VIII INTERNATIONAL SCIENTIFIC PROFESSIONAL CONFERENCE
SECURITY AND CRISIS MANAGEMENT – THEORY AND PRACTICE (SeCMan)
-SAFETY FOR THE FUTURE-
29th and 30th September 2022, Sremska Kamenica, Republic of Serbia

DRONE SAFETY IN U-SPACE USING DIGITAL TWINS

Tomaz Kramberger[1], Bojan Rupnik[2]
[1] University of Maribor – Faculty of logistics, Mariborska cesta 7, Celje, Slovenia, tomaz.kramberger@um.si
[2] University of Maribor – Faculty of logistics, Mariborska cesta 7, Celje, Slovenia, bojan.rupnik@um.si

Received: 22nd July 2022
Accepted: 23rd July 2022

Review paper

Abstract: *Although the use of drones in logistics is already close to reality, some obstacles remain unresolved. Drone technology per se is not enough, it needs to be upgraded and designed in a way that will allow a kind of drone shift, which means that it will allow the development of business models that were not possible without its upgrade. In the paper, we present a system of automatic control, management and control of drone traffic for flights over urban areas (UATM) managed in a digital twin. The system is designed according to the principles of U-Space presented in the EU Blue Book. The UATM system was designed as a digital twin of the real-life system pilot, drone and space where the digital part of the twin takes the lead and first performs a virtual mission and only later maps it into reality.*

Key words: *unmanned aerial vehicles, unmanned air-traffic management, digital twin, U-Space*

1. INTRODUCTION

Recently, we have witnessed significant development and increasing use of drones (Unmanned Aerial Vehicles or UAVs) in many areas. The practical use of UAVs is hampered by problems that are not necessarily technical in nature and are not caused by the technology of the components involved (Gonzalez-Ra, et al., 2020). Among these challenges, the most important for us are the problems arising from the use of UAV in logistics distribution tasks, especially in the so-called "last mile" delivery.

Fast and free delivery has recently become a condition for the success of e-commerce. However, meeting this condition, which is a complex challenge, comes at a price. Deliverers must deliver to multiple addresses in multi-apartment buildings or to single-family homes in congested urban areas. Packages are available in a variety of uneven sizes and need to be delivered quickly throughout the all geographical area (Atkins, 2021).

In order to keep the price we have to pay for free fast delivery to the environment, society and the consumer as low as possible, experts and enthusiasts in the field of logistics are rapidly working in this field. They study various new business models and new technologies that enable these business models.

One of the promising technologies are drones or UAVs as we call them. Drone technology offers huge long-term potential to develop last-mile delivery. Today, however, there are still several obstacles to the day-to-day use of drones for economic purposes. There are a lot of administrative barriers, technological limitations, safety issues, and challenges in regards to public acceptance (Sharma, 2019).

As early as 2016, Wiley announced that today there are five major barriers to the use of drone systems for commercial purposes (Wiley, 2016). Despite the fact that some time has passed since then, later studies also show that there are no significant changes in this area. The study (Bhawes, et al., 2020) concludes that regulations and the threat to privacy and security are the most critical barriers to introducing drones into the logistics sector (Bhawes, et al., 2020). Therefore, the list of barriers to the use of unmanned aerial systems for commercial purposes, developed by Wiley, is still fully valid. The five main obstacles in the year 2016 according to Wiley, were the following (summarized by (Wiley, 2016).

Spectrum of communication

Most current UAV operations are currently performed within the field of view using unlicensed radio spectrum. That won't be enough for long. The forthcoming expansion of activities using UAVs out of sight (BVLOS) will require access to appropriate communication to transmit command signals and data to and from the aircraft.

One way to alleviate this burden is to use existing commercial wireless infrastructure and spectrum to provide command connections for most BVLOS low-altitude missions.

A patchwork of state and local regulation

For decades, there has been no doubt that sky control is solely a matter for the state and that the responsibility for regulating aircraft and air operations lies with state authorities, this is the case in the US as well as elsewhere in the world. But at a time when the use of UAV is expanding, it is necessary to think about new regulations in this area. Many city and local governments have begun to enact or consider new restrictions on where these aircraft can fly, who can fly them, and even what technical specifications they must meet.

But here the problem arises. The inconsistency of different local regulations with each other and with state ones can lead to unmanageable chaos

Rogue and irresponsible operators

A large number of commercial flights currently operated are operated without a certified operator. Even worse, it is on the side of recreational UAV users. They usually don't even take the time to learn where they can (and can't) fly. While most of these operators do not intend to endanger public safety, they are simply trying to shorten what they see as a laborious regulatory process. Nevertheless, the risks posed by these careless operators are important and must be taken into account.

