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Design and implementation of a warning system for detection of sleepiness/drowsiness/sleep state in pilots

Pilotlardaki dalgınlık/uyuklama/uyku durumlarının tespitine yönelik ikaz sistemi tasarımı ve gerçekleştirilmesi

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Abstract

This study introduces a warning system designed for small training aircraft pilots flying below 10000 feet. The system detects the pilots' sleepiness/drowsiness/sleep states. If the system detects such an undesirable situation, it immediately transfers the image of that moment to the predetermined cloud service and activates the warning system consisting of audio and vibration equipment so that the pilot can escape from the current situation and recover. The warning system continues to operate until the pilot exits in that situation. The basic hardware used to implement the system is a Jetson developer kit, a Jetson Wi-Fi module, a vibration motor, a motor control circuit, and a camera. Tests of the designed system were carried out under two main headings: eye condition and head/neck position. In the tests performed according to eye condition, situations in which the eyes are constantly open (sleepiness) and situations in which the eyes are closed (drowsiness) are considered. In the tests performed with and without glasses, depending on the head/neck position, the cases of head tilting forward, backward, right, and left (sleep situation) were examined. It has been observed that the designed system successfully detects the relevant situations in all tests, both warning the pilot and sending the images of that moment to the cloud service.

Keywords: Aircraft, Crash, Sleepiness, Drowsiness, Sleep, Pilot warning.

Öz

Bu çalışmada 10000 feet altında uçan küçük eğitim uçağı pilotları için tasarlanmış bir uyarı sistemi tanıtılmaktadır. Sistem pilotların dalgınlık/uyuklama/uyku durumlarını tespit etmektedir. Sistem böyle bir istenmeyen durum tespit ederse o ana ait görüntüyü hemen önceden belirlenmiş bulut servisine aktarır ve pilotun mevcut durumdan kurtulup kendine gelebilmesi için ses ve titreşim ekipmanlarından oluşan uyarı sistemini devreye sokmaktadır. Pilot o durumdan çıkana kadar uyarı sistemi çalışmaya devam eder. Sistemi hayata geçirmek için kullanılan temel donanımlar Jetson geliştirici kiti, Jetson Wi-Fi modülü, titreşim motoru, motor kontrol devresi ve kameradır. Tasarlanan sistemin testleri göz durumu ve baş/boyun pozisyonu olmak üzere iki ana başlık altında gerçekleştirilmiştir. Göz durumuna göre yapılan testlerde gözlerin sürekli açık olduğu durumlar (dalgınlık hali) ve gözlerin kapalı olduğu durumlar (uyuklama hali) dikkate alınmıştır. Gözlüklü ve gözlüksüz olarak yapılan testlerde baş/boyun pozisyonuna bağlı olarak başın öne, arkaya, sağa ve sola eğilmesi (uyku durumu) durumları incelenmiştir. Tasarlanan sistemin tüm testlerde ilgili durumları başarılı bir şekilde tespit ederek hem pilotu uyardığı hem de o ana ait görüntüleri bulut servisine gönderdiği gözlemlenmiştir.

Anahtar kelimeler: Uçak, Kaza, Dalgınlık, Uyuklama, Uyku, Pilot ikazı.

1 Introduction

Sleepiness (absent-mindedness), drowsiness, and sleep, which occur especially while driving and cause accidents, are different situations in terms of mental and physiological processes. Sleepiness is the state in which the mind becomes disconnected from the environment by failing to focus. The sleepiness individual is aware of his/her surroundings, but his/her attention is distracted. Drowsiness is a condition seen during the transition to sleep, in which consciousness becomes blurred, eyelids become heavy and reactions slow down. In contrast, sleep is a process in which consciousness is completely closed and physiological and mental rest occur. The main difference between these three situations is the level of consciousness and physiological reactions. While a person can react to their surroundings during absent-mindedness, reflexes slow down during drowsiness, and micro sleep attacks may occur. In the sleep state, consciousness is completely disabled and the body goes into rest mode. Sleepiness occurs especially due to reasons such as insufficient sleep or fatigue and can lead to accidents if left unchecked. Absent-mindedness is usually caused by psychological factors, drowsiness by sleep deprivation, and sleep by a biological need. Absent-mindedness is usually caused by psychological factors, drowsiness is caused by sleep deprivation, and sleep is caused by a biological need. While sleep is regulated by the circadian rhythm, drowsiness can be a warning sign that this rhythm is disrupted. Absent-mindedness is associated with a lack of attention or low

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motivation. In an interview with a pilot who flies a small training aircraft, it was stated that these situations begin to occur after a certain period of time after take-off during 3-4 hours solo flights and the eyelids become heavy and tend to close [1].

In order to prevent these undesirable situations, first of all, vehicle users should get enough sleep. However, the widespread use of social media and technological devices today causes disruption of sleep patterns. This has a negative impact on work life. In a study by Salvendy [2], it was revealed that in the last century, people reduced the duration of night sleep by 20%, which led to a lower performance the next day and an increased likelihood of making mistakes.

However, even if the vehicle user has had enough sleep, some other factors can cause the vehicle user to feel sleepy. For example, driving immediately after an overeaten meal, traveling during sunrise/sunset or traveling alone may cause the driver to feel sleepy. Therefore, in such cases, it is necessary to detect and warn the driver of the vehicle. This is even more necessary in aircraft. Because it is a fact expressed by pilots that the pilot gets sleepy after a certain period of time in airplanes such as small training airplanes, where flights are usually made alone, and that the pilot snacks on nuts and nutshell foods to prevent this.

There are different methods used to detect fatigue and sleepiness. It is possible to examine them under four main headings: physiological-based methods, methods based on vehicle dynamics, methods based on behavioral characteristics, and methods based on combining multiple features [3].

