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Architecture Design and Development for Real-time Risk-based Unmanned Aerial System Traffic Management

Thu Ra¹, Wei Dai², Ee Meng Ng¹

*Air Traffic Management Research Institute, Nanyang Technological University, 637460
Singapore*

Kin Huat Low³

*School of Mechanical and Aerospace Engineering, Nanyang Technological University, 639798
Singapore*

Deploying Unmanned Aircraft System in industrial missions has been a heating topic in recent years. Because of the rapid development of UAS flight control, artificial intelligence, as well as communication, navigation, and surveillance (CNS) systems, UAS has been showing a promising performance that satisfy the requirement of being utilized in transportations. However, current air traffic management system is not suitable to provide services to UAS traffic that is significantly different from conventional air traffic in terms of aircraft characteristics, operational environment, and mission types. In this paper, a UAS traffic management (UTM) system is developed. The system enables both strategical and tactical flight planning capabilities and provides interfaces for both UAS service providers and operators.

I. Introduction

UTM represents a framework in enabling safe and efficient operations for sUAS in airspace of low altitude, with the framework being a collection of services connected via network based on a set of established rules for common understanding [1]. Decentralization of UTM is made possible by adopting the principle of distributed authority, in turn allowing more service providers to come into place as the market evolves, while government regulators remain key in overseeing the safety, access and equity of UTM [2]. Putting this into practice, aircraft can communicate with their service supplier of choice, who are held accountable to the safety, security and performance standards set by the regulators, while coordinating with the rest of the network in making efficient decisions [3]. Such approach has been adopted by several countries and trans-national bodies for their respective UTM implementations, with SESAR: U-space (Europe) [4] [5] [6] [7] [8] and NASA: UTM (United States) [9] [10] [11] being the notable UTM schemes for their modular architectures.

II. Comparison of existing UTM Architectures

The NASA and Federal Aviation Administration (FAA) have been published a new UTM Concept of Operations (ConOps) in 2020. UTM ConOps reflect the continued maturity of UAS. It is approaching to integrate the concept of UAVs operating in all airspace. The Air Navigation Service Provider (ANSP), Supplemental Data Service Providers (SDSPs), UAS Service Supplier (USS) and UAS operator are involved as major stakeholders in this architecture. A centralized Flight Information Management System (FIMS) is an essential and it is operated by ANSP.

¹ Project Officer.

² Research Associate

³ Professor, AIAA Member.

In September 2019, the Single European Sky ATM Research (SESAR) project of EU released Concept of Operations for EuRocean UTM (CORUS) ConOps. The CORUS ConOps of SESAR is targeting the UTM concept called U-Space. U-Space is a typically framework. It planned to facilitate any routine and is intended to address a wide range of ailments, including the most congested - in all aerospace and airline classes - with control of aircraft and air traffic control and proper handling. There are four U-space architectures have been studied in terms of their operational logic, capabilities and services offered, namely Gulf of Finland (GOF), Swiss U-Space Implementation (SWISS), Safe Integration of Initial U-Space Services in a Real Environment (SAFIR) and Demonstration of Multiple U-Space Providers (DOMUS).

Generally, the airspace of earth is classified as six classes such as class A, B, C, D, E and G. And Class A to E are the controlled and Class G is an uncontrolled airspace by ATC. However, both the NASA UTM and the CORUS ConOps are targeting on UAVs operations in Class G, uncontrolled airspace by ATC. In the NASA UTM ConOps, the UAVS operations must be within 400 feet above the ground (AGL) and subject to ATC authorization when operating in uncontrolled airspace. Moreover, the CORUS ConOps defines the three types of airspace in very low level (VLL). Those are Type X, Y and Z are providing the different U-space services in different airspace within VLL [4].

- Type X: No conflict resolution service is offered.
- Type Y: Pre-flight (“strategic”) conflict resolution is offered only.
- Type Z: Pre-flight (“strategic”) conflict resolution and in-flight (“tactical”) conflict resolution are offered.

These types of airspaces are specifying the requirement of procedures such as risk assessment for UAVs operations in both VLOS and BVLOS. Airspace type X is permitted to operate the BVLOS operations. The conflict resolution in type Y and Z is integrated. Accordingly, BVLOS operations can operate in both type Y and Z without any consideration.

The participants in both concepts are identified by relevant stakeholders. In addition, it described in detail of Functionalities/Responsibilities of each participant. The participants of CORUS ConOps are similar as U-space ecosystem. Moreover, there are additional stakeholders in the CORUS ConOps which are not involves in NASA UTM ConOps.

