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The Future of AI in Air Traffic Management: Coordinating Autonomous Airliners and UAM within Busy Airspaces using AI

Seminar Paper

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Affidavit

I certify that I have completed the work without outside help and without using sources other than those specified and that the work has not yet been submitted in the same or a similar form to any other examination authority and has been accepted by them as part of an examination. All statements that have been adopted literally or analogously are marked as such.

Ingolstadt, 10 May 2025

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Abstract

The summary gives the reader a rough overview of the content (brief problem definition, approach, solution approaches and possibly key findings). The scope should be about half a page. This chapter is not mandatory and should only be considered optional.

Contents

1 Unmanned Aerial Systems

1.1 Introduction

Unmanned aerial system (UAS) is a system with aircrafts that have no direct intervention from human pilot. It consists of three components: (1) an unmanned aerial vehicle (UAV), (2) a Remote Pilot Station (RPS) or Ground Control Station (GCS), and (3) a command and control (C2) system. An UAV is an aircraft that operates or is designed to operate autonomously, or to be pilot remotely without a pilot onboard. Its use cases are and not limited to security surveillance, emergency response, and small package and bulk cargo transport [1].

1.2 Urban Air Mobility

According to European Union Aviation Safety Agency (EASA), urban air mobility (UAM) refers to an air transportation system for passengers and cargo in urban environments.It primarily consists of electric VTOL (eVTOL) aircrafts, with air taxis used for passengers and drones for delivery of cargos, surveillance, and photography. These aircrafts can either be remotely piloted or with a pilot on board [2]. If these aircrafts are capable of autonomous flying, it is considered a part of UAV.

It differs from traditional aircrafts with its use of rotors, and the ability to take off and land vertically from almost anywhere with a suitable platform (vertiports) whereas traditional aircrafts are mostly equipped with fixed wings and require runways to operate. Its range of opperation also differs, with UAM operate in urban areas (and possibly into remote areas) while traditional aircrafts are able to operate for long distance travel, but only to locations with runway availability.

1.2.1 Benefits of UAM

UAM is envisioned as an alternative for inter-city or intra-city travelling, providing a faster and efficient alternative to land travel. This would help to reduce the amount of vehicles on roads, elleviating traffic congestion and moving some of it to the sky. With eVTOLs, extensive infrastructure does not need to be in place to be adopted compared to electric public transportation system on the ground. Only transportation hubs need to be built, without the need to build extended infrastructure on roads and tracks to support it. [3]

1.2.2 Challenges faced for UAM

The safety of eVTOLs technology needs to be proven to the public, especially with companies developing these aerial vehicles to be automated and work without the presence of a pilot. Despite air travel having a much lower accident rate compared to road travel, there are also more risks involved. Air traffic is also much more heavily regulated than road traffic, and that means that policies and regulations need to be ironed out and tested before this type of transportation can be safely opened to public. Routes that will not disrupt airport traffic, for example, would need to be worked out. Air taxis are unable to take people directly point-to-point, rather from one station to another. This means that integration between different modes of transport would need to be implemented in order to create an efficient and seamless travel experience. [3]

1.3 Autonomous Airliners

Autonomous airliners represent a branch of UAVs, consisting of fixed-wing aircraft capable of flying and navigating without direct intervention of a human pilot, for passenger service. Although modern commercial airliners already automate approximately 93% of flight functions, such as autopilot systems and automatic dependent surveillance-broadcast (ADS-B), there remains a growing demand to implement higher levels of autonomy. Increased automation is seen as a path toward enhanced safety, greater scalability, and improved affordability.

2 Air Traffic Management

2.1 Introduction

Air traffic management (ATM) is the aggregation of the airborne and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations, through controlled airspaces and on the ground at airports [4]. It comprises serveral components, including air traffic service (ATS), airspace management (ASM), and air traffic flow management (ATFM) [4]. Figure 1 shows the structure of ATM and the relationship between ATS, ASM, and ATFM.