Physiologically based methods analyze driver biological signals such as electroencephalography (EEG), electrocardiogram (ECG), electromyography (EMG) and electrooculography (EOG) to detect driver fatigue [4]. These methods provide high accuracy and precision. However, they require the use of complicated equipment and devices that may cause discomfort to the driver. Therefore, they are usually used in laboratory settings due to these difficulties in practical use.

Methods based on behavioral characteristics are called behavioral feature-based methods, which focus on the driver's physical characteristics and behaviors such as blinking, head tilt, yawning and facial expressions [5]. Since it is based on the driver's behavior, it provides a non-intrusive and natural observation. Therefore, it does not disturb the driver during detection. Accuracy has increased with the development of computer vision techniques and it is a low-cost and useful method. However, it can be affected by factors such as lighting conditions and whether the driver is wearing glasses or not.

Vehicle dynamics-based methods detect driver fatigue by monitoring vehicle speed, steering angles and lane violations [6]. These methods are relatively simple and convenient. They do not require much additional hardware because data about the road and driving can already be collected through the vehicle's sensors. However, they are seriously affected by driving habits, environmental factors and road conditions. In addition, they cannot be used in rail systems due to their structure.

Methods based on combining multiple features, where physiological, vehicle dynamics and behavioral data are evaluated together, have the highest accuracy rate. This is because they provide a more comprehensive analysis by combining data from multiple sources. This means maximizing the accuracy rate by using the advantages of each method [7]. However, processing data from multiple sources and using more sensors requires the use of hardware capable of processing them in a short time. Therefore, this method is both more complex and has a higher cost.

The comparison of these methods is summarized in Table 1. Academic studies using these methods are also shared in Table 1.

Table 1. Fatigue detection methods and comparison

Related methods and academic studies in which they are used	Description	Advantages	Disadvantages	Uses
Physiologically based methods [4, 8-23]	Fatigue detection based on biological signals such as EEG, ECG, EOG	- Provides high accuracy. -Biological signals are measured directly	-Electrodes need to be connected to the driver. -Often intrusive and expensive	Research laboratories, medical applications
Methods based on behavioral characteristics [5, 24-41]	Monitoring external behaviors such as blinking, facial expressions, head movements	-Less intrusive. -Applicable with cameras and image processing techniques	-May be affected by lighting conditions. -Variation in facial expressions can reduce accuracy	In-car camera systems, driver monitoring
Methods based on vehicle dynamics [6, 42-46]	Detection based on vehicle movements and driving performance (steering angle, lane violations, etc.)	-No additional hardware required. -In-vehicle sensors can be easily integrated	-Affected by road and traffic conditions. -Personal driving habits can change the outcome	Commercial vehicles, fleet management
Methods based on combining hybrid features [7, 47-52]	Fatigue detection by combining physiological, physical and vehicle data	-Highest accuracy rate. -Provides more precise analysis with multiple data sources	-Costly and complex systems. -Can be difficult in real-time applications	Applications requiring high precision

When academic studies using methods based on physical characteristics are examined, it is seen that eye closure percentage (PERCLOS), eye aperture rate (EAR) or yawning are generally taken into account. As is well known, PERCLOS is a measurement that monitors how long a driver's eyelids remain closed. Long closed eyes are considered a sign of fatigue. EAR calculates the blink frequency and detects fatigue by measuring the distance between certain facial points around the eyes. Lip distance is used to detect yawning.

In [27], [29], [32], [35] and [36], PERCLOS was used as the basis for driver fatigue detection. These studies have also achieved high rates of success. However, the common problem in all of these studies is that the case of the driver wearing sunglasses during the tests was never analyzed. As it is known, the system cannot detect whether his/her eyes are open or closed in case the driver wears sunglasses. Therefore, the proposed systems are ineffective when sunglasses are worn. In the literature, hybrid methods that evaluate physiological and behavioral features together have been proposed to overcome this problem. However, the necessity of wearing devices that may cause discomfort to the driver to collect data is a major disadvantage for vehicle users. In [51], it can be thought that this disadvantage does not exist because the relevant sensor that will collect physiological data is mounted on the steering wheel. However, this time, the vehicle user must constantly position his hand on that sensor. This is also not a realistic approach.

A literature review was conducted on the existence of aviation-specific studies that monitor the alertness of pilots and, when necessary, alert them and send information about their state to a predetermined system. In this review, the work by Zallen, et al. [53] stands out. In [53], the head movements of pilots during flight simulations were monitored in six degrees of freedom (6DOF) and these movements relationship with pilot fatigue and attention loss was investigated in a simulator environment. NaturalPoint TrackIR4 head tracking system was used to measure head movements. However, in order for this system to work, the system component named TrackClip must be attached to a helmet worn by the pilot during the test.

Some of the prominent studies on pilots and their fatigue can be summarized as follows: Identifying the factors affecting pilot fatigue based on surveys conducted on 80 randomly selected pilots [54]; analyzing pilot fatigue based on EEG signals obtained from pilots during flight simulations [55-59]; monitoring the pilot's cognitive state using a chest strap with disposable electrodes directly attached to the left hypochondrium, and a camera [60]; obtaining and analyzing the sleep duration of pilots before, during and after an ultra-long flight from a smart wristwatch they wear [61]; trying to improve flight safety by using equipment to monitor the pilot's pupil and changes in pupil size [62, 63]; investigating the consequences of fatigue and excessive workload in aviation [64]; investigating the fatigue and neurophysiological parameters caused by the frequency of flight operations in pilots [65]; obtaining a mathematical model of pilot fatigue using real data from an airline company and assigning flights based on the fatigue parameter obtained from this model [66]; comparing the disorders seen in military helicopter pilots and cabin crew [67]; examining the human factor in incidents and accidents in military aviation in terms of fatigue [68]; trying to determine the pilot's fatigue and sleepiness from the voice conversation recordings made with the tower before the flight [69]; analyzing how flight programs affect pilot fatigue [70]; analyzing stress, sleep disturbance and fatigue among pilot and non-pilot university students [71].

