The role of Artificial Intelligence in Air Traffic Management

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Abstract

Artificial intelligence (AI) is increasingly being used in air traffic management to improve efficiency, safety, and overall performance in the aviation industry. AI algorithms can analyze vast amounts of data in real-time, such as weather patterns, airspace capacity, and aircraft trajectories, to predict delays and optimize flight schedules accordingly. AI and Machine Learning (ML) are already contributing to a wide spectrum of value opportunities in the aviation/ATM industry, from non-safety critical to safety critical applications. Another transversal component is AI-enabled simulation platforms, where augmented reality offers the possibility of creating a testing and validation environment where new and innovation aviation concepts like U-space can be explored. This paper will show an example of possible use of AI for Dynamic Airspace Sectorisation (DAS). The idea for a possible DAS solution that is going to be a part of this paper is divided in three parts. First one is fuzzy clustering used for clustering of air traffic as initial allocation of flights, the second are Voronoi diagrams that will provide a design of an initial airspace structure in sectors and the third one is an evolutionary algorithm which goal is to optimize the sectorisation. The goal of this approach is to evaluate airspace organization/sectorisation under both operational and economical aspects.

***Keywords**: Artificial intelligence (AI), Air Traffic Management (ATM), Dynamic Airspace Sectorisation (DAS), Machine learning (ML)*

1 Introduction

Artificial intelligence (AI) and machine learning (ML) are closely related fields that are revolutionizing various industries, including aviation. Machine learning is a subset of artificial intelligence that focuses on designing algorithms that can learn from and make predictions on data without being explicitly programmed. In the context of aviation, both AI and machine learning are being used to improve safety, efficiency, and decision-making processes. Overall, the combination of artificial intelligence and machine learning is transforming the aviation industry by enabling new capabilities, improving operational efficiency, and enhancing safety. As technology continues to advance, we can expect to see even greater benefits from these innovative applications in aviation.

Dynamic airspace sectorization (DAS) is a concept of reorganizing and adjusting controlled airspace sectors in real-time based on factors such as air traffic demand, weather conditions, and operational constraints. This process aims to optimize airspace utilization, improve air traffic flow, enhance safety, and reduce delays in the air traffic management (ATM) system. The traditional method of airspace sectorization involves dividing airspace into predefined sectors that are static and do not change frequently. However, with the increasing demand for air travel, the complexity of airspace management, and the need for more flexible and adaptable solutions, dynamic airspace sectorization is

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becoming more crucial. Dynamic airspace sectorization relies on advanced technologies, such as artificial intelligence, machine learning, and real-time data analytics, to analyze and forecast air traffic demand, weather patterns, and other relevant factors. By continuously monitoring and updating airspace sectors based on changing conditions, air traffic controllers can optimize the allocation of airspace resources, adjust sector boundaries, and manage traffic flow more efficiently. In conjunction with dynamic airspace sectorization, air traffic management systems use advanced tools and algorithms to optimize routing, sequencing, and spacing of aircraft, as well as to coordinate interactions between different sectors and air traffic control units. This integrated approach allows for more proactive and collaborative decision-making, leading to enhanced safety, capacity, and performance in the airspace system. Overall, dynamic airspace sectorization and advanced air traffic management technologies play a critical role in modernizing the aviation industry, improving operational efficiency, and enhancing the overall passenger experience. By adapting to dynamic conditions and leveraging real-time data and intelligent algorithms, airspace management systems can meet the challenges of growing air traffic demand and ensure a safe and seamless flow of aircraft in the skies.

Intention of the authors working on this paper is to explain the role of AI in ATM and to see the potential usage of the AI for DAS through the experimental setup. The fusion of AI and machine learning can significantly enhance the efficiency and effectiveness of dynamic airspace sectorization, transforming the way aviation industry manages air traffic. This innovative approach has the potential to revolutionize airspace sectorization, enabling a more streamlined and efficient air traffic management system.

By adopting this approach, we can effectively integrate fuzzy clustering, Voronoi diagrams, and evolutionary algorithms to achieve a seamless and optimized sectorization of the airspace, taking into account traffic flow considerations.