Air traffic controllers (ATCOs), part of air traffic control (ATC) service, are responsible for directing aircraft safely and efficiently, managing takeoffs and landings, maintaining safe distances between aircraft en route and handling emergencies. Their role demands high levels of situational awareness, rapid decision-making, and the ability to manage multiple tasks under high stress conditions. These indispensable skills, such as judgement,

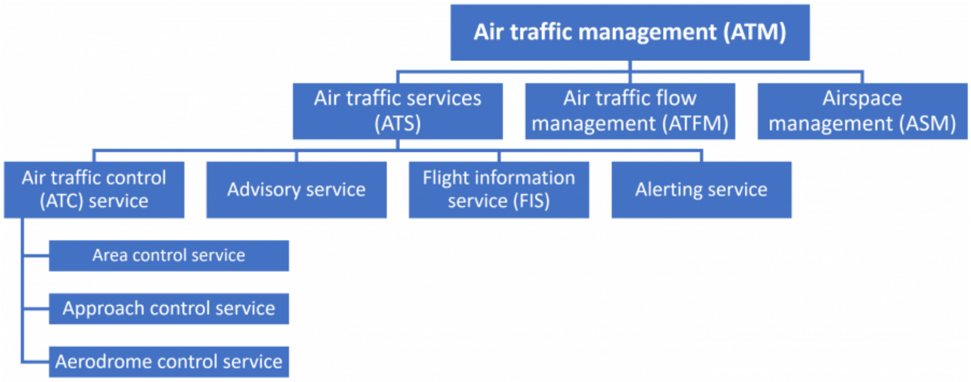

Figure 1: Structure of ATM [4]

flexibility and the ability to handle unexpected situations, remains critical and are not easily replicated by automated systems [5].

2.2 UAS Traffic Management (UTM)

UAS traffic management (UTM) is a system for safely managing UAV operations at low altitude. Separate from but complementary to ATS, it enables fucntions such as flight planning, authorisation, surveillance, and conflicht management to mitigate risks and ensure safe, efficient operations of UAVs. There is ongoing work to fully realize the benefits of UTM [6].

2.3 Challenges with Integrating UTM to ATM

Integrating UTM into traditional ATMis complex but crucial for ensuring safe and efficient airspace operations, primary due to the differing nature of UAS and manned aircrafts. While UTM, designed to manage drone missions, , it must be integrated seamlessly into the existing ATM infrastructure to prevent accidents and enhance scalability. Both systems must work together, as unmanned flight systems need to detect and respond to other aircraft in emergencies, and vice versa [7].

The growing complexity of ASM, driven by the driven by the rapid expansion of commercial aviation, UAM, and UAVs, has led to increased air traffic volume. As air traffic rises, the limited capacity of ATCOs – who are also affected by fatigue and information overload – becomes a major challenge [8]. Human limitations in decision-making highlight the need for AI-based solutions, such as real-time data processing and predictive analytics, to improve system performance [8]. Despite existing automation, current systems often rely on rigid frameworks that lack the flexibility needed for dynamic environments [9].

Additionally, UAS have unique performance characteristics that complicate their integration into the air traffic flow, often resulting in suboptimal use of airspace capacity. UAVs typically operate across both controlled and uncontrolled airspaces, and since ATCOs only manage controlled spaces, the lack of oversight in uncontrolled airspace raises the risk of collisions or accidents. As a result, UTM systems are essential for ensuring safe and efficient UAV operations across all airspaces [10], highlighting the urgent need for scalable, flexible, and automated solutions in air traffic management.

3 Future of AI in ATM

3.1 Safe Flight Pathing Through Hazardous Sky

Natural events such as thunderstorms and volcanic ash clounds present safety challenges for the aviation section. In addition, aerosols and gases arising from natural hazards such as forest fires and desert dust can also severely reduce visibility and damage engines. Even space weather, such as the solar wind, can impact aviation by disrupting satallite communication and increasing radiation exposure.