In [72], which emphasized that it was conducted for pilots, it was stated that fatigue was detected by examining the state of the eye from one-minute video recordings of 37 students. In [61], PERCLOS method was used to detect pilot fatigue. However, in both studies, the wearing of sunglasses was not examined at all.

As can be seen, these summarized studies are generally related to flight fatigue and its causes. In the fatigue determinations based only on PERCLOS, the fact that the pilot may have been wearing sunglasses was not taken into consideration at all.

The main motivation of this work is to prevent potential loss of life and property by alerting small trainer pilots, especially those flying solo, in such situations. The innovations in this study are as follows:

- If the pilot wears sunglasses, making a determination by taking into account neck movements
- Instantaneous notification of the pilot's status to a predetermined system with an image as soon as a detection is made
- Audible and vibrating warning to the pilot upon detection
- When the warning system is active, the warnings continue until the pilot changes his/her current state

In the second part of the study, after presenting the system components, the operation of the designed system is explained in detail and the algorithm is given. In the third section, where the system tests are described, the tests performed for a total of six different cases under two subheadings are shared. The results obtained are summarized in the conclusion section.

2 Materials and method

2.1 Programming language and hardware

The cockpit of training aircraft is small due to the fact that the aircraft is one or two-seater. This is a factor that affects the material selection during the design of the system. Otherwise, it will not be possible to integrate the designed system into the cockpit.

The software components of the pilot warning system are developed with Python. The basic hardware used is as follows:

- Jetson developer kit
- Jetson Wi-Fi module
- Vibration motor
- Motor control circuit
- Headset
- AUX converter

- Camera

A schematic showing these hardware components and their connection patterns is given in Figure 1. The direction of the arrows in Figure 1 indicates the direction of data/energy flow.

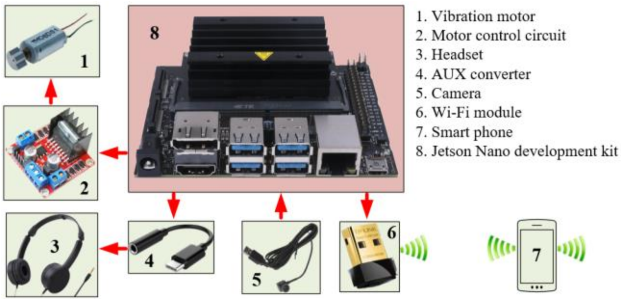


Figure 1. Connection diagram of the hardware used**.**

2.1.1 Python

Python is a high-level programming language that has an important place in popular areas such as data analysis and machine learning. It has a simpler structure compared to other programming languages. It has a rich and powerful library that is updated every day and can be easily integrated with third-party software. In this way, it is possible to get a wide library support. The image processing and face detection codes in this study were written in this programming language.

2.1.2 MediaPipe (Face Mesh ve DLIP)

MediaPipe is an open-source machine-learning platform developed by Google. It is especially optimized for real-time image processing and tasks such as hand, face, and body tracking.

Face Mesh is a model within Mediapipe. It uses a deep learning-based convolutional neural network (CNN) model. The model first detects the face in any image and crops it to the appropriate size (Figure 2). Then it extracts 468 key points for the face. As can be seen in Figure 3, this algorithm identifies distinctive regions on the face such as eyes and lips. The model then estimates the coordinates of each landmark in two and three-dimensional space. Since the numerical equivalents of limbs such as eyes, nose, and lips in landmarks are known, their locations can be easily found. Since these operations can be performed in milliseconds, this model makes it possible to track moving faces in real-time.

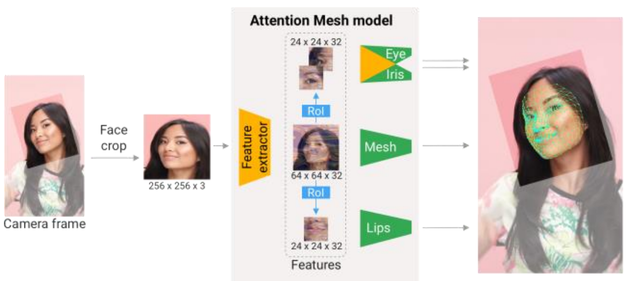


Figure 2. Working principle of Face Mesh metric

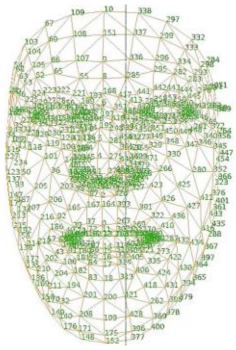


Figure 3. 468 key points in the Face Mesh metric

DLIP (Deep Learning Image Processing) is also an open-source library. It contains machine learning algorithms and tools. The main purpose of the DLIP library is both to detect points on the human face such as the chin, eyes and nose, and to detect the presence of objects such as glasses, etc. that people wear on their faces. In this study, DLIP and Face Detection metric work simultaneously to detect the pilot wearing sunglasses. The 'DLIB Face Recognition' model, which includes many pre-trained models, is used to distinguish between sunglasses and normal glasses.

2.1.3 Jetson developer kit

The Jetson developer kit from NVIDIA is the ideal solution for rapid development and testing of artificial intelligence (AI) applications. It includes a high-performance processor, graphics unit, and memory. It comes as part of the NVIDIA JetPack SDK. The JetPack SDK provides developers with all the tools needed for AI applications and includes TensorRT, cuDNN, CUDA, and other NVIDIA software libraries. These libraries are designed to accelerate and optimize AI applications. The kit consumes maximum 1.25W power with no peripherals attached.