Table 1 : NASA UTM stakeholders and Functionalities/Responsibilities

Stakeholders	Functionalities/Responsibilities
FAA	<ul style="list-style-type: none"> • authority for manned/unmanned flight operations in national airspace. • provides regulations and operating procedures of UAV operations. • Perform real-time airspace control in the event of demand/capacity imbalance.
UAS Operator	<ul style="list-style-type: none"> • Person/organization/institute which responsible for managing of UAVs operation in airspace.
Ancillary Stakeholders	<ul style="list-style-type: none"> • Ancillary stakeholders include entities such as public safety and public entities such as Department of Homeland Security, FAA, law enforcement or other relevant government agencies.

Table 2: NASA UTM stakeholders and Functionalities/Responsibilities

Stakeholders	Functionalities/Responsibilities
UAS Operator	<ul style="list-style-type: none"> • Individual/organization which is the owner of UAVs. • License to operate UAVs operation. • Plans flight path
UAS Pilot	<ul style="list-style-type: none"> • controller of a UAV at the time of operation.
Authorities	<ul style="list-style-type: none"> • Civil Aviation Authority: airspace authority in the region of interest. • Military Authority: Decision maker on military related matters in the region of interest. • Local Authorities: Delegated to replace or complement in the region of interest.
ANSP	<ul style="list-style-type: none"> • Tracking and monitoring the UAVs operations in controlled airspace • Approve/reject the ATC clearance
NAA	<ul style="list-style-type: none"> • Evaluates and authorizes /denies drone operation

Tables 1 and 2 are intended to provide an overview of the stakeholders and their responsibilities. Additional responsibilities can be expected. However, the referenced concepts are not clearly stated the stakeholders and their responsibilities.

The NASA UTM ConOps is using a FIMS interface to exchange data between FAA ATC systems and the participants of UTM. Similarly, there is an interface between ATC and UAVs services which is defined by the CORUS ConOps. Additionally, the terrain, weather, obstacle and environmental data, UAS operating data and airspace constraint information are sharing by the SDSPs inside the UTM ecosystem. Equally, CORUS ConOps provides the services such as drone aeronautical information, weather and environmental information and geo-awareness.

Both NASA UTM and CORUS ConOps provide the services to operate the UAVs operations in both controlled and uncontrolled airspaces and both are similar to the aerospace environment such as aerospace classes, supporting services such as e-identification and geo-fencing, basic principles of airworthiness and operational procedures of a drone such as strategic analysis and flight plans. To integrate UAVs operations into the existing airspace by similar implementation phases such as minimum to high complex operations. The UTM ecosystem is a key element in both ConOps.ss

III. NTU Campus UTM Architecture

This paper is concern with the research based UTM Architecture [Figure 1] [13] for NTU Campus drone testing in Singapore. Singapore is a city-state country, and it is locating at the southern tip of the Malay Peninsula. Moreover, we are more focusing on centralized solution for UTM operations, providing functionalities to UTM stakeholders (pilots, operators, manufacturers, and cloud system providers), surveillance services (police, military and government agencies) and third parties (weather and environmental agencies).

Figure 1: Concept of UTM airspace by NTU: ATMRI [13]

In this architecture of UTM system is illustrated by [Figure 2]. It consists three main modules, frontend, backend and database. The frontend module has two major interfaces. The first one is provided to UAS flight operators. And the other interface is provided to UTM operators, or UAS Traffic Control Officer (UTCOs). These interfaces allow the operators to access the functionalities in UTM server and manage the flights efficiently and safely.

Figure 2: UTM system architecture

The backend module of UTM server has three main functions, flight management, risk management and urban airspace management. Flight management includes operator registration, flight application, monitoring, and route planning. Risk management includes management of static and dynamic no-fly-zones (NFZs) and alerting services. This enables identification, evaluation, and control of the risks in flight operation in the entire urban airspace. Urban airspace management includes airspace structure development, accessibility management, on-demand geofencing, as well as management of other external information inputs like severe weather, crowd recognition and avoidance, etc.

The database module has two main sections. Database management section includes data acquisition, ingestion, processing, and storage management. It collects, processes and stores data including airspace configuration, flight plan, flight operation records, weather information, flight surveillance, etc. The dataset section has two major datasets, namely static dataset and dynamic dataset. The static dataset stores long-term data, while temporary or time-varying data is stored in static dataset.

We developed flight path management and multiple sUAVs, which are equipped with the portable 4G LTE devices for the scenarios of traffic control demonstration. Thereupon, if an operator (service provider or an individual pilot) wants to operate their sUAV in the urban airspace, the operator must register their sUAVs and flight info at the UTM system, in advance. After that, the operator will obtain the flight clearance and/or the predefined flight path planning.

The UTM system has to provide the essential functions for the UAS operators to fly their sUAVs in urban airspace, safely [14]. Here, we describe 3 essential functions, those are registration, flight management and flight monitoring and security of the whole urban airspace.

