Development of Hierarchical UAS Traffic Management (UTM) in Taiwan

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Abstract. The unmanned aerial vehicles (UAVs) will soon be legally flying into airspace in Taiwan and many countries. UAS traffic management (UTM) becomes an important issue to challenge aviation safety. A hierarchical UTM is proposed and constructed based on the concept of Air Traffic Management (ATM) for the manned aviation system. The proposed Regional UTM (RUTM) and National UTM (NUTM) are hierarchical infrastructure to offers traffic management services for all legal UAV flights in Taipei Flight Information Region (TPE FIR) under and over 400 feet. The proposed UTM provides UAV/pilot log-in/out, flight planning, geo-fencing, detect and avoid (DAA), logbook records, big data analysis, ground control redundant support and controller-pilot communication on multi-window monitor system. UTM data are encrypted to prevent hijacking threat to low altitude UAVs. The UTM adopts ADS-B Like communication infrastructure to offer affordable cost for all UAVs with high reliable surveillance data reporting. The ADS-B Like surveillance mechanism includes 4G/LTE, LoRa, APRS and XBee. Their gateway deployment is designed and constructed with supports of Chung Hua Telecommunication (CHT) in urban and suburban areas. While those remote areas, such as mountain and deep forest, the National Forest Bureau workstation will be selected. The ADS-B Like communication will cover full airspace in Taiwan. Surveillance data reliability, continuity, integrity and availability will be examined by flight tests. The proposed Hierarchical UTM will launch trial runs in Tainan County of RUTM operation to verify the proposed concept, system performance and general operation into the national “UAS Innovative Experiment Project”.

1. Introduction
The National Airspace System (NAS) was developed to construct Air Traffic Control (ATC) infrastructure in 1960s for civil aviation. Based on the NAS, communication, navigation and surveillance (CNS) and Air Traffic Management (ATM) project launched in January 1, 2010 using GPS (Global Positioning System) to enhance air navigation and SATCOM (Satellite Communication) for seamless communication [1]. Under this environment, the Automatic Dependent Surveillance (ADS) was developed to enforce aircraft positioning by broadcasting to vicinity aircraft and ground ATC centers. ADS-B affiliates airborne aircraft in clear traffic awareness. The unmanned aerial vehicle (UAS) and its unmanned aircraft system (UAS) have been developing into mature for various applications since 1990. The Unmanned Aircraft System Traffic Management (UTM) was studied by NASA to construct a feasible and effective system to assist UAS operation for aviation safety [2]. UTM system concept focuses on small UAVs in low altitude and to large mission UAVs into the integrated airspace. Military UASs have already flown into NAS, ATC perspectives of UAS integrating into integrated airspace become great concern to NAS flight safety [3].
ADS-B has been proven to be effective and efficient in aviation surveillance. It is very important both in ATM as well as in UTM. Since Traffic Alert and Collision Avoidance System (TCAS) had emerged due to mid-air collision in 1956. Active detect and avoid technology enabled collision avoidance from aircraft to enhance aviation safety for all passenger aircraft, and became a standard equipment in 1990s [4]. Based on ADS system concept, TCAS may be executed by software to estimate the closest point of approach (CPA) between two approaching aircraft and generate warning signals for avoidance [5]. The ADS-B TCAS is used in air transportation and can be extended into unmanned aircraft system (UAS) using ADS-R (Rebroadcast) [6].

UAVs may be classified by their weight and thrust in small or large scale with rotor wings and fixed wings. Command and control (C2) is main function for operation visual line-of-sight (VLOS) or beyond visual line of sight (BVOLS). Small UAVs (sUAVs) are forecasted soon to fly below 400 feet in urban to remote areas for varieties of applications [7]. UAS will be unique problems to UTM and will threat ATM. For those high performance long endurance fixed wing UAVs, UTM will surely merge into integrated airspace in high altitude ATM [2].

Civil Aeronautical Administration (CAA) Taiwan legislated UAS Regulations in April 25, 2018 [8], and will open to the public for legal use in March 31, 2020. An Unmanned Aircraft System (UAS) Traffic Management (UTM) system is proposed and constructed using the similar concept of Air Traffic Management (ATM) based on communication, navigation and surveillance (CNS) for unmanned aerial vehicle (UAV). An ADS-B Like (Automatic Dependent Surveillance – Broadcast Like) communication infrastructure is proposed by introducing 4G/LTE (Long Term Evolution), LoRa (Long Range Wide Area Network) and APRS (Automatic Packet Reporting System) for small UAVs [9]. In UTM development [2], the airspace of 400 feet altitude is regularly controlled for small UAVs in lower speed. In Taiwan, UAVs flying below 400 feet is authorized to local government for management, while those above 400 feet is controlled and monitored by CAA [8]. A hierarchical UTM is constructed under such segmentation to establish Regional UTM (RUTM) and National UTM (NUTM) for prompt management [10].

