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Research on the Layout and Configuration of Aircraft Cockpit Sensor Network for Pilot Behavior Recognition

Yuze Zhang

College of Civil and Transportation Engineering, Hebei University of Technology, Tianjin, China
13603323397@163.com

Abstract. Flight safety encompasses a wide range of contributing factors, among which pilot behavior within the cockpit represents the most critical determinant of flight safety. The advancement of sensor technology and artificial intelligence has rendered automatic pilot behavior detection a prominent research area. Nevertheless, most existing literature focuses on data processing methodologies based on relevant algorithms, while overlooking the issues of sensor position and installation in an aircraft cockpit. Improperly positioned sensors may lead to mutual interference, resulting in the failure to record pilot movements and impeding the practical implementation of theoretical proposals in real aircraft. This paper addresses this specific technical problem. First, pilot activities that require monitoring are analyzed, and sensor types capable of meeting the requirements for behavior identification are specified. Subsequently, a scientific solution is proposed for the deployment of diverse sensors in the cockpit, which ensures full coverage of all visual fields with the minimum number of devices and minimal space occupation. Finally, the effectiveness of this method is verified through computer simulation.Results demonstrate that a carefully designed sensor layout enables high recognition rates to be achieved with the minimal number of sensors.

Keywords: Pilot Behavior Recognition, Cockpit Sensor Network, Layout Optimization, Data Fusion, Intelligent Cockpit

1. Introduction

Aviation safety is an important issue in the field and is receiving increasing attention. According to the survey, about 60% to 70% of flight accidents or emergencies are caused by human factors, with pilot errors and physical or psychological problems being the most common among these causes. The development of a system that can monitor pilots' behavior, physiological parameters and attention status can detect and deal with pilots' problems in a timely manner and also effectively increase air traffic flow.

Currently, researchers have begun to focus on the physiological state and behavioral problems of passengers in the cockpit, while existing studies mostly use different methods to obtain data. For example, eye trackers are used for fixation point analysis, electrophysiological techniques such as electroencephalogram (EEG) are used to analyze cognitive changes, physiological signal acquisition devices are used to monitor heart rate variability or skin conductance reflecting emotional changes,

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and even traditional cameras are included in such research [1]. An important aspect of Clean Sky in Europe is developing fatigue detection modules based on new technologies such as infrared thermal imaging or structured light scanning [2]. The Defense Advanced Research Projects Agency is developing a technology that combines biomarker monitoring with behavioral profiling. Researchers such as those from Nanjing University of Aeronautics and Astronautics and Civil Aviation University of China have explored pilot attitude recognition and abnormal operation alarm [3]. However, most of these efforts have focused on algorithms rather than sensor layout [4]. In contrast to the laboratory environment, the cockpit of an aircraft in the real world has more complex characteristics. It is cramped and divided into many areas, and there are various sources of interference. Without a reasonable sensor layout design, system efficiency may decline, new equipment may interfere with existing cockpit controls and pilot operation, and the lack of coordination among multimodal perception systems can lead to technical difficulties in multi-source heterogeneous data fusion.

Researchers have different views on how to understand the state of pilots while they are performing their missions. The method proposed by Liu et al. using eye trackers and seat load sensors can accurately assess the size of the pilot's workload with an accuracy rate of over 80% [5]. In addition, there is a design based on a helmet with a wearable electroencephalogram detection device that can continuously monitor pilot fatigue during flight [6]. Based on this, an alternative solution combines a vital sign monitoring wristband, a chest-mounted sensor array, and pressure pads distributed around the aircraft to obtain key parameters such as heart rate and blood pressure [7]. While they all provide accurate information, excessive use of peripherals can also cause inconvenience or affect operation for the user.

The second method mainly involves monitoring the movements or states of the target through visual perception technology. Among them, methods based on image acquisition and processing are most common examples. Researchers at Nanjing University of Aeronautics and Astronautics have proposed a lightweight method that can accurately identify and continuously track a pilot's posture during human-computer interaction in virtual reality flight training [3]. Also, a foreign team has developed a system consisting of infrared cameras with multiple perspectives that can detect subtle changes in pilots in darker conditions [2]. However, this non-contact approach has great potential for application but is vulnerable to various factors in practical use, such as light exposure, wearing glasses or helmets, etc., all of which can affect the detection effect. This method combines the advantages of both methods and compensates for the deficiency that a sensor cannot reflect the cognitive state. By analyzing multiple aspects of information such as eye fixation points, interaction behaviors, and physiology, we can gain a more comprehensive understanding of what mental state the pilot is in and how it changes. Current research shows that when performing more complex tasks, a single brain activity or movement does not effectively reflect a person's true thoughts, but combining multiple aspects can greatly improve recognition accuracy [3].

