From Urban 3D Imagery to Low-Altitude Flight Risk Perception: A Construction Method for the Low-Altitude Flight Safety Zones of Surveying and Mapping UAVs and Its Application in Shanghai

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Abstract

With the in-depth penetration of Unmanned Aerial Vehicle (UAV) technology in fields such as geographic information surveying and mapping, the urban low-altitude economy has ushered in a critical opportunity for rapid development. However, surveying and mapping UAVs are confronted with the core technical bottleneck of "accurately determining the safety of flight routes", while issues such as airspace congestion and collision risks have become increasingly prominent. How to enable UAVs to perceive the complex environment in which they operate has thus emerged as a key challenge. Based on remote sensing images, 3D geographic data, and other relevant datasets, this study comprehensively applies multi-source data fusion technology to construct the theoretical framework and technical system of the "Urban Low-Altitude Surveying UAV Flight Safety Zones". It classifies the core causal factors affecting flight safety into three major categories: building height, electromagnetic interference, and controlled areas. Through a series of key technical processes, a standardized 3D spatial grid system is established, and a computable "risk perception" model is developed. Taking Shanghai Municipality as the empirical research area, empirical analysis is conducted using remote sensing images, ultimately generating a low-altitude flight safety field grid dataset covering the entire administrative region of Shanghai. Verification results indicate that this achievement can effectively identify the spatial distribution characteristics of potential safety hazards and height constraints, significantly reduce the collision probability between UAVs and obstacles, and provide standardized technical support for the flight safety of low-altitude surveying UAVs.

1. Background

With the in-depth application of unmanned aerial vehicle (UAV) technology in fields such as logistics and transportation, agricultural plant protection, emergency rescue, and geographic information surveying and mapping, the urban low-altitude economy has entered a stage of explosive growth. However, at the same time， safety hazards including airspace resource congestion, aircraft collision risks, and illegal intrusion into controlled airspace have intensified accordingly. Among these, safety issues in the field of geographic surveying and mapping are particularly prominent—UAVs in this field are mainly used for fieldwork data collection of geographic information products such as digital orthophoto maps and 3D oblique models. They realize a fully automated flight mode through pre-set route planning, which significantly improves operational efficiency and convenience. Nevertheless, they face the core technical challenge of "how to accurately determine the safety of flight routes within the survey area". This problem has become a key bottleneck restricting the safe and efficient operation of surveying and mapping UAVs.

Taking geographic information big data as the core support, integrating multi-source data fusion technology and related algorithms, and drawing on the concept of "low-altitude safety corridors" (Feng, 2021), this study constructs the "Urban Low-Altitude Surveying and Mapping UAV Flight Safety Field". Its essence lies in establishing a standard digital 3D spatial grid system that covers the airworthiness areas of urban surveying and mapping UAVs, features three-dimensional connectivity, and supports intelligent coding. This study conducts data testing and verification with Shanghai as a typical research area. The test and verification results show that the data achievements of this system can efficiently provide flight safety guarantees for surveying and mapping UAV operations, and simultaneously offer key data support for the "air route network" in the construction of the "four networks" for the urban low-altitude economy (Shenzhen Municipal Bureau of Transport, 2024).

2. Key Technologies and Methods

2.1 Analysis of Flight Safety Impact Factors

In the low-altitude airspace of megacities, highly dense and spatially complex building clusters have become the core environmental constraint factor restricting low-altitude flight safety. On the one hand, high-density super high-rise building clusters not only significantly increase the physical collision risk of surveying and mapping UAVs; on the other hand, they also cause significant interference to the stable transmission and full-area coverage performance of low-altitude communication links and navigation signals, thereby exacerbating the uncertainty of flight operations. Based on this, this paper, in combination with national and local policies and regulations on low-altitude airspace management, and by integrating the spatial heterogeneity characteristics of the low-altitude environment in megacities, systematically classifies the core factors affecting the flight safety of low-altitude surveying and mapping UAVs into three categories (as shown in Figure 1):

The first is the building height impact factor, with fixed structures such as super high-rise buildings and industrial chimneys as its core components. The spatial distribution and height parameters of these structures directly determine the vertical safety boundary of UAV flight operations.