2.1.4 Jetson Wi-Fi module

As it is known, the connection of the Jetson Nano development board to the internet is made with the Ethernet port on it. In other words, it does not have any hardware on it to access the internet over a wireless connection. Since the work to be done involves transmitting the images taken from the aircraft to the earth via the internet network created by the pilot's cell phone and the internet capability of the cell phone, the Jetson Nano development card must be capable of connecting to a wireless network connection. For this reason, the Jetson Wi-Fi module model TP-LINK TL-WN725N was used. This module provides fast and wireless communication up to 150Mbps.

2.1.5 Motor control board

It was used to control the direct current (DC) motor, which allowed the pilot to be physically stimulated by vibration. The DC control circuit controls the voltage and current levels of the DC, adjusting them to the desired values and providing a stable output. The DC motor driver model used is L298N. Designed to drive DC motors up to 24V, the driver board has two channels and provides 2A of current per channel. It also has high temperature and short circuit protection.

2.1.6 Audible and physical warning components

A headset and vibration motor are used to warn the pilot. These components are activated simultaneously according to the commands when the pilot needs to be warned.

A Mitsumi TMC6D31 vibration motor was used as the vibration device. The motor has a diameter of 8mm, a length of 21mm, a speed of 14000 rpm, and an operating voltage in the range of 3.3V-5V. The motor was mounted on the back of the pilot's seat.

The headset used for the audible warning is a standard headset with no additional features.

2.1.7 AUX converter

The natural structure of the headset socket is AUX. However, the Jetson Nano development kit does not have an AUX input. So a USB to AUX converter was used to give the pilot an audible warning.

2.1.8 Camera

Since the designed system is based on image processing, it requires a high camera resolution. For this reason, a button-type camera with a resolution of 1280x720 was preferred. The camera, which has a USB 2.0 input and a normal-angle lens, is positioned in the cockpit so that it can see the pilot comfortably as shown in Figure 4.

Figure 4. Positioning the camera to focus on the pilot's face

2.1.9 Smart phone

Internet systems used in passenger airplanes can be used to transfer the images to the cloud service. In this case, there is no problem in transferring the images regardless of the altitude. However, due to both cost and supply problems, cell phone internet was used in the designed system. As it is known, cell phone internet can provide service up to an altitude of approximately 10000 feet. Although the altitudes at which basic training aircraft fly vary depending on the model of the aircraft, they are between 5000 and 10000 feet on average. Therefore, it is sufficient to use cell phone internet for testing the designed system.

2.2 Algorithm of the designed system

The face mesh algorithm creates landmarks around the two eyes. Some of these landmarks represent the horizontal edges of the eye and some represent the vertical edges. The distance between certain landmarks on the left and right edges of the eye is called the horizontal distance. The distance between certain landmarks on the upper and lower edges of the eye is called the vertical distance. Horizontal and vertical distances are calculated as in Equation (1) and (2). As is well known, to avoid negative distances in the calculations, the square of the parentheses is first squared and then the square root is taken.

$$Horizontal\ Distance = \sqrt{(x_2 - x_1)^2} \tag{1}$$

$$Vertical\ Distance = \sqrt{(y_2 - y_1)^2} \tag{2}$$

Where:

x_1, x_2: Horizontal (X) coordinates of the points on the left and right sides of the eye.

y_1, y_2: Vertical (Y) coordinates of the points at the top and bottom of the eye.

The horizontal distance value is not much affected by whether the eye is open or closed. However, the vertical distance value is affected. This is because when the eye is closed, the coordinates of the points on the upper and lower edges of the eye move closer together. The face mesh algorithm tries to determine the state of the eyes by relating these horizontal and vertical distances, as in Equation (3).

$$Blink\ Ratio = \frac{Horizontal\ Distance}{Vertical\ Distance} \tag{3}$$

When the eye is closed, the horizontal distance remains constant while the vertical distance shrinks, and the ratio increases accordingly. If the ratio exceeds a certain threshold, the eyes are assumed to be closed; if not, they are assumed to be open. This threshold value is therefore a critical parameter for making sense of the blinking movement. This rate increases with each blink and decreases when the eye is opened. In the designed system, if the blink rate remains above a certain threshold for a certain period of time, the warning system is activated.

The average blink rate in normal healthy individuals is between 10–20 blinks per minute, which means that a person blinks every 3 to 6 seconds on average [73]. Based on this reference, the maximum eye open time in the designed system was determined as 7 seconds.

When detecting sunglasses, the face is first detected. Then the eyes and glasses are determined. 'FaceDetector' is used for face detection, and 'FaceRecognition' metric is used for eye and glasses detection. After detecting the face, the midpoint of the eyes is first calculated, and then the glasses areas are determined. Finally, coordinate calculation is made. While the pilot is wearing glasses, an estimated position is assigned to the point where the pilot's eyes are located. With this assignment, green dots are left on the estimated eyes to resemble the shape of eyes. Even if the eyes show the opening and closing reflex while wearing glasses, the system normally guesses that the eyes are open, since the camera cannot detect this. However, at this stage, the system waits for three seconds and then checks the glasses. If there are glasses, it warns "GLASSES DETECTED". After this moment, the system starts to predict the pilot's condition based on head/neck movements.

Fatigue detection based on the pilot's head/neck movement is made based on facial landmarks. Landmarks remaining in the same coordinates for a certain period of time means neck immobility. The angle between certain areas of the face is monitored to detect whether the head is tilted in any direction. Facial landmarks shift horizontally when the head is tilted to the right or left. When the head is tilted up or down, the distance between the chin and the eyes changes. Therefore, by monitoring these changes and the duration of stay in that location, it is decided whether the pilot warning system will be activated or not.

