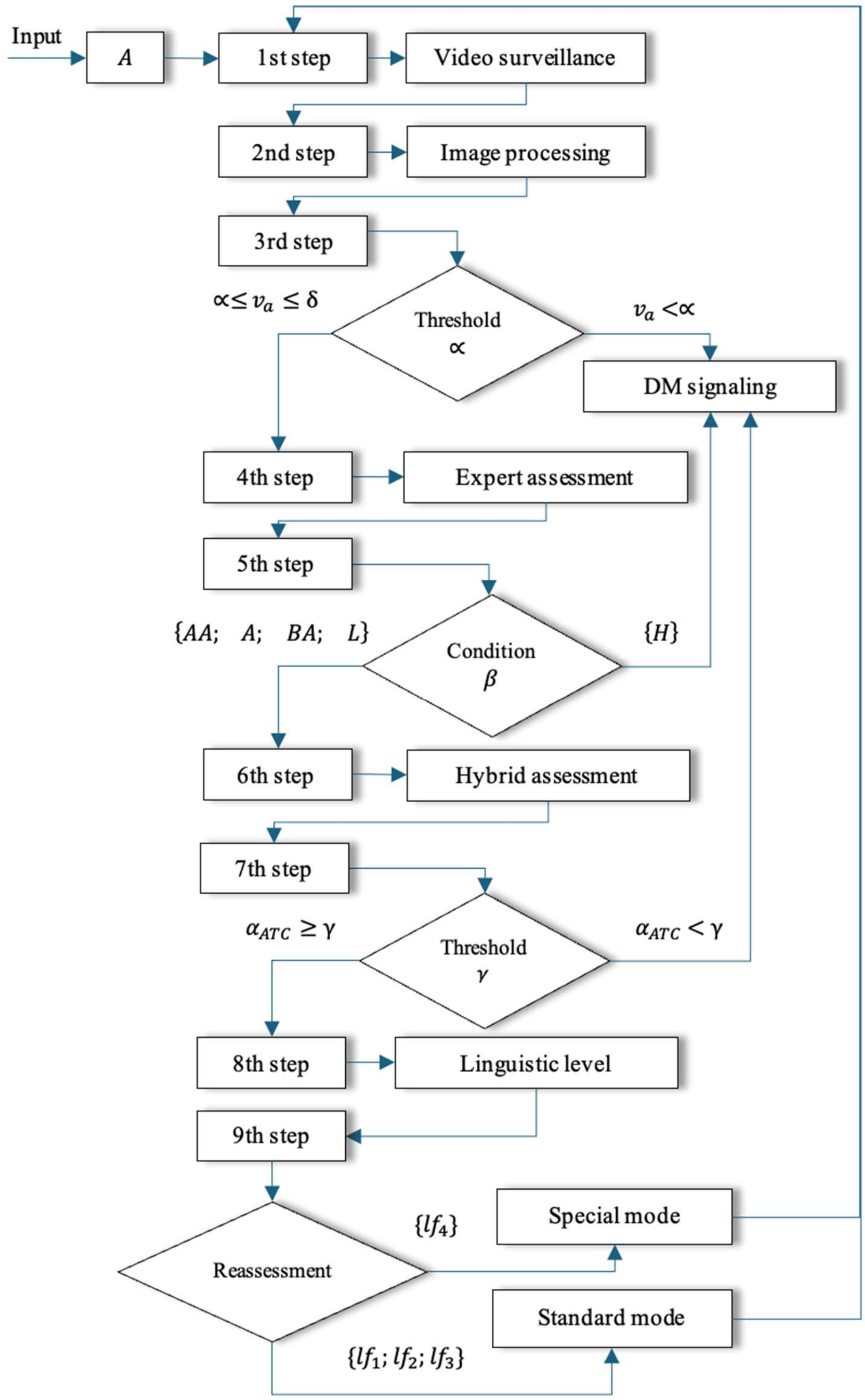

Figure 1. Structural diagram of the software solution

3rd step. *Air traffic controller fatigue signaling based on video surveillance*

If $v_{a(t_j)}(a_i)$ it is under some threshold, $\propto$ The DM signals to take appropriate measures if it is under some threshold. The system analyst in the software configuration sets the threshold. In the opposite case, there is a transition to the 4th step.

4th step. *Expressing the expert's opinion*

Expert evaluation occurs when $v_{a(t_j)}(a_i)$ it is greater than or equal to some threshold $\propto$ but less than $\delta \in [0;1]$, $(\propto \leq v_{a(t_j)}(a_i) < \delta \leq 1)$. Similarly, the value of δ зis set by the system analyst in the software configuration.

