THE USE OF EYE TRACKING IN AVIATION

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Abstract. Eye movement tracking technology, known as eye tracking, has been gaining increasing attention in recent years in the aviation industry. Its applications range from analysing pilots' attention and cognitive load to optimising cockpit design and improving in-flight safety. This paper explores the various uses of eye tracking in aviation, including its use in pilot training, cognitive load monitoring, cockpit design, and improving the interaction between automated systems and humans. The aim of this research is to provide a comprehensive view of the benefits and challenges associated with this technology in the aviation industry.

Keywords: Eye tracking; aviation; security; safety; cognitive load; cockpit design; simulators

1. INTRODUCTION

Eye tracking technology is increasingly being applied in areas where human interactions with complex systems need to be analysed and optimised. In aviation, efficient and safe operations depend on the attention and decision-making skills of pilots, who have to manage complex systems under challenging conditions. In this area, eye movement tracking has the potential to bring revolutionary improvements in pilot training, cockpit design and cognitive load detection. The use of eye tracking in aviation allows analysts to gain valuable information and better understand how pilots perceive and react to different information during flight, as well as how to improve the interaction between humans and automated systems. They offer a new way to monitor and analyse pilot behaviour, which can contribute significantly to improving safety, performance and comfort in aviation. This paper focuses on the applications of eye tracking in aviation and discusses its benefits and limitations.

2. EYE TRACKING

Eye movement research has a long history, as do the methods and techniques used to study these movements [1]. The first eye movement analysis techniques were done through introspection or directly by a researcher observing the user's eye using a mirror. In the late 19th century, Delabarre studied eye movements by placing a cap on his eye connected to a wire that responded to the slightest eye movements and drawing them on a rotating kymograph cylinder. However, his solution, by its design, inhibited eye movements and strained the eye itself [2]. In an effort to address these limitations, in 1901 Dodge and Cline developed a non-invasive eye movement technique based on the use of photography [3]. In 1985, McAllister and Steel refined this technique and developed a system that records eye movements in two dimensions [1]. According to Rayner [4], this period is associated with the discovery of the function of basic eye movements. These studies led to the development of eye tracking devices that are still being developed today. In 1948, Hartridge & Thompson invented the first head-mounted eye-tracking device [1]. These early developments were the basis for advances in accurate and sophisticated head-mounted eye-tracking devices, particularly in terms of reducing the constraints that this device imposed on head movement [1]. Despite advances in existing eye-tracking techniques, until the first half of the 20th century, only the eyes of subjects were measured in relation to the head. This limitation meant that the subject's head had to remain fixed during eye movement studies [2]. In the 1970s, a new solution with simultaneous measurement of two optical characteristics of the moving eye appeared. Since these characteristics behave differently during head movement and eye rotation, the difference between these characteristics helps to calculate the "point of regard" (POR), the location in space where the subject is looking [5, 2]. Although the use of older or modern POR techniques still requires some head stability, some head movement is tolerated without altering

the quality of the results obtained. Much of the technological advances in this period are still being applied in modern eye-tracking devices.

Eye-tracking (ET) is a behavioral research method based on the technology of recording eye movements while the participant being observed tracks certain visual stimuli [6]. Eye-tracking is thus based on the proposition that eye movements are related to cognitive information processing [7]. Eye movements are captured by an eye camera (called an eye-tracker), which emits infrared radiation and determines the location of a person's gaze based on its reflection (from the retina and cornea of the eye) using infrared-sensitive cameras. The acquired data is then processed by eye-tracking software to obtain information related to the time, speed, and tracking method of examining the observed image [8]. When orienting and searching for information in an unfamiliar environment, two types of actions usually occur in the observed person - perceptual and cognitive. In the perceptual process, the user only notices the stimulus, in the cognitive process, he is already concerned with its function, and the time spent observing the feature also corresponds to this [9]. In aviation, various methods are often used in eye movement analysis, such as gaze trajectory visualizations, temperature maps, regions of interest, cluster analysis (clusters), and the beeswarm method. The potential offered by Eye-tracking enables companies and researchers to develop more efficient and effective services and products that emotionally appeal to the consumer. It is therefore important to develop a set of methods and techniques to understand how users receive and process information. This multiple use suggests that eye tracking is a very powerful technology when it comes to assessing the performance and interaction of users with a given product or service. Therefore, it is considered that the use of eye tracking becomes important to better understand the reception of visual and auditory cues in content information processing.