Lack of resources of state agencies, inconsistent procedures, backlogs

Existing rules and procedures are mostly temporary substitutes that have been designed to act as a transition to the development and finalization of rules. The relatively low cost of entry and operation means that the use of UAVs will soon far exceed air operations with crew. The use of this technology will continue to grow and develop, while the relevant state agencies will continue to step on the ground, unless radical changes take place soon.

To date, there is still no plan in place to capture a broader consensus on how to enable and safely operate UAVs during flight in low-altitude airspace (at or below 500 feet) and, above all, out of the operator's field of vision. The lack and absence of certain “sky rules” for the use of UAVs at low altitudes increases the risk of collisions. Both between UAVs themselves, between UAVs and manned aircraft, and UAVs and property.

The development and establishment of a UAV traffic management system is urgently needed as it will enable the establishment and implementation of certain airspace rules for UAVs. The UAV traffic management system will thus be able to balance the need for national and regional security, the safe integration of UAV into the airspace and will at the same time enable the use of UAV for commercial purposes.

After reading the text above it becomes clear that the need for some sort of UAV flight control and management system was clearly expressed. It becomes clear that we cannot solve problems without focusing on all five exposed barriers at once. An incomplete approach and tackling only some of the barriers exposed cannot bring success in the desire to make the use of UAVs for commercial purposes truly possible.

Much has changed since then, but there is still no functioning system to address all of the above obstacles. However, big progress has been made by adopting European regulations EU Regulations 2019/947 and 2019/945 (The European Commission, 2019) which set out the framework for the safe operation of civil drones in the European skies. In accordance with this regulation, drone traffic management will be provided through the so-called U-space, which is a set of services deployed in the airspace where heavier drone traffic is expected, for example in urban areas.

2. CURRENT SITUATION IN THE FIELD

As we stated before, the EU answer to these challenges is so called U-Space which represents the European ecosystem of services and specific procedures designed to support safe, efficient and secure access to airspace for drone operations (Eurocontrol, 2020). The idea of U-space is designed to be able to ensure the smooth operation of drones in all possible operating environments and in all types of airspace (Single European Sky ATM Research 3 Joint Undertaking, 2017) to a Blue Book U-space will support the needs of all types of missions, concern all drone users and all drone categories. But the needs of individual missions can vary greatly. For example, filming a sporting event is not comparable to regular safety overflights. Both, however, cannot be compared to package delivery.

In the first case, a trained operator and an excellent director are needed, but there is no need for any pre-determined routes or automatic guidance. In the second case, there is already a need for a pre-prepared flight route, which is repeated cyclically, but is still static. The routine changes only in the event of an incident. In the third case, however, much more is needed. Pre-arranged flight routes are needed, but they can be constantly changing, depending on the reality in which we find ourselves at a given moment.

Urban logistics using air drones on a larger scale does not seem very credible at the moment. Drones are not energy efficient yet, as well as it is unlikely that the urban population will easily cope with the noise of air drones. But before we can solve these two problems, we need to deal with some of the more fundamental problems. The first is flying out of the operator’s field of vision. The acronym BVLOS describes this and stands for Beyond Visual Line of Sight. BVLOS is exactly what it sounds like, when your drone is in flight such that you can no longer see it.

And yet here is another problem. If we are flying in VLOS or even BVLOS we need one PIC (Pilot in Command) for every drone in the. However, this is not acceptable from a logistics point of view. Dealing with only one customer per flight is very inefficient compared to conventional delivery, where one van delivers packages to 10 or 20 customers. From a logistics point of view multiple drones on multiple missions operating by one PIC or even better multiple drones on multiple missions flying autonomously.

From this point on it is clear that some kind of automatization is needed. In order to be able to use drones efficiently for transport and logistics purposes, it is therefore necessary to enable BVLOS flights, with several drones at once, with one or, if possible, without a pilot in command.

If so far the excuse is shifting and inconsistent legislation, this is no longer the case. Regulation around the U-space allows the construction of efficient systems, the vast majority of which are up to the task.

Let’s take a closer look. A typical U-pace drone mission consists of 4 consecutive stages, as follows: Preparation of the drone mission, Submission of a flight request and receipt of an acknowledgement, Execution of the flight, Mission completed.

Given that the adoption of such a system is demanding in a lengthy process, the EU Commission has planned it in several phases. These phases are also four and are timed over several years.