The expert E expresses his formalized opinion $E_{a(t_j)}(a_i)$ regarding the fatigue of the investigated air traffic controller A in the form of linguistic variables $E_a = \{H; \quad AA; \quad A; \quad BA; \quad L\}$: H – "high level"; AA – "level above average"; A – "average level"; BA – "level below average"; L – "low level".

5th step. *Signaling of the DM regarding the fatigue of the air traffic controller based on the opinion of the expert*

At this stage, the logical condition β of the expressed expert assessments of air traffic controllers' fatigue is checked: IF $E_a = \{H\}$ THEN the DM is signaled. In the opposite case, there is a transition to the 6th step.

6th step. *Hybrid assessment*

IF $E_a = \{AA; \quad A; \quad BA; \quad L\}$ THEN, hybrid evaluation occurs.

The quantitative assessment of air traffic controllers' fatigue, obtained with the help of video cameras, is based on the principle: that the higher the value, the better the condition. Expert assessments of fatigue also follow this logic: the higher the score, the better the dispatcher's condition. Therefore, the logical derivation is based on applying the S-shaped membership function to formalize this process.

IF $E_a = \{AA\}$ THEN:

$$\alpha_{ATC(t_j)}(a_i) = \begin{cases} \frac{1}{5}\left(\sqrt{\frac{v_{a(t_j)}(a_i)}{2}} + 1\right), & 0 \leq v_{a(t_j)}(a_i) \leq 0.5; \\ \frac{1}{5}\left(2 - \sqrt{\frac{1 - v_{a(t_j)}(a_i)}{2}}\right), & 0.5 < v_{a(t_j)}(a_i) \leq 1. \end{cases} \quad (3)$$

IF $E_a = \{A\}$ THEN:

$$\alpha_{ATC(t_j)}(a_i) = \begin{cases} \frac{1}{5}\left(\sqrt{\frac{v_{a(t_j)}(a_i)}{2}} + 2\right), & 0 \leq v_{a(t_j)}(a_i) \leq 0.5; \\ \frac{1}{5}\left(3 - \sqrt{\frac{1 - v_{a(t_j)}(a_i)}{2}}\right), & 0.5 < v_{a(t_j)}(a_i) \leq 1. \end{cases} \quad (4)$$

IF $E_a = \{BA\}$ THEN:

$$\alpha_{ATC(t_j)}(a_i) = \begin{cases} \frac{1}{5}\left(\sqrt{\frac{v_{a(t_j)}(a_i)}{2}} + 3\right), & 0 \leq v_{a(t_j)}(a_i) \leq 0.5; \\ \frac{1}{5}\left(4 - \sqrt{\frac{1 - v_{a(t_j)}(a_i)}{2}}\right), & 0.5 < v_{a(t_j)}(a_i) \leq 1. \end{cases} \quad (5)$$

IF $E_a = \{L\}$ THEN:

$$\alpha_{ATC(t_j)}(a_i) = \begin{cases} \frac{1}{5}\left(\sqrt{\frac{v_{a(t_j)}(a_i)}{2}} + 4\right), & 0 \leq v_{a(t_j)}(a_i) \leq 0.5; \\ 1 - \frac{1}{5}\sqrt{\frac{1 - v_{a(t_j)}(a_i)}{2}}, & 0.5 < v_{a(t_j)}(a_i) \leq 1. \end{cases} \quad (6)$$

As a result, $\alpha_{ATC(t_j)}(a_i) \in [0;1]$ is obtained - a generalized quantitative assessment of the fatigue of air traffic controllers.

7th step. *Signaling to the DM based on the generalized quantitative assessment of fatigue of air traffic controllers*

A threshold γ is introduced, compared with the generalized quantitative assessment of air traffic controllers' fatigue α_{ATC}. When the given estimate exceeds the permissible threshold value $\alpha_{ATC} < \gamma$, signaling occurs. In the opposite case, there is a transition to the 8th step. Similarly, the system analyst sets the threshold in the software configuration.

8th step. *Derivation of the linguistically complex level of fatigue of air traffic controllers*

At this step, LF the linguistic complexity level of fatigue of air traffic controllers is derived. This level is formalized using four linguistic levels $LF = \{lf_1, lf_2, lf_3, lf_4\}$ and is compared with the generalized quantitative assessment of fatigue of air traffic controllers α_{ATC}:

IF $\alpha_{ATC} \in$ (0,89; 1] THEN "low level of fatigue" – lf_1;

IF$\alpha_{ATC} \in$ (0,79; 0,89] THEN "fatigue level is below average" – lf_2;

IF$\alpha_{ATC} \in$ (0,69; 0,79] THEN "average level of fatigue" – lf_3;

IF$\alpha_{ATC} \in$ (γ; 0,69] THEN "high level of fatigue" – lf_4.