The outlines of the algorithm used to detect the pilot's sleepiness/drowsiness/sleep states are given in Figure 5. As can be seen from the algorithm, the designed system first detects faces. Then, it checks whether the head is tilted in any direction. If it detects bending in any direction, it waits for the set time and checks again. If the head remains tilted at the last check, it activates the warning system. If not, it switches to detection based on eye closure rate.

In the detection phase based on the eye closure rate, the eyes are detected again and the presence of sunglasses is investigated. If eyes are detected, the presence of sleepiness/drowsiness/sleep is investigated by calculating the closing rate of the eyes. If one of these situations is detected, the appropriate warning system is activated and the process starts again.

However, if the eyes cannot be detected, then the presence of sunglasses is investigated. If sunglasses are not detected in this search, the algorithm returns to the beginning. But if it is detected, the current position of the head is detected immediately and the position of the head is followed for a certain period of time. If there is no change in the position of the head during the period, that is, if it remains motionless, then the relevant warning system is activated and the algorithm returns to the beginning again.

3 Tests of the designed system

In order to determine the pilot's condition, the head/neck must remain tilted or motionless in any direction for a certain period of time, or the open/closed periods of the eyes must be evaluated separately. Since the pilot's wearing sunglasses also affects the detection of these situations, separate tests were conducted for the situations without glasses and with glasses.

The tests were conducted after connecting a monitor to the Jetson Nano running the designed system. In this way, it was possible to compare the raw pilot image on the monitor, which has different data and information, with the image sent to the cloud. When the system is turned on, the following information is included in the image displayed on the monitor.

- The number of images captured by the camera in one second (FPS).
- Total number of blinks
- How long have the eyes been open/closed?
- Warning message generated when eyes remain open/closed for more than a specified time (picture taken, sent to the cloud, cloud warned, etc.)
- In which position the head remains fixed
- Information about when the pilot is detected to be wearing glasses

Which of these information will appear on the screen varies depending on the pilot's situation.

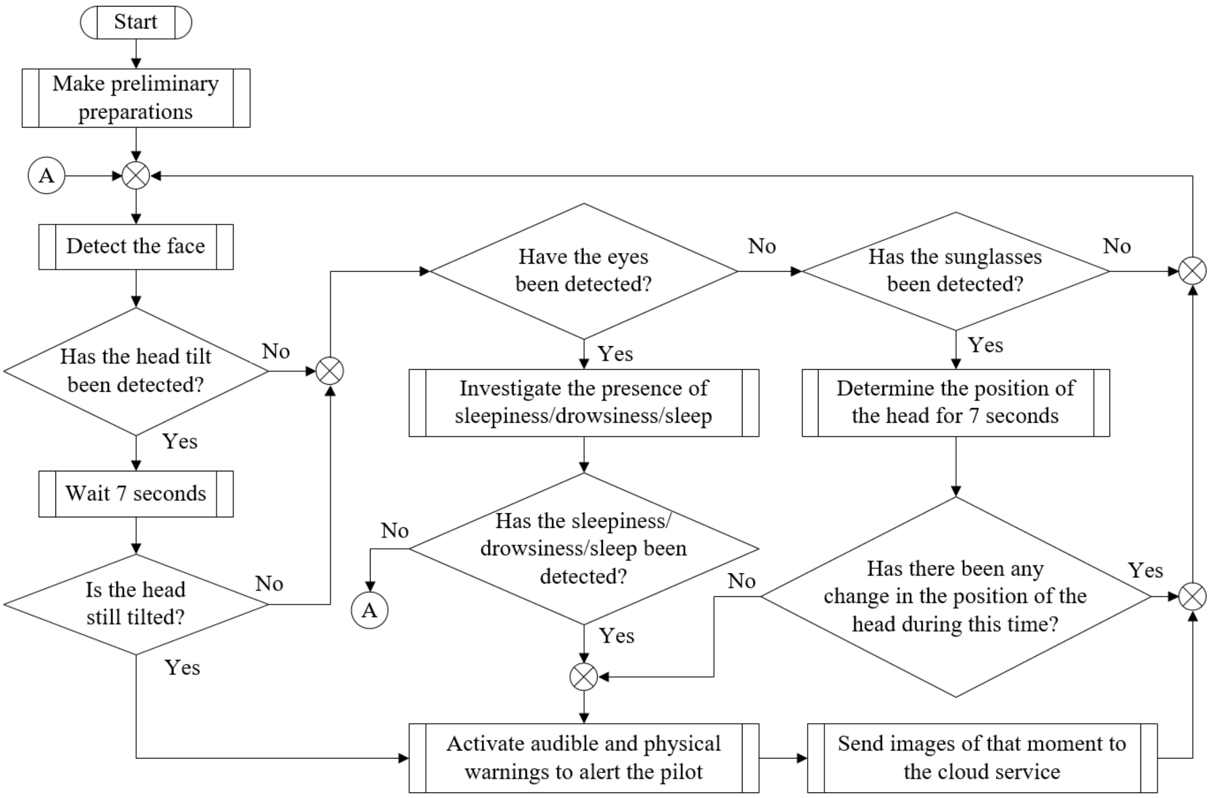


Figure 5. Basic algorithm used to detect sleepiness, drowsiness and/or sleep

3.1 Perception test according to eye condition

In the first stage of the tests, the pilot's ability to keep his eyes open for a long time (sleepiness) was examined. Figure 6 is a screenshot from the monitor connected to the Jetson Nano if the pilot keeps his eyes open for a long time. Since the time the eyes remained open during the test exceeded 7 seconds, the audible and vibration alarms of the designed system were activated. In addition, the snapshot taken at that moment, seen in Figure 7, was sent to the cloud service with the relevant error message added.