The second is the electromagnetic interference impact factor, which mainly covers electromagnetic radiation sources such as radio transmission towers and high-voltage power lines. The electromagnetic radiation characteristics of these sources pose potential interference to the signal stability of UAV navigation and communication systems.

The third is the controlled area impact factor, defined in accordance with airspace control policies, including special airspaces such as public security-sensitive areas and airport clearance protection zones. The flight restrictions in such areas are directly related to the compliance and safety of flight operations.

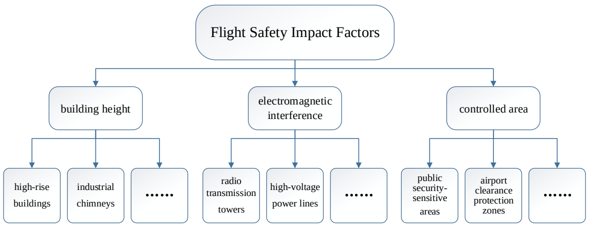


Figure 1. Framework diagram of flight safety impact factors.

2.2 Analysis of Geographic Information Data Utilization

Based on the core low-altitude flight safety impact factors defined in the previous section, this paper systematically sorts out and screens the available geographic information data that supports the flight safety assessment of low-altitude surveying and mapping UAVs, which specifically covers the following four categories:

The first category is the full-area coverage Digital Surface Model (DSM). This data is generated through refined modelling of airborne Light Detection and Ranging (LiDAR) point cloud data, with a grid resolution required to be better than 1 meter and an absolute elevation accuracy controlled within 0.2 meters. It can fully characterize the 3D morphological features of surface structures, terrain undulations, etc., providing a high-precision elevation benchmark for the quantitative extraction of the building height impact factor and directly supporting the delineation of the vertical safety boundary for UAV flight operations.

The second category is the full-area coverage Digital Orthophoto Map (DOM). This data is generated through image rectification, mosaicking, and other processes, with a spatial resolution required to be better than 0.2 meters and a horizontal position error meeting the accuracy requirement of being better than 0.5 meters. It provides intuitive support for the visual interpretation of the spatial distribution characteristics of ground objects, assists in identifying potential risk areas such as dense building clusters and isolated obstacles, and supplements the verification of the accuracy of ground object elevation information extracted from the DSM.

The third category is the full-area coverage Digital Line Graphic (DLG). In the form of vector data, this data details the spatial locations, attribute characteristics, and topological relationships of basic geographic elements such as surface residential areas and facilities, transportation roads, and water systems. It provides key attribute support for the identification and localization of the electromagnetic interference impact factor, enabling the accurate extraction of core information such as the alignment of high-voltage power lines and the coordinates of radio transmission towers, and supporting the delineation of electromagnetic radiation risk areas.

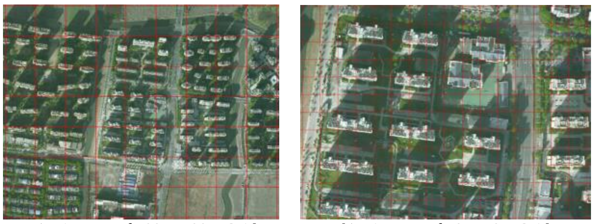
The fourth category is the thematic data of controlled area scopes. Mainly presented in the form of vector polygon data, this type of data covers special areas defined in accordance with national and local airspace control policies, such as airport clearance protection zones, military administration zones, and protection scopes for important immovable cultural relics. It provides an authoritative boundary basis for the spatial localization of the controlled area impact factor, directly supporting the compliance assessment of UAV flight operations and preventing intrusion into no-fly or restricted-fly areas

2.3 Construction of 3D Spatial Grids and Update of Grid Factor Attributes

For the entire urban space, when constructing a regular square vector grid surface dataset, the parameter value of grid spacing has a decisive impact on the accuracy of subsequent safety height calculation for low-altitude surveying and mapping UAV flights, data processing efficiency, and risk control effect. First, if the grid spacing is set too large, it will lead to deviations in the calculation results of the safety height in local areas due to insufficient spatial resolution (i.e., safety height distortion), which fails to meet the technical requirements for safety assessment accuracy in the refined management and control of low-altitude airspace in megacities. Second, if the grid spacing is set too small, it will not only cause massive data redundancy—resulting in increased data storage costs, prolonged time consumption for iterative calculation of safety height, and waste of computing resources—but also lead to misjudgement of navigable airspace by the route planning algorithm due to the excessively small spatial scale of grid units. This significantly increases the probability of unplanned traversal of UAVs through gaps between super high-rise buildings, thereby elevating the risk of physical collision. The specific risk characteristics are as shown in Figure 2.