2 Artificial intelligence in the aviation sector

2.1 AI in ATM

Artificial intelligence (AI) is already starting to transform how the world lives and works, and the pace of AI deployment is currently rapidly accelerating. In a world increasingly driven by big data, and with massive developments in recent years in computing power and advanced algorithm use, AI will play a major role in all industrial sectors, driving competitiveness and productivity, and offering, if correctly deployed, huge economic and societal advantages. In the global race to achieve a crucial advantage in innovation, Europe needs to keep pace with other actors which are leading the way in AI development, which is why the European Union has declared AI to be a major strategic priority. At the same time, the EU also aims to ensure that European AI developments are also safe, secure, human-centric, ethical, and trustworthy and support the core values of the EU. As a sector, aviation and air traffic management (ATM) is ideally placed to take full advantage of AI, in particular machine learning. ATM is powered by air to ground and ground to ground data flows – and ‘big data’ is a prerequisite for the successful use of AI. Indeed, AI and machine learning are already contributing to a wide spectrum of value opportunities in the aviation/ATM industry, from efficiency-focused to safety critical applications. [1]

Table 1 summarises the main aims and benefits of the AI applications in the aviation sector.

Table 1. *Aims and benefits of the AI applications in the aviation sector [1]*

Area	Benefits
Traffic predictions /forecasts/modeling	Improving predictions of aircraft trajectories, reducing uncertainty and increasing capacity
Resource management / Optimisation	-Deploying the optimal configuration of sectors and thus optimising capacity with the available resources -Supporting ATM demand and capacity balancing
Workload / Automation / Autonomy	-Reducing ATCO workload (e.g. using speech recognition models for controller assistance) -Reducing risks with safety intelligence tools
Airport performance	-Improving runway throughput (e.g. ROT

	prediction, improving spacing buffers) - Cutting airport delays
Airline performance	-Optimising fuel usage -Proposing better and more routes
Passenger experience	-Improving passenger transfer/ customer satisfaction -Using biometrics to accelerate secure boarding
Infrastructure monitoring	-Improving GNSS monitoring 4 -Cybersecurity monitoring
Airborne capabilities	-Improving validation capabilities -Generating environmental improvements -Pilot and ATCO assistant through automatic speech recognition -Enhancing safety with automatic taxi, take-off and landing enabled by computer vision

The ATM/ANS domain foresees important deployments of AI/ML applications. AI-enabled assistants have already been introduced in operations to support air traffic controllers (air traffic controllers (ATCOs), flow management positions (FMPs)) or other end users of the ATM/ANS domain. Just to mention one example, such assistants can improve the 4D trajectory predictions, thus improving the quality and accuracy of any local or network situation assessment (early detection of hotspots). By analysing data on weather patterns, sectors configurations, air traffic congestions, and other factors, AI/ML models could support the optimisation of flight routes to reduce flight time, fuel consumption, and, ultimately, costs. Such an optimisation would then lead to a more efficient air traffic management system, reducing delays and increasing the capacity of air travel.[2]

MLEAP project is a research project initiated by EASA and funded under the Horizon Europe framework. MLEAP has been tailored to investigate the challenging objectives of the W-shaped process at the core of EASA AI Concept Paper. The project deals with the approval of machine learning (ML) technology for systems intended for use in safety-related applications in all domains covered by the EASA Basic Regulation (Regulation (EU) 2018/1139). [3]

Figure 1. shows MLEAP research expected benefits.

Fig. 1. *MLEAP research expected benefits [1]*

The reports will highlight a set of anticipated concepts for the evaluation and certification of AI-based systems supporting the EASA roadmap deliverables and help industry stakeholders in planning new strategies for deploying AI in their human and technical organisations.

2.2 Common AI challenges in aviation

There are several challenges associated with implementing AI in the aviation industry, including:

1. Data quality and availability: AI algorithms require large amounts of high-quality data to operate effectively. However, data in the aviation industry can be complex, fragmented, and not always readily available in digital formats. Ensuring the accuracy and reliability of data is essential for the successful implementation of AI.

2. Regulatory compliance: The aviation industry is heavily regulated, and implementing AI systems that meet regulatory requirements can be challenging. Ensuring that AI systems comply with relevant safety and security standards, data protection regulations, and industry guidelines is essential.

3. Interpretability and transparency: AI models can be complex and opaque, making it difficult to understand how they arrive at decisions. In the aviation industry, where safety is paramount, the ability to explain and interpret AI system outputs is crucial for gaining trust and acceptance.

4. Integration with existing systems: Implementing AI solutions in aviation may require integrating new technologies with existing systems and infrastructure. Ensuring compatibility, interoperability, and seamless integration can be a significant challenge.

5. Liability and accountability: As AI systems become more widespread in aviation operations, questions of liability and accountability arise. Determining responsibility in the event of an AI-related incident or accident can be complex and may require legal and regulatory frameworks to be updated.

6. Ethical considerations: AI technology raises ethical concerns, such as issues of bias, discrimination, privacy, and autonomy. Ensuring that AI systems in aviation are developed and used ethically and responsibly is a key challenge for the industry.