3. DATA REPRESENTATION AND VISUALISATION

The representation and visualisation of data and information is important because it helps people to see and understand abstract data that is not comprehensible. Some of the most common and widely used information visualization techniques have been summarized in the work done by Fry and Behrens [10-11]. These include the "scatter plot", "star chart", "bubble chart", "dot matrix", "pie chart", "tree map" and "tree diagram". In order for eye-tracking data to have the highest possible meaningful value and to be easy to interpret, it is crucial to choose the right visualisation method to process it. The resulting data in the form of matrices, coordinates and values are not sufficient on their own to formulate conclusions. However, once properly processed, they are much easier and more intuitive to work with. In the context of visualisation of data obtained through eye-tracking, other techniques such as the 'gaze plot', the 'heat map', the 'beeswarm', 'clusters', 'areas of interest' are preferred [4].

3.1. A gaze plot

This method effectively shows the sequence of eye movements of an individual , the individual fixation points, their sequence and the first places where the eye focuses. The visualization (see Figure 1) uses circles whose size indicates the specific locations where the eye movement briefly stopped (fixated). The larger the circle, the longer the fixation. Inside the circles may be numbers indicating the order in which the subject looked at these points. The circles are connected to each other by lines that represent the movement of the eyes from one fixated point to the next. These lines between fixation points represent saccades [4, 12].

3.2. A heat map

The temperature map shows the features of greater interest through the use of "hot" and "cold" spots. It is better suited for examining static backgrounds rather than moving objects. It uses a colour palette reminiscent of thermal imagers: red shows areas with the longest fixation, green shows areas with the shortest fixation, and areas with minimal fixation are left uncoloured. Although this method does not present saccades, it reveals the places on which attention was most focused. This

visualization is very clear and easy to understand, which is why it is often used when analyzing eye-tracking data [12, 13, 30].

3.3. A Bee Swarm

This technique displays in the form of dots the location that the user is focusing on (tracking). The measurement analyzes how subjects interact with each area. The results include data such as fixation duration, the number of fixations on a given area, or the ratio of fixations on different locations. In Figure 1 we see the on-board apparatus divided into specific zones of interest. In aerial surveys, each device often represents a separate area of interest, while the cockpit view constitutes one zone and the engine monitoring instruments are evaluated as another. It can also simultaneously present points of attention to different users. [12, 14].

3.4. Clusters

This technique consists in imaging areas where there is a greater concentration of fixation points, taking into account some limitations of eye tracking. It connects spatially and temporally close points of view to fixations. It is a clustering technique that aims to include in the same group (or cluster) points that are similar to each other. The intent is very similar to what our brains do when we try to recognize a pattern and group elements based on similarity. In this way, each data trace is grouped separately. In the expert options, you can customize the clustering parameters according to your preferences [29].

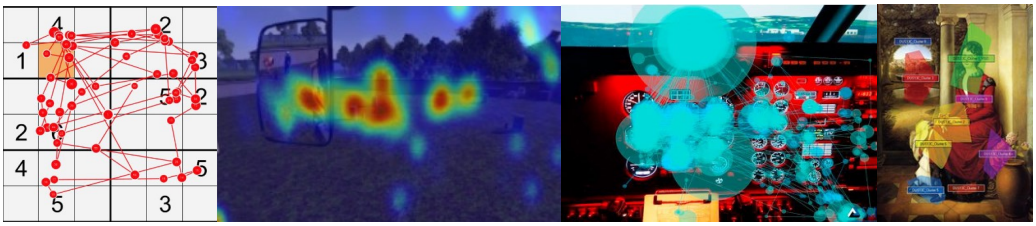

Figure 1 Eye tracking visualization techniques: Gaze-plot [12], Heat map [30], Bee swarm [14], Clustering [29]

4. EYE TRACKING IN AIR TRANSPORT

Eye tracking is a technology that is increasingly being used in a variety of industries, including aviation. In aviation, eye tracking has the potential to improve safety, pilot performance, cockpit design and in-flight service delivery. The following chapter focuses on the use of eye tracking in the context of aviation, analysing its applications, benefits and challenges based on the existing scientific literature.

