Applications of Artificial Intelligence in Investigating Aviation Accidents

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The aviation industry stands as a live example of innovation, efficiency, and continued improvement, playing an essential role in modern life by transporting goods and passengers globally. According to the International Air Transport Association (IATA), the number of airline passengers is expected to double from 4.4 billion in 2019 to 8.2 billion by 2040 (IATA, 2023). However, as the aviation industry grows and state-of-the-art aircraft are introduced into the aviation system, the complexity of its operations will make investigating accidents an increasingly challenging task. A growing number of aviation operations and data available to investigate may cause a data overload (Cabrera et al., 2015), hindering the ability of Aviation Safety Investigators (ASI) to identify the root causes of the safety events and propose recommendations to reduce its occurrence in the future. The Artificial Intelligence (AI) applications for aviation accident investigations offer a solution to automate tasks, identify patterns, speed up processes, and assist aviation safety professionals during the investigation process.

This paper explores how AI's applications may help ASIs overcome challenges during aviation accident investigations by analyzing current developments in data analysis, accident simulation, and human factors identification and analysis. The investigation of aviation accidents involves analyzing large amounts of information and software the onboard computer uses to control modern aircraft (Strauch, 2017). Moreover, investigating aviation accidents related to aircraft that used advanced composites and construction techniques requires simulation to understand material failures or design flaws. Therefore, the introduction of emerging technologies and big data in the aviation industry reinforces the need to use new tools provided by AI to investigate accidents promptly and efficiently.

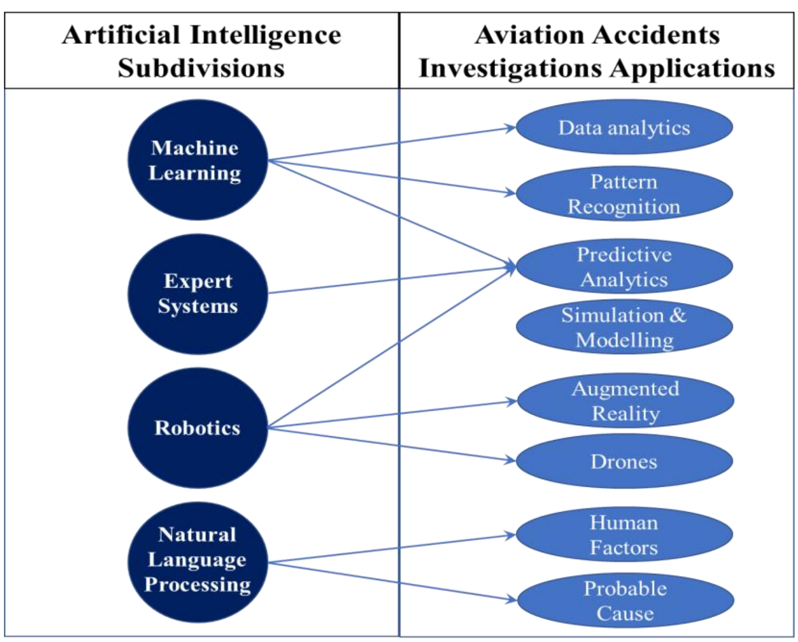
Artificial Intelligence

The definition of *Artificial Intelligence* involves the use of algorithms to simulate human intelligence (Helm et al., 2020). Eisenecker (1995) defines AI as the engineering process of creating machines and software that are able to replicate the human cognitive process to solve problems. AI has been incorporated into transportation (Abduljabbar et al., 2019), healthcare (Saxena & Chandra, 2021), finance (Arslanian & Fischer, 2019), and manufacturing (Soroush & Braatz, 2024), among others, to automate tasks and increase efficiency.

When investigating aviation accidents, AI can potentially revolutionize the identification of root causes. Figure 1 visualizes some of the AI's subdivisions: 1) Machine learning, 2) Expert systems, 3) Robotics, and 4) Natural Language Processing and its use during aviation accident investigations. The next part of this paper summarizes the role of AI in enhancing investigative processes for aviation accidents and the potential scenarios where AI may be essential to overcome aviation safety challenges.

Figure 1

Artificial Intelligence Applications in Aviation Accidents Investigations.



Machine Learning

Machine learning focuses on developing algorithms for analyzing data and making decisions with minimum human intervention (Haroon, 2017). The applications of this subdivision of AI in aviation accident investigations encompass using data analytics, pattern recognition, and predictive analytics techniques to reduce the safety professional's workload. İnan, & Gökmen (2022) used machine learning techniques to investigate 220 aviation accidents that involved more than 100 fatalities from 1950 to 2018. The authors compared logistic regression models and supervised learning algorithms, finding that the machine learning techniques predict fatality rates with higher accuracy. Using pattern recognition, machine learning can process large amounts of data with high levels of accuracy (Zhang et al., 2020). Therefore, aviation safety professionals may use this tool to investigate accidents by comparing common anomalies or deviations between a safety event and chain events that led to accidents in the past.