Table 1: U-Space services framework

Phase	Service
U1 Foundation services	U1.1 e-Registration
	U1.2 e-Identification
	U1.3 Pre-tactical Geo-fencing
U2 Initial Services	U2.1 Tactical Geo-fencing
	U2.2 Flight Planning Management
	U2.3 Weather Information
	U2.3 Tracking
	U2.5 Monitoring
	U2.6 Drone Aeronautical Information management
	U2.7 Procedural Interface with ATC
	U2.8 Emergency management
	U2.9 Strategic De-confliction
U3 Advanced services	U3.1 Dynamic Geo-fencing
	U3.2 Collaborative Interface with ATC
	U3.3 Tactical De-confliction
	U3.4 Dynamic Capacity Management
U4 Full Services	TBD

Each phase of the succession of the gradual implementation of U-space contains an additional set of services (table 1), and at the same time includes everything from the previous upgraded version of services. Each phase of the succession of the gradual implementation of U-space contains an additional set of services (ref. Table 1), and at the same time includes everything from the previous upgraded version of services.

The high-level regulation about U-space (EU 2021/664) has been in force since May 2021. However, U-space is still work-in-progress and still needs amendment by more detailed regulations. Once U-space will be fully operational it is expected to enable efficient, automated, and safe operation of large and diverse fleets of drones. With services such as flight approvals, traffic information (on manned and unmanned aerial vehicles), remote aircraft identification, airspace management, weather updates and geographical awareness, it must at least approach, if not exceed, the safety of commercial civil aviation.

A central decision was to use a federated architecture which allow a high level of autonomy of service providers while defining precise rules and protocols for interaction between them. This is quite an opposite with the traditional monopolies of national Air Traffic Management (ATM) providers at civil aviation.

In such an imagined ecosystem, a large number of U-space service providers (USP or USSP) are expected to work together. Sometimes there should be several providers in the same area, and offer different functions, services and specializations tailored to their customer base. And then the main issue of U-space traffic safety, which is how to prevent two vehicles from occupying the same airspace at the same time, will come to the fore.

By contacting nearby USPs individual USP checks for conflicting flight plans. If such a conflict is detected the flight plan is modified until it is free of conflict. For low traffic densities, this is sufficient, but in the peaks, it gets harder the to maintain a consistent view of the airspace. In a sudden increase of network latency or complete failure internet connection the USP can be detached from the others or even with the drone itself. Solving that kind of technical problems is complex, making it harder and more expensive or commercially infeasible for companies to become a USP in the first place. In that case U-space will be dominated by a very small number of financially very potent players?

Designing a next-generation air traffic management system from scratch is a really difficult task. As a result, more cycles of improvements to this new and complex technology are to be expected, but we run the risk that these cycles will be too slow or turn in the wrong direction. Thus, we run the risk of end up with a dysfunctional or overly complex and overpriced solution in which only a few big players can compete, or, similarly to civil aviation, national agencies.

We still don't know much or almost nothing about the future planned drone ecosystem. Civil aviation has needed decades of continuous development and improvement to develop the efficient and secure mechanism it uses today. A similar approach to U-space development would mean a simpler, less ambitious, less distributed design with fewer features that would be practical and commercially feasible today.

3. UATM DIGITAL TWIN

A digital twin is a virtual representation of a real-world system with the purpose of improving the performance or gain new insight. While the digital twins were first introduced in the scope of simulating and optimizing industrial system (Jones et al., 2020), its concept can be expanded beyond the initial purposes.

An unmanned air traffic management system is a necessity for ensuring safety with multiple airborne drones in a restricted area. While the planned U-space services provide guidelines for drone management, their implementation is not specifically defined. We propose a digital twin solution for management of drones that follows the U-space paradigm.

For this purpose, any real-world operations that either take place or are planned are directly translated onto the digital twin, which includes any U-space services. The digital twin must be designed in order to be able to emulate any real-world scenario and process it in virtual space first. A UATM system in this case no longer functions independently to govern specific drones, but is just a component of the digital twin. The digital twin must in this case to collect real world data in real-time and provide an interface for the in-built UATM system. The main data that needs to be collected include:

1. Drone mission request
2. Active drone positions
3. Active drone battery status
4. Active Drone sensor activity status
5. Operator data
6. Weather information
7. Environmental status
8. Emergency service notifications

While most of the data is a requirement for the UATM within the digital twin the main advantage is that the digital twin allows forecasting of the events based on real-time data and detect or predict hazardous scenarios. The digital twin acts not only for collecting the data from the real world in case of successful simulation maps the decision into the real-world drone activities (see Figure 1).