4.1. Monitoring pilot attention and cognitive load

Cognitive load and pilot attention are critical factors that affect safety and performance during flight. Eye tracking provides a way to objectively assess how pilots perceive and respond to visual stimuli during flight. Research shows that tracking eye movements can help identify warning signs for cognitive load or distraction that may lead to reduced pilot performance.

- ***Attention tracking and analysis:*** According to studies that have investigated the use of eye tracking in the cockpit, this technology is used to monitor where the pilot focuses his attention during different phases of flight. For example, according to a study [15], eye tracking can help analyse how pilots allocate their attention between different visual stimuli in the cockpit, which is crucial for effective decision making, especially during challenging flight scenarios and in preventing distraction-induced accident situations.

- ***Cognitive overload:*** O'Hare et al. [16] report that analysis of eye movements can detect signals of cognitive overload, such as prolonged fixations on certain objects or lower saccade rates. These indicators may suggest that the pilot is facing excessive stress or a complex task.
- ***Reaction to emergency situations:*** According to research [17], eye tracking is used to monitor pilots' reactions to simulated emergency situations. This data can help improve training and prevent errors during real emergency situations. In their study [18], author Nippold et al. suggest that Eye tracking can help in analyzing pilots' reactions in simulated crisis situations such as engine failures or navigation problems. By analyzing eye movements, it is possible to determine which tasks are challenging for the pilot, which can help in improving training.

4.2. Improving cockpit design and interaction with automated systems

An efficient cockpit layout and pilot interaction with the controls are key to safety and comfort during flight. Eye tracking is used to analyse how the pilot interacts with different parts of the cockpit and which areas of instruments or screens require more attention. These analyses provide valuable information that can help optimize cockpit design to minimize unnecessary cognitive load and simplify critical operations.

- ***Cockpit ergonomics:*** According to a study [19], eye tracking allows to identify the areas of the cockpit that are most monitored by the pilot, and therefore the ones that are most important for his performance. This information can be used to improve cockpit design to minimize cognitive overload and facilitate decision making, thereby reducing reaction time and improving safety (see Figure 2). Boeing used Eye tracking in the development of the 787 Dreamliner to ensure that important information is in the pilot's natural field of view [27].

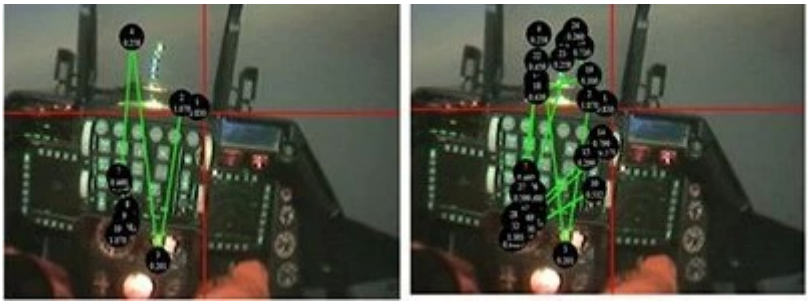

Figure 2 Fixation of the pilot's view of the instruments after 10 sec and after 20 sec [28]

- ***Automation and pilot interaction:*** In their research [20], authors Jiang, Y. et al. show that eye movement analysis can help evaluate how pilots interact with automated systems such as autopilot. This data can help in designing better and more intuitive interactions, thus improving efficiency and safety in the operation of these systems and enabling the pilot to make faster and more accurate decisions.

4.3. Pilot fatigue and stress detection

Fatigue and stress are significant factors that affect pilot performance. Research shows that these factors can lead to a reduction in the ability to react correctly to critical situations, which can have serious consequences for flight safety. Eye tracking is an effective tool for monitoring physiological and cognitive signs of fatigue and stress that manifest themselves in changes in eye movements.