Among all implementation plans, UTM surveillance is the most important part to realize. Effective communication infrastructure and available frequency spectrum for data reporting to UTM is key develop. The UAS DAA in UTM shall take the similar concept in ATM using ADS-B based TCAS [5, 6]. A conformance monitoring was discussed similar to separation bubble concept in TCAS [11]. The UAV is surrounded for protection in this manner. The conformance monitor creates a new idea to enclose UAVs for protection.

The proposed hierarchical UTM tries to construct a prototype demonstration of UAS surveillance and collision avoidance based on the constructed ADS-B like communication infrastructure [9]. G. Orrell et al. presented ADS-B like system concept using 4G/LTE for small UAS (sUAS) surveillance in low altitude [12]. Unlike manned aircraft, sUAVs are not detectable via radar or other independent surveillance techniques. Automatic dependent surveillance (ADS) shall be feasible to develop. Mobile communication is the most affordable communication system to adopt, for its opening to the public in most areas. 4G/LTE is available to use onto UAVs. However, 4G/LTE will not guarantee for those flying above 400 feet. Similar concept is proposed in our team to construct a UAS surveillance infrastructure using multiple communication media. In addition to 4G/LTE, LoRa, APRS and XBee are eligible candidates as ADS-B Like for UAS [9].

C. Ramsey introduced a small ADS-B device by “uavionix” [13] for UAVs. It uses commercial frequency 1090MHz and 978MHz into UAVs. However, radio stations for ADS-B are not designed to provide coverage down to low altitude [12]. The UAS providers are not affordable to construct a new infrastructure for use. J. Scardina presented the use of ADS-B for general categories of commercial air transportation systems [14] by FAA and ICAO. Under very limited ADS-B authorizations, it is difficult to broadly open to all types of UAVs, especially those small ones flying below 400 feet. In the proposed UTM system concept, the ADS-B Like communication requires adopted devices in high reliability, light weight, low cost and wide coverage through gateway deployment. Other than 4G/LTE, the LoRa and APRS require to establish relay gateways to relay radio surveillance from UAVs into the UTM Cloud. In the preliminary surveys, LoRa can cover a 15 km radius range; while APRS is capable...
for 40 km radius range. Multiple ABS-B Like systems play redundancy capability for UAV surveillance.

According to Taiwanese UAS Regulation, the proposed pilot test is launched on Tainan Regional UTM under the approval of Tainan City Government. The test tries to verify the performance of ADS-B Like communication for UAV surveillance.

2. System Infrastructure

The proposed hierarchical UTM manipulates UAV surveillance data from embedded ADS-B Like communication devices to report position and flight data into a UTM cloud and distribute to controllers in Regional or National UTM Centers, as shown in Figure 1. Based on the National UAS Regulations, the Regional UTM (RUTM) will monitor all UAVs flying under 400 feet; while the National UTM (NUTM) controls all UAVs flying over 400 feet into National Airspace System (NAS), as shown in Figure 2.

![Figure 1. The proposed hierarchical UTM system infrastructure](image)

In Figure 2, the red line expresses the 400 feet boundary for RUTM and NUTM. Higher altitude flights into NAS shall interconnect to ATM with effective surveillance by ADS-R via Air Navigation Service Provider (ANSP). The UAVs will be transparent to all manned aircraft in NAS. ADS-R media by 1090 MHz for air transports and 978 MHs for general aviation.
Figure 2. Airspace surveillance below and above 400 feet for UAS

ANSP connects the NUTM to ATM system via the Aeronautical Telecommunication Network (ATN) in UAV surveillance data rebroadcasting (Fig.3). Since ATN is a complete communication infrastructure with HF, VHF, UHF and Satellite Communication (SATCOM), ATN will definitely relay UAV data to airborne. ATN coverage is worldwide.

Figure 3. Concept of surveillance rebroadcast from UTM to ATM via ATN
Figure 4 shows the surveillance data flow from UTM to ATM. All UAVs flying below 400 feet belong to RUTM surveillance, such as multi-rotors, will be ignored. UAVs flying higher altitude for long distance missions shall report to ATM with their surveillance data. This will apply to fixed wing UAVs and link to its GCS (Ground Control Station).

Figure 4. Surveillance data flow from UTM to AYTM

The UTM system processes surveillance data to UTM Controller monitors in quasi real time, since significant time delay happens during ADS-B Like transmission and UTM processing. Figure 5 shows the typical time delay in the UTM system data processing.

| ADSB Like | Period | Tx/Rx | Cloud | UTM | C-P |
|-----------|--------|-------|-------|-----|-----|
| 4G/LTE    | 6~8    | 0.8   | 0.8~1 | 1~2 | 6~10|
| LoRa      | 6~10   | 1~2   | 1~2   | 1~2 | 6~10|
| APRS      | 5~13   | 4~8   | 2~4   | 1~2 | 6~10|
| Xbee      | 6~10   | 1~2   | 1~2   | 1~2 | 6~10|

Figure 5. Real time delay estimation in UTM

In UTM system, the UAV surveillance data should appropriately display on the control monitor. UAV icon is design to include necessary UAV information, as shown in Figure 6. They are UAV ID (MX1122), operating at 45 meter AGL, with red heading arrow in length for speed, pulling a tail dashed line as past track. Red circle is its protection bubble. The outside block represents surveillance boundary.