The multi-hAzard monitoring and earLy wARning systeM (ALARM) project was funded within the framework of the Single European Sky Air traffic Research system (SESAR) Joint Undertaking to move the aviation sector towards mordenising Europeans glsATM system by developing a prototype monitoring and early warning system for various hazards. To achieve this, near real-time data from ground-based and satellite systems was gathered. This highly granular information was then processed and fed into models for identifying the displacement of particles and gases derived from natural hazards, as well as extreme weather situations. The first step is to provide a snapshot of what is happening, then to develop predictive models that is able to provide the aviation sector with forecasts of between one hour ahead and a day ahead. To achieve this, artificial intelligence (AI) was applied to observational data and historical observation and create a model that is able to learn from past localised forecasts and weather observations, in order to be able to better predict the likely evolution of any given natural event. This model can be used, for example, to accurately predict the behaviour of severe thunderstorm over an airport, and ATCO can use this information to make in-flight deviations or reschedule flights altogether.

[11]

3.2 Maintain optimal airfraft separation in airspace

In a research by Liu [12], a routing optimisation model was proposed to be used independently by multiple routing agents that allows real-time dynamic allocation of airspace volumes withr obust mechanisms for conflict resolution. Safety standards held equal, a traffic management system built on this model can support more concurrent flights in a given volume of airspace than what existing systems are capable of, thus allowing more goods to be transported via automated aerial delivery.

In this system, each agent represents a USS executing central control over its own fleet of UAVs. Multiple agents passively interact with each other via observing and reacting to the motion of each other's fleets. No complicated inter-agent communication is required to achieve harmonious traffic outcomes. UAVs within the same fleet are cooperative, while UAVs across different fleets are semi-cooporative – they share the same goal of maintain safe separation, but do not communicate flight intents or negotiate right of ways as do UAVs manage by the same USS.

While centralised traffic management is most conducive to efficient point-to-point air trips, the practical reality demands a more flexible architecture in which multiple private fleets can operate independently, yet harmoniously, in shared airspaces. Sufficient separation is the most fundamental operating requirement shared among all airspace users, but how to maintain the desired level of separation in a decentralised operation environment is a core challenge to be addressed.

3.3 Automatic Speech Recognition and Understanding (ASRU)

Voice communication between ATCOs and pilots using radio equipment is still the main communication channel used in air traffic control, with ATCOs issue verbal commands to the cockpit crew. Whenever the information from the voice communication has to be digitalised, ATCOs are burdened to manually enter the information, although it was already uttered. On one hand, Automatic Speech Recognition (ASR) transform the analog voice signal into spoken sqeuence of words. On the other hand, Automatic Speech Understanding extracts the meaning from the sequence of words, .

When the formal problems of representing lexical syntatic, and semantic information are solved, the spoken call signs still need to be extracted from a verbal transmission. + noisy environment with diffrent spoken accents

Another application of ASRU is the pre-filling of radar labels with information extracted from ATCOs voice transmissions.

3.4 Cybersecurity

Security threats to civil aviation operations have become more sophisticated and challenging. Cyber attacks are increasing in quantity and persistence, so the consequences of a successful malicious cyber-attack on civil aviation operations could be severe nowadays.

In ATM, the reliance on computer-based and information technology systems is expected to grow with new and modern airports being developed, new aircrafts introduced into service and stakeholders seeking to meet the demands of the growing demand of the more IT-savvy passengers with new passenger facilitation process, using digital and IT-based systems.

3.5 Autonomous UTM

4 Conclusion and Outlook

Acronyms

ADS-B automatic dependent surveillance-broadcast. 2

AI artificial intelligence. 4

ALARM multi-hAzard monitoring and earLy wARning systeM. 4

ASM airspace management. 2, 3

ATC air traffic control. 2

ATCO air traffic controller. 2–4

ATFM air traffic flow management. 2

ATM air traffic management. 2, 3

ATS air traffic service. 2, 3

C2 command and control. 1

EASA European Union Aviation Safety Agency. 1

eVTOL electric VTOL. 1, 2

GCS Ground Control Station. 1

RPS Remote Pilot Station. 1

SESAR Single European Sky Air traffic Research system. 4

UAM urban air mobility. 1, 3

UAS unmanned aerial system. 1, 3, 4

UAV unmanned aerial vehicle. 1–4

UTM UAS traffic management. 3, 4

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