Registration has two major functions in this registration section, operator and sUAV registration and flight registration. Operator and sUAV registration, the operator who desires to fly their sUAVs in an urban airspace, the operator must register as an operator and the type of sUAV which they want to fly in the UTM system. In this Flight registration has two parts, 1) to submit the takeoff point, landing point and departure time. 2) to submit the whole flight path [Figure 3Figure 3].

Figure 3: Flight registration workflow

In Flight path management, there are validating flight path and defining route planning are the major functions of this section. Before flying the sUAV in an urban airspace, the registered operator needs to register their flight info to the UTM system. The flight path management function has the authority to adjudicate all of the registered flight plans and designate the route to prevent midair collision and accidents among all sUAVs which are flying, instantaneously and simultaneously.

Lastly, flight monitoring. The UTM system must track the real-time position and condition of all sUAVs which are flying in the urban airspace, continuously. This function helps to identify and tackle the unregistered counterfeit sUAV to prevent accidents and midair collision [15]. Illustrated [Figure 4] is a meaningful procedure to prevent the accidents and midair collision of all flying sUAVs in urban airspace.

Figure 4: The procedure of UTM system

Before going to the demonstration, we would like to introduce the AirMatrix Framework. This AirMatrix Framework can provide accurate and standardized units to manage interested urban airspace, divided into uniform airblocks or cube array, precisely. And the size of airblocks in AirMatrix are flexible and it can change dynamically depend on the urban airspace of interested [16] [17], called “The Flexible resolution of AirMatrix”. The Flexible resolution of AirMatrix is the different size of airblock where digital information can be encoded on links and nodes, to provide more accurate services for UAV operations. And it is the set of different nodes and links count in different areas based on population density. And it provides more services than the current UTM solutions. In our UTM system, we are using path finding and validating the flight info algorithms of AirMatrix Framework [Figure 5].

Figure 5: AirMatrix at NTU

IV. Drone Setup, communication, and Demonstration Plans

In our demonstration, we two Tarot 650 self-build UAVs, one DJI Matrice 600 Pro, two QGround Control stations and our own UTM system and. The Tarot UAs are 650mm wide quadrotor weighs around 3-4 assembled in-house by ATMRI. Which has a maximum takeoff weight (MTOW) is 4 kg. We installed Raspberry PI 3B SBC and Pixhawk 4 flight controller into each self-build UAVs.

For communication, we used MAVLink protocol between PI 3B and PX4. And we installed 4G USB dongle into PI 3B for internet connection. PX4 autopilot is an open-source autopilot system designed for inexpensive autonomous aircraft. It provides cost-effective hardware designs for developer and academic communities. In this event, a UAV with PX4 is sent the data as JSON format to UTM server via PI 3B using HTTPs Protocol. HTTPs is the secure version of the standard “Hypertext Transfer Protocol”, to communicate among the computers over LAN (Local Area Network), Intranet and on the Internet, securely. RESTful is a software architectural style that defines a set of constraints to be used for creating Web services [18]. Our own UTM system is using the Web HTTP, REST API [Figure 6] [19] [20].

Figure 6: Set Temporary risk zone and share risk info to USS and another UTM system

This UTM system research and implementation was designed to go through a complex and risk flight test. And to explore the UTM system performance. In [Figure 7], after submitting takeoff points and landing points by the pilot/operator, the AirMatrix Framework set the flight paths to avoid midair collision. You can see there are different altitude. In [Figure 8], after setting up the predefined route for three drones when they were registered such as the first drone is flying from point 1 to 2 (east to west). The second drone is flying from point 3 to 4 (north to south). The third drone is flying from point 5 to 6 (south to north). In [Figure 9]Figure 6], the first drone was malfunction when it is flying to target location. And then, the first drone pilot reported to the UTM system as 10 meters diameter risk zone [21]. The UTM system received and confirm the temporary risk zone of drone #1 and sent the temporary risk zone info to drone #2 and #3 and to hold their position. Within a few seconds, the UTM system recalculates all the routes in the specific area, sends the new routes to all drones in the affected area and shares the risk info to other UTM systems [22]. During flight tests, the system collected the data from the operators, members including flight crews, and their experiences in this demonstration about using our UTM system and their different GCS.

Figure 7: Flightpath set by AirMatrix Framework

Figure 8: Flightpath in the initial scenario

Figure 9 : Flightpath re-planning with geofence

In the conclusion, the crucial functions of the UTM system which we design, and architecture are registration, flight management and analyzing the message flow among the UTM systems and operators. In the scenarios of traffic control implementation and demonstration, we used the multiple sUAVs which are accoutered with the portable 4G LTE devices [23].

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