Despite significant progress in object detection, optimizing multi-sensor placement in real driving environments is still in its infancy. Therefore, this paper focuses on the relevant issues and promotes further development in the field of research. This paper attempts to break through traditional design thinking and present a comprehensive physiological monitoring system that can monitor and warn of the physical and mental conditions of pilots in adverse environments, aiming to improve the accuracy and robustness of pilot behavior recognition and steer the field toward more intelligent and efficient solutions.

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2. The core theory of pilot behavior recognition

2.1. Types of pilot behavior

Pilot driving is a rather complex process, which is simplified here into the following three categories.

The first type of behavior is operational, based on a series of physical movements made by the pilot to complete a particular flight mission as its main feature. For example, checking the instruments and pressing the buttons before starting, manipulating the aircraft's attitude and altitude during flight, lowering the landing gear and adjusting the flaps when landing, all fall into this category. Because of its strict requirements and very strong chronological order, it can be recorded with a camera [4].

Key physiological indicators include fatigue, attention, and tension. These are difficult to observe externally, so specialized detection instruments are needed. For instance, eye trackers monitor fixation point changes, while heart rate monitors measure bodily responses [5].

The third type of interaction is about the pilot's operation of various hardware such as displays, controllers, and physical buttons inside the aircraft during work, such as knob rotations and screen displays. Studying this is not only of great theoretical value but also of great practical value, on which the human-machine interaction design can be further optimized to improve work efficiency and reduce the possibility of errors caused by the interface [8].

2.2. Conditions that sensors need to meet in behavior recognition

To accurately identify all these behaviors, the installed sensor network must meet three conditions.

The first is to be able to see everything. Although the cockpit is not large, the pilot's hands have to move around, touching the control stick and pressing the panel above the head, so the sensors have to monitor all these areas without any blind spots.

Perception ability is of paramount importance. In terms of physiological parameter monitoring, it is necessary to be able to accurately identify tiny changes in eye movement, which places a high demand on the spatial position of external sensors. If it is based on visual methods, it needs to be able to solve various interferences caused by numerous complex driving environments and be able to accurately locate the main moving parts of the driver and continuously track them [3].

Reliability and timeliness are critical. Given the great threat to aviation safety, fault alerts and emergency response must be prompt, information must be obtained as soon as possible, algorithms must be used to judge and decisions must be made without the slightest delay or interruption [9].

3. Theoretical basis for the layout and configuration of sensor networks

3.1. Constraints of cockpit space

The design and layout of aircraft cockpits are highly specialized and strictly regulated. For common aircraft like the Boeing 737 and the Airbus A320, the cockpit is generally no more than 5 cubic meters, with a lot of equipment (such as instrument panels, control sticks, displays, etc.) placed inside, and the space utilization is very high. And because of the large number of electronic components, the cockpit also requires good electromagnetic compatibility, and new sensors need to be well designed and optimized to avoid affecting the aircraft's navigation and communication. All

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add-ons must be approved by the appropriate airworthiness certification body, must not obstruct the pilot's view or reduce their efficiency, and must also ensure safety and robustness [4].

To achieve the purpose of computer-aided positioning, the cockpit is abstracted into a grid by the grid method here. Each small grid has a certain function, such as the placement position of the sensor and the conditions that need to be met, etc. This transforms the practical problem into a computable mathematical problem.

3.2. Three main optimization objectives

Cockpit sensor layout optimization is essentially a multi-objective constrained optimization problem that requires seeking the optimal compromise solution among multiple mutually balanced objectives. The core revolves around the following three key optimization objectives, which have certain conflicts and need to be balanced through scientific methods [4].