Figure 2. Dangerous areas between buildings (green areas) in 5m×5m grid.

Based on the above multi-dimensional trade-off among accuracy, efficiency, and risk, this study determines the basic grid spacing of the entire survey area as 100m×100m. For special key-controlled areas (such as areas with higher requirements for safety assessment accuracy, including urban central business districts and areas around airport clearance protection zones), encrypted grid spacing of 20m×20m or 10m×100m can be adopted for safety height calculation in accordance with differentiated safety assessment needs. This aims to achieve the dual goals of "efficient full-area coverage + accurate assessment of key areas" (as shown in Figure 3).



a) Diagram of 100m×100m Grid *b) Diagram of 20m×20m Grid*

Figure 3. Diagram of different grid spacing.

2.3.1 Building Height Impact Factor: In the process of constructing the 3D grid data for the building height impact factor, the specific implementation steps are as follows:

The first step is the grid unit-based clipping of DSM data. Based on the regular square vector grid of the entire urban area constructed in the previous section, a spatial clipping algorithm is used to perform unit-based segmentation on the DSM data covering the survey area, enabling spatial precise matching between the clipped DSM sub-data blocks and each vector grid unit. Meanwhile, the corresponding DSM sub-data blocks are named according to the "unique serial number in the vector grid attribute table" to ensure the uniqueness and traceability of subsequent data association.

The second step is the extraction of DSM maximum point parameters within grid units. Based on the program module developed by the multi-source point cloud data elevation extreme value recognition algorithm, elevation analysis is conducted unit by unit for each clipped DSM sub-data block. The plane coordinates (X, Y) of the highest point of surface structures and the corresponding elevation value (Z) within each grid unit are automatically calculated and output. This parameter provides core basic data for the quantitative characterization of the building height impact factor (as shown in Figure 4).

The third step is the spatial association between elevation data and vector grids. First, a new "Z_max" field is added to the vector grid attribute table. Subsequently, through the spatial association algorithm based on the unique grid serial number, the maximum point elevation value (Z) of each grid unit extracted in the second step is assigned in batches to the "Z_max" field of the corresponding vector grid unit. Finally, a 3D grid dataset of the building height impact factor, which includes spatial location information (vector grid boundaries) and attribute information (maximum grid elevation), is formed. This completes the transformation of the building height impact factor from discrete data to structured and standardized data, providing direct data input for the subsequent safety height calculation of low-altitude surveying and mapping UAVs.

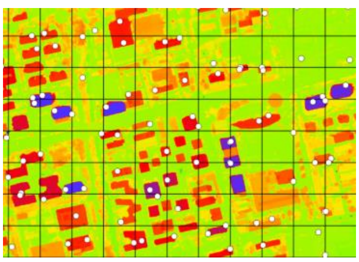


Figure 4. Calculating highest positon of grid based on DSM.

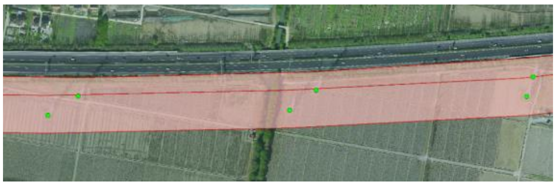
2.3.2 Electromagnetic Interference Impact Factor: In the construction of 3D vector surface data for the electromagnetic interference impact factor, a processing approach of "classifying ground object types and integrating multiple methods" is adopted, with the specific implementation process as follows:

The first step is the 3D vector surface modelling of discrete towers (high-voltage towers, radio transmission towers). Based on the multi-source data collaborative interpretation method, the tower elevation information is extracted from the DSM, and combined with the verification of DLG vector boundaries and DOM ground object texture features, the plane coordinates (X, Y) and actual height (Z) of high-voltage towers and radio transmission towers are accurately obtained. Considering the spatial influence range of electromagnetic radiation and the UAV safety redundancy distance (Yang, et al, 2021), the plane boundary of a single tower is expanded outward by 30 meters in all directions, and the elevation direction is increased by 30 meters on the basis of its actual height. A discrete 3D vector surface dataset with a single tower as the unit is constructed to realize the spatial characterization of the core electromagnetic interference area around the tower.

