SCIENCE CHINA
Information Sciences

• NEWS & VIEWS •

October 2022, Vol. 65 207201:1–207201:2
https://doi.org/10.1007/s11432-022-3516-2

IEEE standard pioneered an IT-led interdisciplinary approach to structure low-altitude airspace for UAV operations

Chenchen XU[1,2], Xiaohan LIAO[1,2*] & Fei YANG[3]

[1]*State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing* 100101*, China;*
[2]*The Research Center for UAV Applications and Regulation, Chinese Academy of Sciences, Beijing* 100101*, China;*
[3]*Office of Air Traffic Regulation, Civil Aviation Administration of China* (*CAAC*)*, Beijing* 100101*, China*

Received 21 February 2022/Accepted 13 May 2022/Published online 16 September 2022

Citation Xu C C, Liao X H, Yang F. IEEE standard pioneered an IT-led interdisciplinary approach to structure low-altitude airspace for UAV operations. Sci China Inf Sci, 2022, 65(10): 207201, https://doi.org/10.1007/s11432-022-3516-2

Unmanned aerial vehicles (UAVs) equiped with state-of-the-art information and automation technologies are developing rapidly, especially in low-altitude airspace within 1000 m above ground. Many commercialized UAV flights may soon jam this slice of airspace. Thus, the IEEE Communications Society has established a working group to develop a standard for structuring a low-altitude airspace framework for UAV operation. This standard defines a structure for low-altitude airspace that enables safe and efficient UAV traffic management (UTM). On December 1, 2021, IEEE 1939.1TM-2021, the first IEEE standard for UAV operation, was officially published [1]. It was elaborated in five sections: gridding technology, remote sensing, communication and networking, air route planning, and operation and management. In the participation of shaping this standard, we realized that multiple disciplines would play important roles in constructing low-altitude airspace infrastructures, or "sky roads" in popular term. Unlike ground roads that are visible and materialized by sand and cement, "sky roads" are digitized, time-dependent, and constructed using technologies such as geographic information, communication, and aviation.

Background. The increasingly diversified UAV applications in low-altitude airspace combined with the rapidly booming information technology has brought about not only the prosperous economy of low-altitude airspace but also serious issues regarding safe and efficient operations of UAVs in the sky. Considerable efforts have been made to develop a set of UAV laws and regulations to cope with these challenges, such as China's operations-focused system. It includes flight control, license, airworthiness, air traffic, manufacturing, and pilot qualification management documents [2]. Additionally, UAV regulation technologies are also developing rapidly, such as the UTM jointly developed by the US Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) [3], the U-Space system implemented by the European Aviation Safety Agency (EASA) [4], the UAV operation and management (UOM) system constructed by the Civil Aviation Administration of China (CAAC) [5], and the TM-UAS system led by the Singapore project [6]. A typical UTM system can alert collaborative UAVs when unauthorized flying occurs and regulate UAVs to avoid collisions.

However, other problems remain in low-altitude airspace; for example, the collision risks between UAVs and surface obstacles (such as ground buildings), especially in urban areas where current urban air mobility (UAM) research has gained great interest from larger stakeholders. Moreover, the signal coverage of ground mobile communication may not guarantee all-time UAV connections with UTMs. The optimization of fixed and shared roads is needed to best serve commercial UAVs in large numbers. Much like roads are essential for ground transportation, air routes are indispensable for UAV air mobility. This standard proposes a low-altitude operation framework with UAV low-altitude public air routes ("sky roads") as the core technology.