Addressing these challenges requires collaboration between industry stakeholders, policymakers, regulators, and technology providers to ensure the safe and responsible deployment of AI in aviation.

3 Dynamic Airspace Sectorisation

DAS is a flexible method enabling a continuous restructuring of airspace sectors and no predefined airspace blocks are necessary to build airspace sectors.

The sectorisation of airspace considers requirements of air traffic management (safety, capacity and efficiency), users (unhindered access) and environment (restricted areas over cities, residential areas, etc.). Particularly, air traffic control requires the airspace to be structured to accommodate an appropriate operational infrastructure for airspace users and operators. The airspace sectorisation is primarily triggered by operational demands (such as handling of mixed traffic, balanced controller workload, procedure design or capacity management), territorial aspects (air sovereignty) and operational performance. [5]

3.1 An overview of previous research studies

Today's air traffic operations follow the paradigm of 'flow follows structure', which already limits the operational efficiency and punctuality of current air traffic movements.

The paper from authors Majumdar A., Ochieng W., Polak J. called Estimation of European airspace capacity from a model of controller workload aims to provide a method of determining airspace capacity of Europe using a simulation model of air traffic controller's workload. This paper has shown a method by which to estimate the capacity of Europe's airspace, given that this capacity is limited by the air traffic controller's workload. This method relies upon a well validated simulation model of the air traffic controller's workload, RAMS, together with the use of appropriate definitions of controller workload and threshold workload value at capacity. Based upon a series of controlled experiments, the output from the RAMS model is used for a functional analysis to relate workload, and hence capacity, to its various possible drivers. [4]

Therefore, the paper from the authors Gerdes I., Temme A., Schultz M. called Dynamic airspace sectorisation for flight-centric operations, introduces the dynamic airspace sectorisation and consequently change this paradigm to the more appropriate approach of 'structure follows flow'. The dynamic airspace sectorisation allows an efficient allocation of scarce resources considering operational, economic and ecological constraints in both nominal and variable air traffic conditions. Their approach clusters traffic patterns and uses evolutionary algorithms for optimisation of the airspace, focusing on high-capacity utilisation through flexible use of airspace, appropriate distribution of task load for air traffic controllers and fast adaptation to changed operational constraints. [5]

The paper from the authors Standfuß T., Temme A., Schultz M. called Future airspace design by dynamic sectorization. The authors of this paper developed a dynamic airspace sectorization (DAS) approach, which differs from the dynamic airspace configuration (DAC) where pre-defined airspace blocks are combined to superior structures. Authors are assuming a continuous airspace that will be separated without a specific demand for underlying structures but considering both the current/future air traffic flows and the controller's ability to manage all assigned aircraft (e.g. measured by task/work load). In this paper, they fundamentally changed the common method of 'traffic flow is following the provided structure' to 'a structure follows the traffic flow' paradigm. Furthermore, the approach bridges the gap between structured and unstructured airspace

designs and will be a fundamental key element for efficient air traffic operations taking into account both regular and disruptive events. [6]

3.2 The possibilities of implementing an airspace sectorisation model

An airspace sectorisation model can be implemented using (any combination of) different algorithm design methodologies or optimisation technologies:

- Stochastic local search (SLS),
- Constraint programming (CP),
- Mathematical programming (MP), such as integer programming (IP) and mixed integer programming (MIP).
- Global optimisation (GO).
- Evolutionary algorithms (EA).
- Computational geometry. Ad hoc algorithm design.
- etc.

The possibilities of sectorisation include: [5]

Improved Air Traffic Management: reducing congestion and increasing safety

Enhanced Surveillance: providing more accurate information about aircraft positions

Increased Efficiency: reducing fuel consumption, lowering emissions, and decreasing flight times

Better Crisis Management: responding to changing situations quickly and effectively

Improved Safety: reducing the risk of mid-air collisions

Enhanced Capacity: managing more flights simultaneously and reducing delays

Increased Automation: automating air traffic control processes and reducing workload

Better Weather Management: providing more detailed information about weather conditions and forecasting

Increased Flexibility: accommodating changes in flight routes, schedules, and weather conditions

Cost Savings: reducing the need for costly re-routes, delays, and cancellations

Improved Communication: facilitating better communication between air traffic controllers, pilots, and other stakeholders.

4 Possible experimental setup

Today, quantifying the complexity of a given air traffic situation has become an issue for the assessment of Air Traffic Control (ATC) and ATFM performances, the building of new airspace structures/sectors.