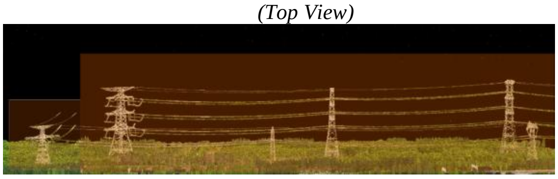
The second step is the 3D vector surface modelling of power lines between high-voltage towers. It is first necessary to clarify the technical bottleneck in extracting power line elevation information: the DSM data is generated from LiDAR point clouds with a point cloud density of 5 points per square meter. Limited by the point cloud sampling resolution, point cloud missing phenomenon tends to occur for thin linear ground objects such as power lines between high-voltage towers, making it impossible to directly obtain power line elevation information from the DSM. To address this issue, this study proposes a multi-source data complementary scheme: a method combining DOM image feature matching and DLG vector element topological association is adopted to accurately extract the linear vector elements of power lines between high-voltage towers. Based on the lateral influence radius of electromagnetic interference and the UAV safety avoidance distance, the extracted linear vectors of power lines are expanded outward by 30 meters on both sides to generate the planar vector elements of power lines. Meanwhile, to ensure coverage of the possible spatial distribution range of power lines, the elevation value of these planar elements is set to the maximum height of the towers in the corresponding power line segment (i.e., the two towers connected by the power line). Finally, a linear 3D vector surface dataset with power line segments as units is constructed (as shown in Figure 5).

The third step is the data fusion of the electromagnetic interference impact factor. Through the spatial topological overlay algorithm and attribute consistency verification mechanism, the "discrete tower 3D vector surface dataset" constructed in the first step and the "power line segment 3D vector surface dataset" constructed in the second step are fused. Attribute conflicts in spatially overlapping areas are eliminated, and finally a 3D vector surface dataset of the electromagnetic interference impact factor covering the entire survey area and including two types of electromagnetic interference sources (towers and power lines) is formed (as shown in Figure 6). This provides standardized spatial boundary data support for the subsequent electromagnetic interference risk assessment and avoidance planning of low-altitude surveying and mapping UAV flight paths.

Figure 5. Discrete 3D vector surface based on buffered towers.



(Top View)



(Side View)

Figure 6. Linear 3D vector surface based on connection lines of towers.

2.3.3 Controlled Area Impact Factor: In the construction of 3D vector surface data for the controlled area impact factor, policy compliance must be taken as the core prerequisite, with the specific implementation process as follows:

The first step is to conduct the collection and pre-processing of thematic data for controlled areas. Thematic vector data of controlled areas within the survey area is systematically collected, including airport clearance protection zones, military administration zones, key public security-sensitive areas, and protection scopes for important immovable cultural relics. Topological inspection and coordinate unification are performed on the collected vector data to ensure the consistency of spatial datum.

The second step is to implement 3D attribute assignment and dataset construction for controlled areas. Based on policy constraints and safety redundancy considerations, the safety height attribute of the vector boundaries of all controlled areas is uniformly set to 1000 meters. This threshold is higher than the maximum operating height of current mainstream low-altitude surveying and mapping UAVs, which can achieve the management objective of "full-area no-fly". The 1000-meter no-fly height is assigned to the corresponding controlled area vector surfaces through an attribute association algorithm. Finally, a 3D vector surface dataset of the controlled area impact factor, which includes spatial boundary information and safety constraint attributes, is constructed. This provides an authoritative policy-based and spatialized constraint basis for the subsequent compliance screening of flight routes of low-altitude surveying and mapping UAVs and the avoidance of no-fly areas.

2.4 Formation of Low-Altitude Flight Safety Field Achievements

2.4.1 Elevation Obfuscation Processing: Given that elevation data belongs to geospatial sensitive information, directly releasing original elevation values poses a risk of information leakage. To ensure data security and compliance while balancing the availability of data in subsequent low-altitude flight safety assessment scenarios, it is proposed to perform obfuscation processing on the original elevation values calculated in the previous sections.