Contents and key technologies. This standard elaborates on gridding and coding, remote sensing, communication and networking, air route planning, operation and management. In detail, a gridding flight environment is constructed by "gridding and coding" technology, which can efficiently store, organize, and retrieve geographic information to realize grid-based precise management of UAVs. UAV-based "remote sensing", characterized by flexibility and maneuverability, is an effective means to collect high-precision geographic data and to form a dynamic data-refreshing mechanism. The "communication and networking" aspect elaborates the low-altitude communication and data link requirements in various operation scenarios. "Low-altitude public air routes" are fine airspace structures to allow UAVs of different technical capacities to have equal access to airspace. "Operation and management" facilitate the coupling between air routes and UTM by clarifying the requirements for communication, navigation, and surveillance (CNS), and other capabilities of low-altitude operations. Regarding the individual technologies mentioned by the standard, their combinations formulate an interdisciplinary approach to structure the low-altitude airspace.

Efficient organization and utilization of low-altitude airspace by multi-scale geographic gridding system. The low-altitude operating environment is highly dynamic. Multi-scale gridding and coding technology can accurately visualize geographic entities and organize and manage multi-source data uniformly and efficiently by associating spatio-temporal data, airspace, and trajectories. The GeoSOT-3D method embedded in this standard is developed by Peking

* Corresponding author (email: liaoxh@igsnrr.ac.cn)

University group, and is established in an integer coding rule to easily discretize data in a digital computing environment. It has significant advantages in the modeling, analysis, and visualization of multiscale geographic information. In this method, a two-dimensional gridding system of equal longitude and latitude is first constructed by iteratively subdividing the Earth through a quad-tree subdivision principle. Then, a three-dimensional geo-spatial reference ranging from the geo-center to a height of 5000 km is formed by introducing the height dimension through an octree subdivision principle.

Accurate identification of geographic constraints of low-altitude operations by UAV remote sensing and scientific definition of their spatial boundaries by multiple geofences. The low-altitude operating environment, especially in urban areas, is complex, with diverse types and multiple scales of objects. It is not sufficient to accurately identify the species of sub-meter-resolution objects, such as individual trees, by using spectral and shape information from satellite-based images. UAV remote sensing, which is a promising method for recognizing and extracting objects using height information, has been widely used. For example, based on the point cloud image collected by airborne LiDAR, the operator can effectively extract the building outline and height information using an automatic extraction method and the multi-marker point process. Challenges remain, however, in accurate object identification and dynamic geographical information refreshing. There is no consensus on the optimal parameter values, such as the optimal resolution, flight height, and speed. We propose to adaptively refresh data by forming a real-time information feedback mechanism between on-board sensors and a cloud system in advance and standardize the identification and extraction process to simplify enforcement and promote consistency. After constructing a constraint database, the safe separation between UAVs and constraints has gained considerable traction. Currently, UAVs that move toward no-fly zones receive geofence warnings. Usually, geofences are formulated by regulations issued by aviation-related authorities or local governments. For example, CAAC has publicized the clearance area of civil airports, which are composed of effective time, height limits, and boundaries [7]. In their early development stage, a planned space is greater than that of actual needs. Simulated or real flights of UAVs should be ongoing to scientifically define an optimal separation between UAVs and obstacles by balancing privacy, noise, and local turbulence effects.

Construction and optimization of three-dimensional air routes and visualization technology. In a flight environment constructed by the above gridding and object identification technology, a low-altitude air route network, including path and network planning, is designed. Path planning, a search and optimization process for the air route determined by the starting and ending points, is divided into global planning and dynamic replanning. The former mainly focuses on path-searching and optimization algorithms. In a complex environment, bionic intelligent algorithms such as the optimized ant colony algorithm are generally used. Dynamic replanning requires timeliness and efficient local path searching algorithms such as artificial potential field algorithms. For the network planning, routing rules are the priority, especially for the design of approaching and crossing routes. Additionally, it is necessary to scientifically and quantitatively calculate and reasonably stipulate the classification, spatial shape, width, safety separation, UAV performance requirements, and safe operation rules of low-altitude air routes. The three-dimensional visualization of air routes accelerates their application in UTM. For example, augmented reality (AR) technology, developed from computer graphics, vision and image processing, sensors, and other technologies, is a promising technology that has recently drawn significant attention. It has been used to realistically and efficiently visualize the three-dimensional air route network and its operations in a flight simulation verification system based on an electronic sand table (illustrated in the demo video).