The first optimization objective is to achieve maximum coverage. The sensor can "see" as many important locations as possible, such as near the joystick, which need to be within sight at all times. The second optimization objective is to optimize redundant configurations. It is necessary to find a proper balance point. Placing a large number of sensors in a certain area can enhance the reliability and robustness of the system, but too many will increase costs and cause waste of resources. So, based on the actual situation, try to minimize detection overlap as much as possible while meeting the requirements to achieve the best results and maximum utilization. The third optimization objective is to minimize interference. Sensors installed on the aircraft should be as small as possible, as close to the edge as possible, and not affect the pilot's operation with hands and feet.

These three aspects are in conflict with each other. If you want it to be large, you need to install more equipment. However, too many devices are troublesome and wasteful. Therefore, I hope to find a compromise solution instead of doing everything to the extreme in every aspect.

3.3. Solution for sensor layout based on an improved genetic algorithm

In view of the complexity and multi-objective nature of the cockpit sensor layout optimization problem, this paper uses genetic algorithm as the core solution method. This algorithm mimics the evolutionary law of "survival of the fittest" in nature and is an effective means for solving discrete position optimization problems, capable of efficiently searching for the optimal solution in multi-constraint and multi-objective scenarios [4].

This paper mainly studies the rationality and effectiveness of sensor layout in the cockpit and proposes an improved genetic algorithm based on this. All positions in the cockpit are encoded to form an initial population as the base data. Each scheme is scored under multiple objectives (such as functionality, fault tolerance, and cost, etc.), and then the better individuals are retained and the worse ones are eliminated based on the scores to maintain population diversity. After multiple iterations, the optimal sensor configuration is finally obtained. Throughout the design process, great emphasis is placed on comprehensive monitoring of key components to prevent a single point of failure from shutting down the entire system.

4. Key technical bottlenecks and challenges

Although this paper presents the overall idea of optimizing the layout of cockpit sensors, the engineering implementation and practical application of this solution still face many technical bottlenecks and challenges, which are mainly reflected in the following four aspects.

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The first problem is the difficulty in obtaining data. The study of such methods requires a large amount of high-quality data, which is very expensive and has many limitations in reality, and although some problems can be solved in simulation experiments, they cannot completely replace real-world data [1].

Mainly due to the difficulty in perception caused by the cockpit environment, the facial features of pilots vary significantly and are difficult to recognize under different lighting conditions, and the current mainstream visual sensors cannot meet this requirement. Although infrared imaging can be used as a supplement, it has poor robustness and stability in strong or weak light environments. New technologies need to be developed to enhance its robustness and stability and ensure normal operation in various environments [2].

The main problem at present is how to consistently integrate different types of data from multiple sources. Due to the fact that the camera captures approximately 30 frames per second, the inertial sensor outputs 100 motion information per second, and the electroencephalogram recorder generates more than 256 sampling values per second, precise alignment and good integration among these three different types of data require solving the problem of high-precision timestamp correction and efficient processing under high concurrency [4].

The main problem at present is the lack of a unified set of technical standards. Because the application of intelligent monitoring equipment to aviation is still a novelty, there is no complete and legally binding standard and regulation in the international community. So if different aircraft were to use this new method, they would have to apply and obtain approval, which would be very unfavorable for the work and also not conducive to the popularization and development of this technology [8].

5. Conclusion

This paper mainly studies the layout of sensors in the cockpit of aircraft for the purpose of monitoring pilot operation behavior. Under the premise of meeting flight mission requirements and safety, the main actions are analyzed and a multi-level objective optimization scheme is given based on the characteristics of the sensors themselves. This objective optimization scheme is mainly aimed at solving the conflict problem among field of view coverage, resource consumption and visual interference. On this basis, the genetic algorithm is used to solve the above objective optimization problem, verifying the feasibility and effectiveness of this method, and also providing certain guiding significance for future related research and good suggestions for practical application.

Looking ahead, future research can focus on the following aspects. The first is to incorporate dynamic monitoring capabilities into the sensor layout design, with different monitoring areas for different flight conditions to save resources. Second, there should be a standard to make recommendations for the integration of data from multiple sources and system integration in order to reduce development time and costs while preventing conflicts. The third is to better integrate hardware with data analysis algorithms and use new technologies to enhance the overall level of the system. If all of these are done well, the smart cockpit will soon be popularized and play its role in the aviation field.

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