- ***Fatigue tracking:*** According to research [21], eye tracking is effective in monitoring pilot fatigue, which can manifest itself in a slowing of eye movements and an increase in the number of fixations on the same objects. This research demonstrates that longer fixations and slower reactions during eye tracking can indicate pilot fatigue, which is important for early warning of the risk of fatigue that can lead to errors caused by reduced concentration.
- ***Stress monitoring:*** According to research [22], eye movements such as acceleration of saccades or change in fixation frequency can be used to detect pilot stress during challenging

flight scenarios such as emergencies, which helps in optimizing training and avoiding risk factors.

4.4. Applications in simulators and pilot training

Flight simulators equipped with eye tracking technology allow to simulate real flight conditions and provide valuable data to assess pilots' decision-making abilities. Tracking eye movements during simulated flight scenarios can reveal how pilots analyse situations that require an immediate response. This approach can aid in the development of more effective training scenarios and improved training methods.

- ***Simulation decision making:*** According to research [23], deploying Eye tracking in simulators can help in analyzing how pilots react to emergency situations, which is crucial for training in safety procedures and critical decisions. A study conducted at Delft University of Technology showed that the use of eye tracking in simulators improved pilots' ability to quickly identify errors by 20%.
- ***Optimizing training programs:*** Eye tracking technology can provide data to analyze the factors affecting their performance leading to the development of more accurate and effective training methods by identifying areas where pilots make the most frequent mistakes or do not pay enough attention to critical indicators.

4.5. Utilization in passenger experience and cabin layout

Eye tracking is not limited to pilots and flight operations. It is also used in the analysis of passenger behaviour and their reactions to cabin layout, safety briefings or in-flight advertising.

- ***Optimising cabin layout:*** according to research results [24], Eye tracking can help airlines to optimise cabin design and improve passenger information, for example by analysing which parts of the cabin are most important to passengers and which areas need improvement.
- ***Advertising effectiveness:*** A study [25] shows that tracking passengers' eyes can help determine which advertising materials or in-flight services attract the most attention, which can improve marketing strategies and increase airline profitability.

5. CHALLENGES AND LIMITATIONS IN THE APPLICATION OF EYE TRACKING IN AVIATION

Despite the many benefits of eye tracking in aviation, there are some challenges and limitations in its implementation.

- ***Technological limitations:*** Research [17] states that the accuracy of eye tracking devices can be affected by various factors such as the quality of the optical sensors, pilot head movements, and cockpit lighting conditions. The solution to these problems lies in constantly changing technological innovations, such as the use of multipoint sensors or advanced data processing algorithms.
- ***Ethical and security issues:*** according to [22], there are privacy concerns about pilots, as tracking their eye movements can reveal not only their attention but also their psychological state, which may raise concerns about privacy and the ethics of using this data.
- ***Accuracy and Reliability:*** in a high-dynamic environment such as a cockpit, eye movement tracking may be less accurate.
- ***Cost:*** Eye tracking devices and their integration are costly.

6. CONCLUSION

Eye tracking technology has become prominent and widely used in assessing user interaction and behavior with study objects in a variety of contexts. The complexity of specific study objects requires visualization techniques that eye tracking software alone cannot always interpret. Hence, in many

cases, visualization techniques need to be developed in order to better understand the data collected by Eye tracking. The value of Eye tracking as an evaluation and analysis tool has not gone unnoticed and many studies have been carried out focusing on aviation. The visualization techniques described in this document are the result of the specifics of each study and the limitations of the existing software. in addition, they are the result of the renewed methods that were developed in each study. Eye tracking in aviation offers a wide range of possibilities in safety, training and cockpit design. Monitoring a pilot's attention and cognitive load can contribute significantly to improving in-flight performance and safety. On the other hand, the technological and ethical challenges associated with this technology require further research and development to maximise its potential. In the future, eye tracking may play an even more important role in improving human-technology interactions in aviation. The evolution of the technology is expected to result in even more accurate and easier to use devices. In the future, artificial intelligence could enable advanced analysis of eye tracking data and its automatic integration into aviation safety systems.

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