Enablement of dedicated applications for UAVs' operations at low-altitude airspace by using shared infrastructures of the cellular communication network. Mobile communication networks have been widely used to serve low-altitude UAV flights. Actual tests in different scenarios show that the current 4G mobile communication facilities can serve flying UAVs within approximately 300 m above ground level (AGL) with robust data and video transmission but cannot serve the supervision communication well at heights above 300 m AGL [8]. 5G communication, which is characterized by high rate, low latency, and ultra-reliability, has been rapidly developed and widely deployed. By the end of 2021, China's 5G stations has exceed 1 million, covering all prefecture-level cities. It can be used as infrastructure to strengthen the low-altitude communication capacity of UAVs. Considering that current 5G stations are mainly deployed for terrestrial services, issues such as interference and discontinuous coverage for the air business are challenging for UAVs' operations. We call for a distribution optimization of 5G stations by deploying them along low-altitude air routes to enable dedicated applications of UAVs based on shared communication infrastructures.

Summary. The newly published IEEE standard clearly illustrates the structure of low-altitude airspace for efficient UAV air-traffic management. It elaborates on the structural low altitude based on air routes from five sections: gridding technology, remote sensing, communication and networking, air route planning, and operation and management. This is the first IEEE standard to depict low-altitude airspace environments for UAV operations, creating an IT-led interdisciplinary approach including geography, aviation and traffic disciplines to research low altitudes. Additionally, practical cases of air routes planning in this standard also provide reference and experience for industries to open up low-altitude transportation. For example, during the creation of the standard and since its publication, the Peking University group designed four types of low-altitude air routes from grids of different sizes. China Mobile Corporation modeled and mapped the spatial distribution of 5G signal coverage along air routes through rigorous real flights. The Antwork, Fengyi, and Meituan jointly and normally transport nucleic acid samples by UAVs in Hangzhou city, which is a symbol of the UAV air routes from private to public characterized by compatibility and multi-operator. The authors' team has also developed an air route planning system for UAVs (ARPS), which essentially reads remote-sensing images and outputs air routes. Further development and applications of the newest IT and other technologies are expected to accelerate the construction of low-altitude air traffic infrastructures.

Acknowledgements This work was supported by Key Research Program of the Chinese Academy of Sciences (Grant No. ZDRW-KT-2020-2) and National Natural Science Foundation of China (Grant No. 41971359).

Supporting information Demo video. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

References

1 IEEE Communication Society. IEEE 1939.1 Standard for a Framework for Structuring Low Altitude Airspace for UAV Operation. IEEE Std 1939.1-2021, 2021. https://standards.ieee.org/standard/1939_1-2021.html
2 Liao X H, Xu H. UAS Operational Regulation Technology Development and Applications. Beijing: Science Press, 2020
3 FAA. UAS UTM Concept of Operations v2.0. 2020
4 SESAR Joint Undertaking. U-space Blueprint Brochure Final. 2017
5 Quan Q, Li G, Bai Y Q, et al. Low altitude UAV traffic management: an introductory overview and proposal (in Chinese). Acta Aeronaut Astron Sin, 2020, 41: 323238
6 Salleh M F B M, Tan D Y, Koh C H. Preliminary concept of operations (ConOps) for traffic management of unmanned aircraft systems (TM-UAS) in urban environment. In: Proceedings of AIAA Information Systems-AIAA Infotech @ Aerospace, Grapevine, 2017
7 CAAC. UAV Geofence. MH/T 2008-2017. 2017. http://www.caac.gov.cn/HDJL/YJZJ/201707/t20170710_45235.html
8 CAAC. Test Report for the Safe Flight of Low-altitude Networked UAVs. 2018. http://www.caac.gov.cn/XXGK/XXGK/GFXWJ/201811/t20181127_193186.html