Figure 6. Screenshot showing the situation where the eyes are constantly open

Figure 7. The situation where the eyes are constantly open and sent to the cloud service

In the second stage of the test, the pilot kept his eyes closed for a long time (drowsiness) and the test image related to this is given in Figure 8. The pilot's normal duration of keeping his eyes closed is set to 7 seconds, just like the open duration. Since the duration of eyes closed during the tests exceeded 7 seconds, the audible and vibration alarms of the designed system were activated. In addition, the snapshot taken after 7 seconds up (Figure 9) was sent to the cloud service with the relevant error message added. After this process, the system continues counting. The reason for this is to enable the pilot to save himself from an undesirable situation thanks to the relevant alarms. As can be seen from Figure 8, although the set time of 7 seconds has passed and the 16th second has been reached, the current situation in question still continues.

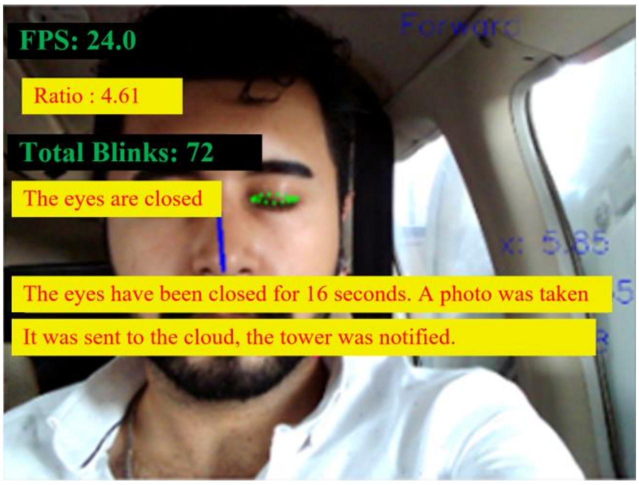


Figure 8. Screenshot showing the eyes closed situation

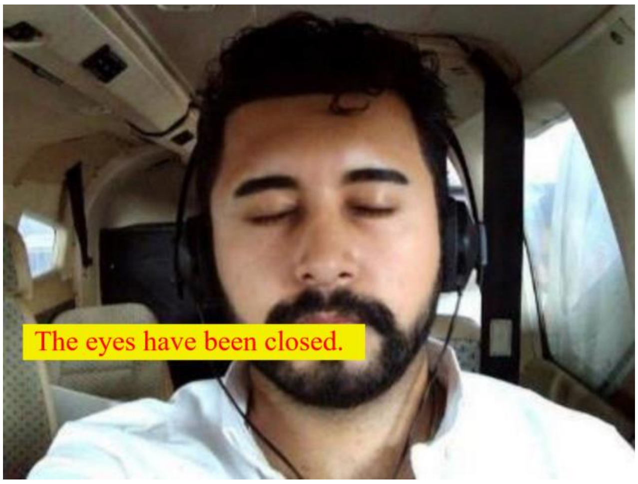


Figure 9. Eyes closed situation sent to cloud service

3.2 Detection test based on head/neck position

In this part of the test, detection based on the pilot's head/neck movements was examined. When the pilot's head is tilted in any direction, the neck-related image processing algorithm is activated, independent of the eyes and glasses.

First, the pilot's head tilt forward while wearing glasses was examined. A screenshot of these tests is shared in Figure 10. When Figure 10 is examined, it is understood that when the pilot's head is tilted forward while wearing glasses, the algorithm is activated independently of the eyes and glasses, and since the tilt of the head lasts longer than the set threshold value, it takes the image of that moment and sends it to the cloud. The snapshot taken as soon as the set time was reached and seen in Figure 11, was sent to the cloud service with the relevant error message added. Additionally, an audible and vibration warning system has been activated.

In the second test, the pilot's head tilt backward was examined. The screenshots taken during these tests with and without glasses are given in Figure 12. It is understood from Figure 12 that when the pilot's head falls back, the neck-related image processing algorithm is activated, independent of the glasses and eyes, and when the set time passes, pictures of those moments are taken and sent. Those images sent to the cloud service, with the relevant error message added, are shared in Figure 13.