9th step. *Re-evaluation*

After receiving the linguistic evaluation, a re-evaluation is carried out - the transition to step 1. The re-evaluation takes the next determined period (t_{j+1}). Two options are offered: standard or special mode. The special regime provides for a reduction in the time frame of the assessment if the obtained evaluation indicates a high level of fatigue of the air traffic controller. The system allows you to dynamically assess the state of the air traffic controller during the performance of his work. The system or the responsible person determines time limits and the need for additional expert evaluation.

3. EXPERIMENTS AND DISCUSSION

The software is developed based on the hybrid assessment algorithm of the air traffic controllers' fatigue level using TypeScript and React programming tools. TypeScript is an open-source programming language that enhances JavaScript by adding static type definitions. The choice of this programming language is determined by the fact that it allows developers to catch errors during development, refactor code more easily, and ensure greater program clarity and reliability. React is a JavaScript library designed for building user interfaces, specifically for creating reusable, modular components that help organize code more efficiently. It simplifies web development by breaking down the interface into smaller components that can be reused across different parts of an application. React also enhances performance through its virtual DOM, allowing fast and efficient updates to the user interface, resulting in smoother and more responsive web applications.

The software was validated and tested using real data from air traffic controllers provided by students from the Faculty of Aviation at the Technical University in Košice. A step-by-step example of the evaluation process is presented based on data collected from five air traffic controllers over an 8-hour work period.

1st step. *Data collection using video surveillance*

Based on the camera video, the eye image is captured, and the resulting video goes to image processing in step 2.

2nd step. *Image processing from video surveillance*

Image processing takes place according to the logic of determining the percentage of the closed eye and formula (2). Thus, normalized input estimates for five air traffic controllers were obtained, fig. 2.

Without reducing the generality, we will demonstrate the input estimates and calculation results immediately for the 8-hour work of air traffic controllers. In other words, the evaluation took place according to the algorithm 8 times.

3rd step. *Air traffic controller fatigue signaling based on video surveillance*

At this stage, the input data is compared with the threshold $\propto$ set in the software configuration. For example, $\propto = 0.55$ DM signaling occurs, and the data in the following calculations are displayed as "-."

	α1	α2	α3	α4	α5
t1	0,69	0,76	0,88	0,97	0,87
t2	0,81	0,78	0,78	0,95	0,85
t3	0,89	0,82	0,72	0,91	0,68
t4	0,87	0,69	0,66	0,83	0,67
t5	0,73	0,82	0,76	0,78	0,76
t6	0,78	0,88	0,68	0,82	0,64
t7	0,62	0,77	0,78	0,78	0,55
t8	0,54	0,45	0,77	0,78	0,58

Figure 2. Input data

4th step. *Expressing the expert's opinion*

For example, δ =0.85, the expert assessment takes place under the condition that $0.55 \leq v_{a(t_j)}(a_i) < 0.85$. In the software, the result when δ >0.85 is presented in green. For each air traffic controller in the section of their working hours, the expert expresses his formalized opinion about the fatigue of the air traffic controller under study in the form of a pop-up list of linguistic variables E_a. The presented fragment of the software for the 4th step is shown in Fig. 3.

	α1		α2		α3		α4		α5	
	Vα(α1)	Eα(α1)	Vα(α2)	Eα(α2)	Vα(α3)	Eα(α3)	Vα(α4)	Eα(α4)	Vα(α5)	Eα(α5)
t1	0.69	BA	0.76	AA (list: H, AA, A, BA, L, -)	0.88	-	0.97	-	0.87	-
t2	0.81	L	0.78	[illegible]	0.78	BA	0.95	-	0.85	L
t3	0.89	-	0.82	[illegible]	0.72	L	0.91	-	0.68	L
t4	0.87	-	0.69	[illegible]	0.66	L	0.83	L	0.67	L
t5	0.73	AA	0.82	[illegible]	0.76	L	0.78	L	0.76	L
t6	0.78	BA	0.88	-	0.68	BA	0.82	BA	0.64	A
t7	0.62	A	0.77	A	0.78	A	0.78	A	0.55	A
t8	-	-	-	-	0.77	A	0.78	BA	0.58	BA

Figure 3. Expressing the opinions of an expert

5th step. *Signaling of the DM regarding the fatigue of the air traffic controller based on the opinion of the expert*

The logical condition β is checked. IF $E_a = \{H\}$ THEN the value is signaled in red in the software.

6th step. *Hybrid assessment*

In all other cases, a hybrid assessment is performed to obtain a generalized quantitative assessment of air traffic controllers' fatigue using formulas (3)-(6).