Expert Systems

This branch of AI, also known as a knowledge-based system, uses computer software, databases, and a set of rules to assist humans in the decision-making process and predict outcomes (Sulistiani et al., 2021). In aviation safety, expert systems can assist the ASI by offering "skilled" guidance while analyzing large amounts of information during the investigative process. In the same way, modern aircraft use Flight Data Recorders (FDR) that store up to 300 flight hours (Dub & Pařízek, 2018) and can use cloud computing to continuously record more than 1,000 parameters (Souley & Nkemdilim, 2018). The expert system may use the information from previous aviation accidents to train the new generation of ASIs by creating simulations and education programs tailored to develop core competencies.

Robotics

In the context of AI, robotics involves designing, manufacturing, and operating robots that can autonomously perform complex tasks (Soori et al., 2023). Drones have been used in the agriculture (Tagarakis & Bochtis, 2023) and healthcare (Yu et al., 2019) industries to improve data collection and analysis of multimedia information. Using robots with computer vision may be an essential tool to collect images and video from an aviation accident scene. Moreover, robots may assist in collecting information from dangerous or remote sites where sending humans can be life-threatening. AI-enabled robots, on their part, can interpret data collected on the site of an accident, including debris patterns and environmental conditions, and hence reconstruct accidents in aviation. The information will help investigators acquire wreckage data with dispatch and timeliness to seek incident causes and dynamics.

Natural Language Processing

This AI subdivision focuses on human-computer interactions using natural language (Tapsai, 2021). Natural Language Processing (NLP) applications involve performing speech recognition, sentiment analysis, and text summarization (Khurana et al., 2022). Previous studies have explored the benefits of this emerging technology in aviation safety. Madeira et al. (2021) analyzed 1,674 accident reports from 2000 to 2020 in the Aviation Safety Network (ASN) database using NLP. The authors used the Human Factors Analysis and Classification System (HFACS) for data labeling and accident categorization. The applied research found that using NLP with Bayesian optimization performed better than the baseline model in categorizing and classifying accidents on the different HFACS levels.

Ziakkas & Pechlivanis (2023) used the open-access Chat GPT to explore the accident classification capabilities using three safety events as case studies. The authors compared the differences between the NLP model and a subject matter expert (SME), finding that Chat GPT performance is better for classifying aviation accidents using linear models such as Bowtie. Additionally, after comparing the accident analysis results, the authors found “fair” levels of agreement between Chat GPT and the SME. Similarly, using speech recognition to identify keywords or sentences on the Voice Data Recorders (VDR) during accident investigations exemplifies a tool that may help ASIs expedite the analysis process. Therefore, continuing to explore the applications of NLP models for aviation accident investigations represents an opportunity to enhance human-computer interactions, allowing the ASI to exploit the benefits of advanced computer systems using natural language without requiring extensive training for the operators.

Limitations

While AI technology offers advantages and potential applications during aviation accident investigations, these technologies have limitations that the ASI must recognize during the investigative process. The AI systems rely on the availability of the safety event’s information to operate. Incomplete or corrupted data may lead the AI system to draw incorrect conclusions about the probable causes or classification of the accident. Additionally, complex systems such as aviation require interdisciplinary teams to analyze accidents. So far, AI systems have demonstrated limitations in integrating interactions from different disciplines, which may ultimately limit the AI system’s ability to operate without close human supervision during the investigation process. Equally important are the ethical and legal considerations of using AI systems as the sole tool to analyze an aviation accident. The capabilities of an AI system for data analysis are undeniably powerful. However, it is crucial to note that even with its advanced technology, it cannot replace the judgment and experience of an ASI.

Conclusions

The role of AI in investigating aviation accidents represents an opportunity to enhance aviation safety practices. Using machine learning, expert systems, robotics, and NLP offers aviation safety professionals new tools to analyze the increasing amount of information that state-of-the-art aircraft have. Customized AI solutions developed through a collaboration of AI technologists with ASIs would efficiently cater to the specialized needs in the field. Establishing training programs for safety professionals to become skillful users of AI tools may contribute to increasing the benefits associated with employing this emerging technology. Prospective research should focus on the interpretability of AI models to make outputs transparent, aiming to build trust among the stakeholders.

As the aviation industry evolves, safety professionals must continue advocating for incorporating advancements in accident investigation practices, technology, and training. Adopting AI innovations may become an essential tool for “Safely Navigating Uncharted Waters” and overcoming the challenges posed by the increasing complexity of the aviation system.

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