Dynamic Airspace Sectorisation (DAS) is a flexible method enabling a continuous restructuring of airspace sectors and no predefined airspace blocks are necessary to build airspace sectors. [5]

One of possible use of machine learning algorithm for DAS is clustering (see figure 2), which is unsupervised learning. Unsupervised learning means you have a data set that is completely unlabeled. You don't know if there are any patterns hidden in the data, so you leave it to the algorithm to find anything it can. It is used for raw datasets.

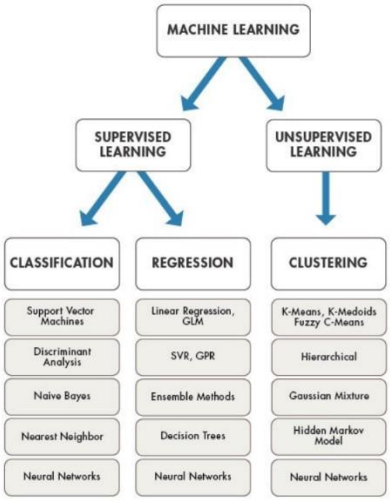

Fig. 2. *Machine Learning Algorithms [7]*

Using a clustering algorithm means you're going to give the algorithm a lot of input data with no labels and let it find any groupings in the data it can. Those groupings are called *clusters*. A cluster is a group of data points that are similar to each other based on their relation to surrounding data points. Clustering is used for things like feature engineering or pattern discovery.

Clustering base sectorization involves combining smaller units of airspace (air blocks) into sectors and has been observed to yield better solutions but may require post-processing steps to ensure that the convexity and connectedness of the shape of sectors are being satisfied.

Basic elements for possible DAS solution can be split in the three major steps: [7]

1. Fuzzy Clustering: clustering of air traffic as initial allocation of flights,
2. Voronoi diagrams: design of an initial airspace structure in sectors
3. Evolutionary Algorithm: optimize the sectorisation

The clustering solution consists of cluster centers, i.e. the center of gravity of a cluster with regards to a characteristic distance function. For this approach, we use the fuzzy-c-means clustering that is based on the Euclidean distance measure. The resulting centers are used as initialization for the following structuring with Voronoi diagrams. (see Figure 3 and 4)

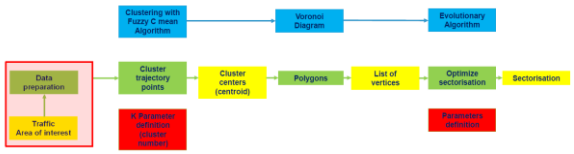

Fig. 3. *Clustering Base Sectorisation [Author]*

A Voronoi diagram is a possibility for structuring an area, depending on a certain number of so-called center points, into sections where every point belongs to the section with the nearest center point. Edges are created of all points which belong to two center points, i.e. the points of an edge have the same distance to the two center points, and vertices are those points which are associated with three different center points. (see figure 4)

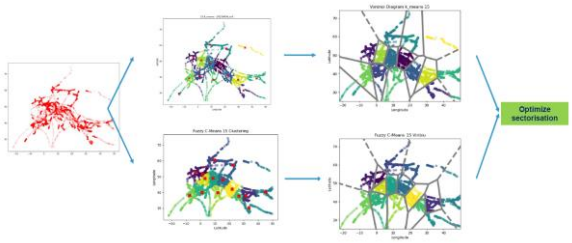

Fig. 4. *Process test [Author]*

The common principles of evolutionary algorithms follow the idea of biological evolution. In the context of the dynamic airspace sectorization, the idea of evolutionary algorithms is used to optimize the initial airspace structure considering different evaluation functions. These functions are defined depending on the specific research/operational scenario. [6]

5 Conclusion

In conclusion, the integration of artificial intelligence and machine learning technologies has the potential to significantly improve the efficiency and effectiveness of dynamic airspace sectorisation in the aviation industry. The utilization of these advanced technologies has the capability to revolutionize the way airspace sectorisation is managed, ultimately paving the way for a more seamless and innovative air traffic management system.

With this possible approach we can demonstrate the efficient combination of fuzzy clustering, Voronoi diagrams, and evolutionary algorithms to an appropriate sectorization of the airspace regarding to traffic flow.

This approach can be used to evaluate airspace organization/sectorisation under both operational and economical aspects.

Dynamic airspace sectorization is a relatively new field that has gained significant attention in recent years, particularly in the context of advanced air traffic management (ATM) systems. As the aviation industry continues to evolve, there is a growing need for more efficient, flexible, and adaptive airspace management systems. Here are some potential areas of future work in this field: advancements in automated sectorization, integration with other ATM systems, disaster response and recovery and human-machine interface design

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