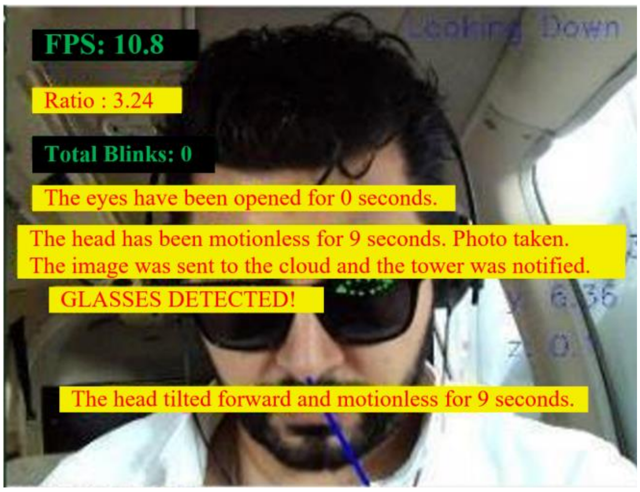


Figure 10. Screenshot showing the forward (down) position of the head

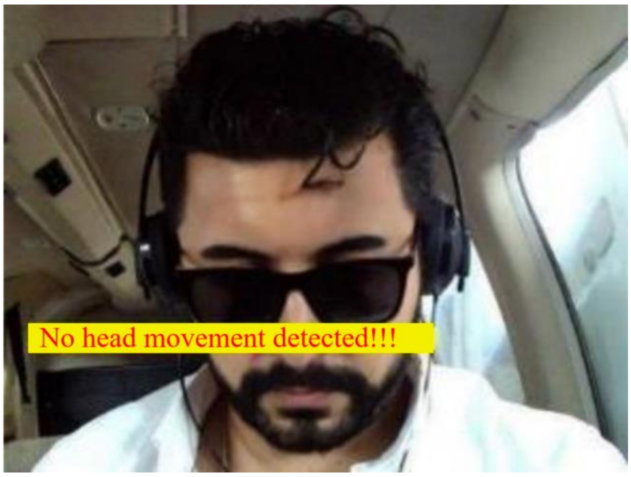
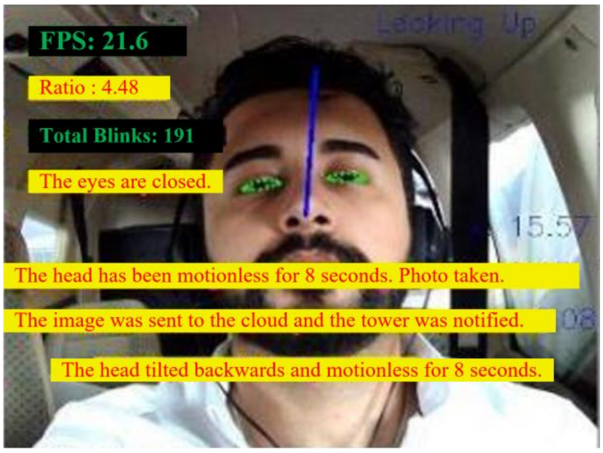


Figure 11. Visual showing the forward (down) position of the head coming to the cloud service

In the third test in this section, the pilot's head tilt to the right was examined. Screenshots taken during these tests with and without glasses are given in Figure 14. It is understood from Figure 14 that when the pilot's head falls to the right, the neck-related image processing algorithm is activated, independent of the glasses and eyes, and when the set time passes, pictures of those moments are taken and sent. Those images sent to the cloud service, with the relevant error message added, are shared in Figure 15.

In the fourth and final test, the pilot's head falling to the left was examined with and without glasses. Screenshots taken during the tests are given in Figure 16. When the pilot's head fell to the left, the neck-related image processing algorithm activated again and worked as expected. The images sent to the cloud service are seen in Figure 17.

(a)

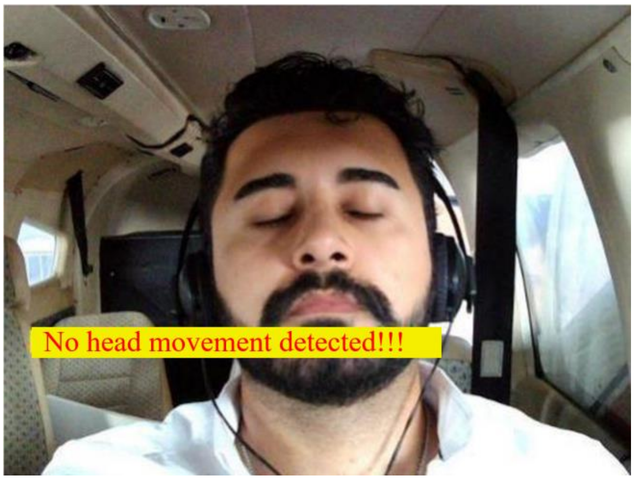


(b)

Figure 12. Screenshots showing head position backwards (up) (a) Situation with glasses (b) Situation without glasses

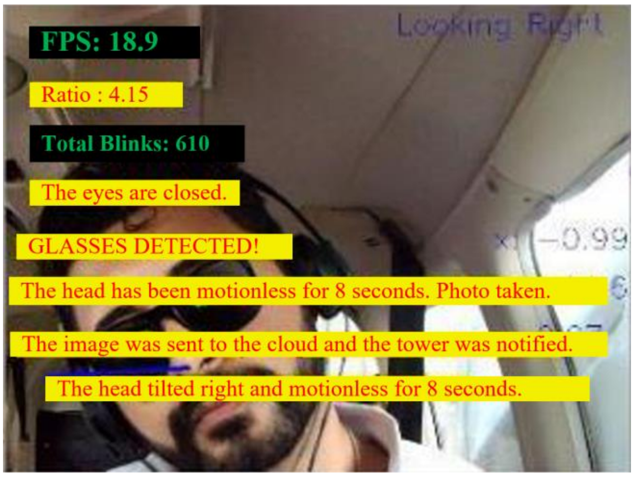
(a)

Figure 13. Visual showing the backward (up) position of the head coming to the cloud service (a) Situation with glasses

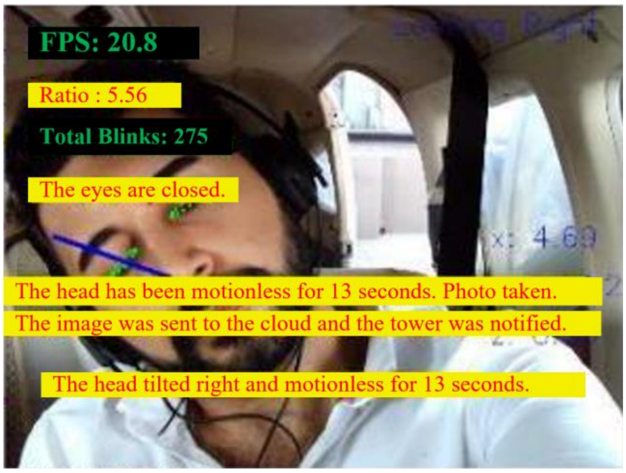


(b)

Figure 13 (continued). Visual showing the backward (up) position of the head coming to the cloud service (b) Situation without glasses