7th step. *Signaling to the DM based on the generalized quantitative assessment of fatigue of air traffic controllers*

In the software settings, a threshold γ is set, which is compared with the generalized quantitative assessment of air traffic controllers' fatigue. For example, $\gamma=0.5$. If the estimates are lower than the threshold value in the software, such values are signaled in red.

8th step. *Derivation of the linguistically complex level of fatigue of air traffic controllers*

For all values not about the signaled DM and went to expert evaluation, LF, it is derived - the linguistic complex level of fatigue of air traffic controllers. The result is shown in Fig. 4.

	$a1$		$a2$		$a3$		$a4$		$a5$	
	$\alpha ATC(a1)$	LF	$\alpha ATC(a2)$	LF	$\alpha ATC(a3)$	LF	$\alpha ATC(a4)$	LF	$\alpha ATC(a5)$	LF
t1	0.72	$lf3$	0.93	$lf1$	-	-	-	-	-	-
t2	0.94	$lf1$	0.53	$lf4$	0.73	$lf3$	-	-	0.95	$lf1$
t3	-	-	0.74	$lf3$	0.93	$lf1$	-	-	0.92	$lf1$
t4	-	-	0.92	$lf1$	0.92	$lf1$	0.94	$lf1$	0.92	$lf1$
t5	0.33	-	0.94	$lf1$	0.93	$lf1$	0.93	$lf1$	0.93	$lf1$
t6	-	-	-	-	0.72	$lf3$	0.74	$lf3$	0.52	$lf4$
t7	-	-	0.53	$lf4$	0.53	$lf4$	0.53	$lf4$	0.51	$lf4$
t8	-	-	-	-	0.53	$lf4$	0.73	$lf3$	0.71	$lf3$

Figure 4. The result of the hybrid assessment and the derivation of the linguistic level

Thus, monitoring the fatigue level of air traffic controllers using the designed software solution was demonstrated.

A nine-step algorithm was developed to construct a software solution for the hybrid assessment of the air traffic controllers' fatigue level. The algorithm checks the level of fatigue using acceptable levels. The first level is a fatigue check based on the logic of determining the percentage of the closed eye, which is determined based on video surveillance. The next level is peer review. The third level is a check based on a generalized quantitative assessment of the fatigue of air traffic controllers, which is obtained in a hybrid way, that is, a combination of video surveillance data and experts' conclusions. Any non-compliance with the permissible levels results in an automatic notification to the DM. Algorithmic support and software were tested and configured based on real data, where the participants of the experiments were students of the Aviation Faculty of the Technical University in Košice.

The study uses modern methods such as fuzzy set theory, expert evaluation, intelligent data analysis, and pattern recognition, which improves the accuracy of determining air traffic controllers' fatigue levels. The advantage of the development lies in the combination of technical data from video surveillance and expert assessments. With the ability to adjust the settings levels, the software is suitable for both civil and military aviation, making it versatile in application.

A limitation of this study is that it may be difficult to accurately determine whether the eyes are fully open or closed when using video surveillance to determine the degree of eye closure in real-time. This affects the quality of the received input data. Additionally, changes in lighting, glare, and the position of the user's head can interfere with accurate analysis, leading to false or incomplete conclusions. The lack of a variety of testing conditions also limits the general validity of the obtained results for a wide range of users. Another limitation is the problem of choosing membership functions to formalize logical derivation. These limitations may lead to ambiguity in the results but do not affect their reliability. The obtained scientific and practical conclusions fully confirm the validity and rationality of the conducted research.

4. CONCLUSIONS

The main goal of the conducted research is developing a software solution for monitoring air traffic controllers' fatigue level using expert opinion. For this purpose, a step-by-step algorithm for the hybrid assessment of air traffic controller fatigue level ($HATC$) – was developed for the first time. Its value lies in the fact that, on the one hand, it considers data from video surveillance and image processing to determine the percentage of closed eyes, which indicates that a person is in a state of fatigue, and on the other hand, it considers the opinions of experts. The algorithm is designed to work dynamically and involves experts only if needed. For the first time, a software solution for monitoring air traffic controllers' fatigue levels was constructed using the TypeScript programming language and the React library. At the output, a generalized quantitative assessment and linguistic complex level of fatigue of air traffic controllers is obtained. In case of significant fatigue, the software automatically notifies the DM, allowing timely measures to be taken, such as suspending the dispatcher from work.

Further research is planned with an emphasis on verifying the technology on a wider sample of air traffic controllers. This will allow more precise adjustment of the software solution, which will ultimately improve the quality and accuracy of the results obtained.

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