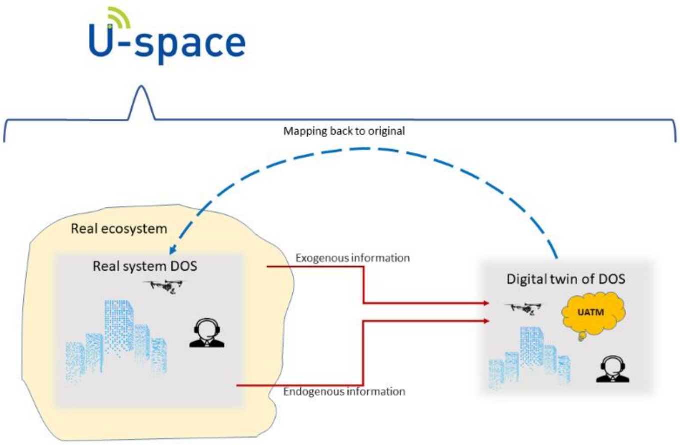

Figure 1. Digital twin solution for drone services

As U-Space service providers can be multiple and allow for services of different offers to operators, compatibility of the services can be an issue, although those should be addressed through the Common Information Services (CIS), the approach via the digital twin allows testing at a level that goes beyond mere simulations. A digital twin must allow the integration of protocols and behave in a virtual environment in real-time as it would have in the real-world system.

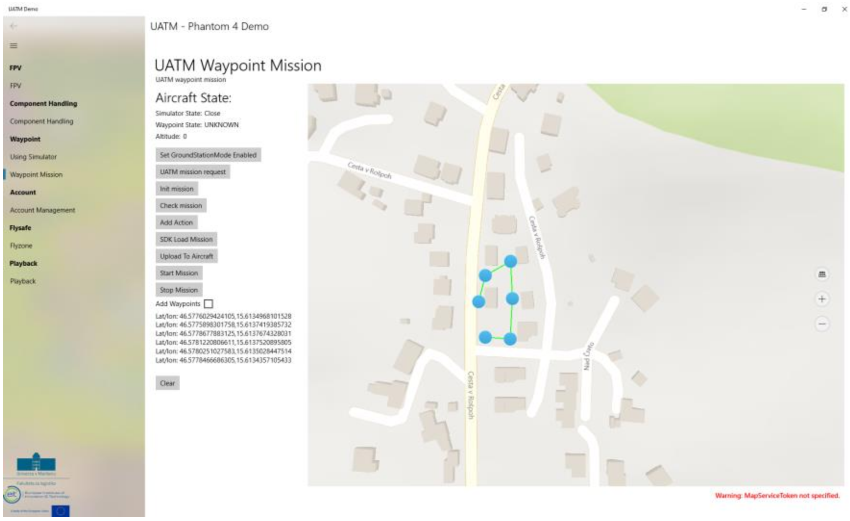

Figure 2. A DT approved and executed drone mission

Figure 2 displays a waypoint drone mission that is requested by the operator and approved by the digital twin UATM module. While the flight mission is taking place the drone is sending telemetry data including position, battery status among others for the UATM module to check whether the approved flight plan is being followed. In the case of a deviation from either from positional or temporal parameters, the digital twin detects a hazard and informs the operator about the situation.

The benefit of the digital twin as a virtual environment is that it enables testing the limits of the systems by allowing simulation of drone flights, hazardous events, and information flows. Within this scope, the UATM module can be tested against its maximal workload in order to analyse how many drone missions can be processed for requests, monitoring, hazard analyses, and other events. Not only can these be simulated in order to analyse the maximal workload, but using the digital twin approach, simulated events can be seamlessly integrated with real-world flights to check the behaviour of the system prior to actual events happening.

4. CONCLUSION

With the U-space paradigm is the set standard for the future development of drone activities in the European Union, the framework is set ambiguously enough to allow for various development directions, while maintain a firm direction that oversees the drone use in their current and future uses. The proposed digital twin approach allows not only a virtualized analysis of air traffic management, but through it a safe way of testing the control system themselves without the requirement to launch and operate numerous drones. Safety and security can be maximized by simulating hazardous events and observing the behaviour within the digital twin in order to identify and redeem mend systemic hazards.

REFERENCES

Atkins, E., (2021). How startups are trying to solve the notorious ‘last mile’ challenges of home deliveries. [Online] Available at: https://www.theglobeandmail.com

Bhawes, S., Gupta, R. & Bani-Hani, D., (2020). Analysis of barriers to implement drone logistics. International Journal of Logistics Research and Applications, 23 Jun.

Gonzalez-Ra, P. L. et al. (2020). Truck-drone teamlogistics:Aheuristicapproachtomulti-drop route planning. Transportation Research PartC, (Atkins, 2021).

Jones, David, et al., (2020). "Characterising the Digital Twin: A systematic literature review." CIRP Journal of Manufacturing Science and Technology 29: 36-52.

Sharma, A., (2019). How drones prove to be an optimal solution for last mile delivery. [Online] vailable at: https://jungleworks.com/how-drones-prove-to-be-an-optimal-solution-for-last-mile-delivery/

The European Commission. (2019). REGULATION (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft. Official Journal of the European Union, 24 May.

Wiley, (2016). 5 Major Obstacles For Unmanned Aircraft Systems. [Online] Available at: https://www.wiley.law/article-5-Major-Obstacles-For-Unmanned-Aircraft-Systems