Figure 6. UAV Icon for UTM
All UAV surveillance data will report to the UTM cloud and connect to all RUTM Centers and NUTM Center. In the developing phase, only one RUTM for low altitude and NUTM for higher altitude are operating. UTM to ATM surveillance data flow chart is shown in Figure 7. This is important connection from UTM to transparent to ATM for all UAVs flying into National Airspace System (NAS). ANSP rebroadcasts UTM surveillance data via 1090 MHz to large transportation aircraft above 180 FL and 978 MHz to general aviation below 180 FL.

3. Flight Test Demonstration
A drone delivery in Sai-Gia area is tested to carry parcel to fly across river (Fig.8). The surveillance data is reporting to RUTM and displays with its track in RUTM Center. In this test, only Tainan RUTM is performed in the preliminary proof of concept (POC).
In Tainan City tests, UAVs are flying in the north part of the city. Two UAVs are flying under full surveillance by Tainan RUTM Center as shown in Figure 9. In Figure 9 (a), Google Earth is selected as the background to get better awareness of ground feature; while in Figure 9 (b), Google map is selected to get more clear display.

To verify the functional capability of UTM system, software detect and avoid (DAA) is performed in Tainan RUTM. The proposed DAA mechanism is presented in Figure 10, where the time to conflict (TTC) from two approaching UAVs are checked from RUTM. Once the closest point to approach (CPA) appears dangerous to each other, DAA initiates. The Traffic Advisory (TA) is set 48 seconds and the Resolution Advisory (RA) is set 25 seconds according to ICAO TCAS standards [4].

In the position estimation, since RUTM is still a small area, the UAV positions of longitude and latitude vary mostly in “Minute” and “Second” terms, and their “Degree” term can be ignored. Within the RUTM area, it is assumed X-Y coordination in rectangular. When multiple UAVs appear in one area, they should be firstly checked with the “Minute” term to identify their relative separation to classify into a “closed group”. Then check any two UAVs in a “closed group” by heading angle, if there will be an intersection. If positive, then check their TTC. When UAV1 in (x1, y1) and UAV2 in (x2, y2) are identified in a “closed group”, their separation can be calculated by:

\[ X = x_1 - x_2 = \text{difference in “Minute” and “Second”} \]
\[ Y = y_1 - y_2 = \text{difference in “Minute” and “Second”} \]

Their difference of one “Minute” is 1.85 km, and one “Second” is 30.9 m in Taiwan. The separation for two UAVs can be calculated by trigonometric function. Since TTC is expressed in terms of time, the calculated separation should be converted into seconds by their speeds. Typically, speeds are 8 m/sec or less. The TTC calculation is recursively operated when UAVs are grouped into one small area.
Figure 10. DAA with TTC and CPA

Figure 11. Flight surveillance with DAA, (a) TA, and (b) RA and avoidance

Figure 11 shows the DAA performance for two UAVs by approaching to each and violate the separation minima. When TTC is checked from RUTM to drop to TA<48 seconds, DAA alerts, and later RA responds to perform avoidance. In Figure 11(b) UAV in the right hand side has less priority, it detours 15 degrees to make ways for the higher priority UAV. The RUTM controller establishes voice communication to the pilot to send the avoidance command. The priority and avoidance follows ICAO regulations [5, 6] with head-on, cross-over and pass-over.

Figure 12. Flight surveillance with DAA from TA, RA and solved

Figure 12 shows a real flight conflict and DAA. Two UAVs are flying along the coast in opposite direction. Figure 12 (a) shows the TTC alert and (b) shows DAA resolution for the lower UAS making 25 degrees turn for avoidance, (c) DAA solved and (d) real track on RUTM monitor. The RUTM surveillance record for flight tests is shown in Figure 13. This is a daily record from tests in Tainan Area. There are 4 UAVs flying several routes to check the availability of ADS-B Like and gateways. Some long run statistical test is required for ADS-B Like system performance.
4. Conclusion
This paper demonstrates the design and construction of a hierarchical structure concept of UTM system in Taiwan. A preliminary test in Tainan RUTM is demonstrated with parcel delivery and other mission flights. Using the appropriate ADS-B Like communication devices, the UAV position data are transparent to RUTM Center for surveillance and management. This is valid for UTM controller to help UAV pilots during the mission flights. DAA in a similar mechanism of TCA in the manned aircraft system has been verified by UTM software performance. Flight demonstration supports its usefulness and effectiveness.
In this paper, RUTM display and surveillance shall be the key to open the sky for UAVs in mission flights. The preliminary test of the proposed hierarchical UTM is successful for future perspectives.

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