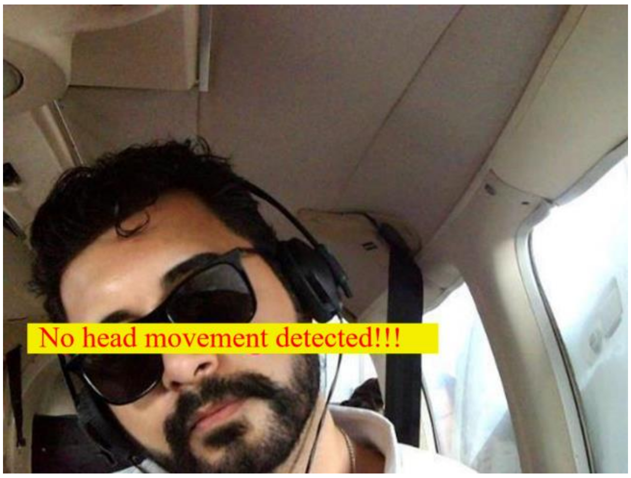


(a)



(b)

Figure 14. Screenshots showing the head drooping to the right (a) Situation with glasses (b) Situation without glasses



(a)

(b)

Figure 15. Visual showing the right position of the head coming to the cloud service (a) Situation with glasses (b) Situation without glasses

(a)

Figure 16. Screenshots showing the head drooping to the left (a) Situation with glasses

(b)

Figure 16 (continued). Screenshots showing the head drooping to the left (b) Situation without glasses

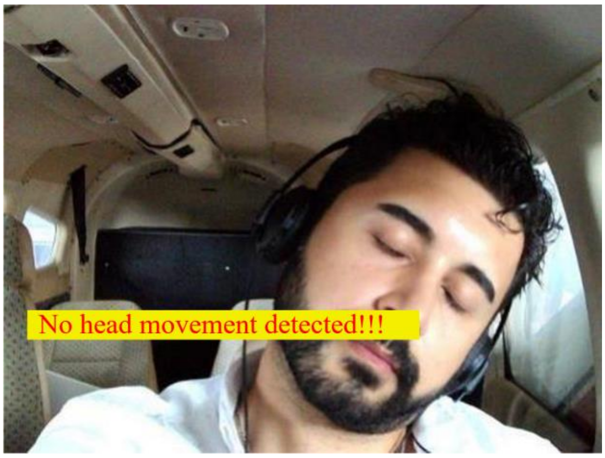
4 Discussions

The system developed in this study monitored pilots' eye opening and head/neck position to detect absentmindedness, drowsiness, and sleepiness. Tests demonstrated that the system operated accurately in targeted scenarios and activated its warning mechanisms promptly. These findings demonstrate that a low-cost and easily implemented approach can be effectively used to monitor pilot fatigue in small training aircraft.

The system's performance was summarized through the analysis of screen outputs from selected scenarios. As shown in Table 2, the system produced the expected outputs accurately in all cases, and there was a complete match between the observed conditions and the system detections.

The results in the table indicate that the system performed reliably in all tested scenarios. However, the tests were limited to daytime conditions and a small number of participants. Conducting tests under different lighting and weather conditions, with larger participant groups and multiple repetitions, would provide stronger evidence for the system's generalizability and performance. Furthermore, integrating AI-based predictive algorithms in future studies could enable not only the detection of current states but also the early prediction of fatigue.

(a)



(b)

Figure 17. Visual showing the left position of the head coming to the cloud service (a) Situation with glasses (b) Situation without glasses

Table 2. Evaluation of the accuracy of system outputs through sample scenarios

Scenario	System Output	Expected Output	Accuracy
Eyes open (Figure 6)	"The eyes have been open for 7 seconds"	Eyes open	Correct
Eyes closed (Figure 8)	"The eyes have been closed for 16 seconds"	Eyes closed	Correct
Head tilted forward (Figure 10)	"The head tilted forward and motionless"	Head tilted forward	Correct
Head tilted back + glasses (Figure 12a)	"The head tilted backwards and glasses detected"	Head tilted back + glasses on	Correct
Head tilted back (Figure 12b)	"The head tilted backwards and motionless"	Head tilted back	Correct
Head tilted right + glasses (Figure 14a)	"The head tilted right and glasses detected"	Head tilted right + glasses on	Correct
Head tilted right (Figure 14b)	"The head tilted right and motionless"	Head tilted right	Correct
Head tilted left + glasses (Figure 16a)	"The head tilted left and glasses detected"	Head tilted left + glasses on	Correct
Head tilted left (Figure 16b)	"The head tilted left and motionless"	Head tilted left	Correct

5 Conclusion

In this study, a warning system was developed for pilots of small training aircraft operating below 10,000 feet. The system is designed to detect states of sleepiness, drowsiness, and sleep by monitoring eye conditions and head/neck positions. When such a state is detected, the system activates a warning mechanism (sound and vibration) and sends an image of the moment to a predefined cloud service. The warning continues until the pilot exits the detected condition.

The system was tested in two main categories: eye state (open or closed) and head/neck position (tilted forward, backward, right, or left). Tests were conducted both with and without glasses. The system successfully detected all targeted conditions in each scenario, and responded correctly by alerting the pilot and sending relevant visual data.

These results indicate that the system can be used effectively to monitor pilot fatigue and provide timely warnings. Although the tests were conducted under daylight conditions, the system can be adapted for night use with infrared cameras. Additionally, performance issues due to overheating can be prevented by using appropriate cooling mechanisms such as high-efficiency fans.

The system will address a critical gap in aviation safety by mitigating fatigue-related risks in low-altitude training flights, where pilot alertness is paramount.

Future work will focus on optimizing the system for diverse lighting and weather conditions, as well as exploring AI-driven predictive analytics to preempt fatigue before critical stages. This technology not only enhances pilot safety but also sets a foundation for next-generation aviation monitoring systems.

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Conflict of interest

The author declares no conflict of interest.

Similarity rate (iThenticate): 9%

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