Comprehensively considering the data confidentiality level, the actual demand for elevation accuracy in safety assessment, and computational convenience, a numerical processing strategy of "rounding up to the nearest ten" is determined. This strategy can effectively reduce the sensitivity of original elevation information while ensuring that the processed data still meets the core requirement for determining the UAV flight safety height thresholds. The specific calculation process shall be implemented with reference to Equation (1).

$$H_m = \text{Ceiling}\,(H_1/10) * 10 \qquad (1)$$

In the Equation, H_m denotes the post-fuzzification elevation, H_1 denotes the elevation of the true highest point extracted from the DSM, and the Ceiling function refers to a function that rounds up to the nearest integer.

2.4.2 Grid Data Fusion: During the development phase of spatial data products for the low-altitude flight safety zone, systematic fusion processing must be performed on the 3D grid vector surface data generated respectively by the building height impact factor, electromagnetic interference impact factor, and controlled area impact factor. The specific processes and rules are as follows:

First, conduct spatial fusion of multi-factor 3D data. Adopt the integration strategy of "spatial topological overlay + elevation priority determination" to perform spatial overlay analysis on the 3D grid vector surface data of the three types of factors. For the overlapping and intersecting areas formed by different factor data in space, in accordance with the principle of "maximizing safety constraints", select the highest elevation value corresponding to each factor in the overlapping area as the final grid elevation result of that area. This ensures that the fused data can fully reflect the constraining effects of various potential safety hazards on low-altitude flights.

Second, implement lightweight processing of the fused data. To reduce subsequent data storage costs and improve the efficiency of data retrieval and safety assessment calculations, for adjacent vector surface units with the same elevation value after fusion, apply the "vector surface merging algorithm for same-elevation attributes" for spatial aggregation processing. By eliminating redundant boundary information, discrete vector surfaces with consistent elevation attributes are integrated into continuous areal units, achieving effective data volume reduction without compromising the accuracy of safety assessments.

Finally, establish a standardized safety zone spatial dataset. Through the aforementioned fusion and lightweight processing, a set of standardized and structured spatial datasets for the low-altitude surveying and mapping UAV flight safety zone is constructed. This dataset covers the entire survey area and incorporates spatial location information and safety constraint attributes (as shown in Figure 7).

Figure 7. Examples of fused 3D grid.

2.4.3 Safety Altitude Classification: Based on the 3D grid dataset of the low-altitude flight safety zone constructed in the previous section, and combined with the constraints on UAV flight altitude specified in national and local policy documents, the work of classifying the safety levels of low-altitude flight altitude thresholds is carried out.

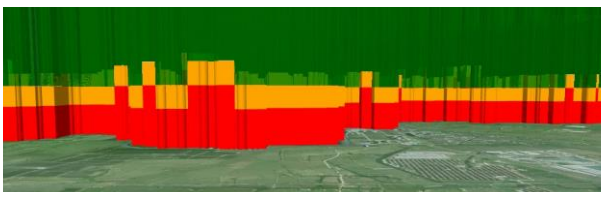
According to the current airspace management policies, the authority for UAV flight altitude is directly linked to airspace filing procedures: Firstly, without completing airspace filing procedures or if filing applications are not approved, UAVs are only permitted to operate at altitudes below 120 meters. Secondly, after completing airspace filing procedures and obtaining approval from the competent authority, the default upper limit of flight altitude is 1000 meters.

Based on this, the safety level classification must simultaneously incorporate two dimensions: "airspace filing status" (unfiled airspace, filed airspace) and "flight altitude risk thresholds". The low-altitude airspace is uniformly divided into three categories: Dangerous Zone, Early Warning Zone, and Safe Zone. The criteria for determining safety levels under different airspace filing statuses are detailed in Table 1. This classification system can provide a quantitative basis for the safety assessment, risk early warning, and dynamic adjustment of UAV flight routes (as shown in Figure 8).

Table 1. Description of safety altitude classification

Serial Number	**Area Type**	**Altitude Range** (meter)		
		Situation 1 (without completing airspace filing procedures)		**Situation 2** (completed airspace filing procedures)
		H_m <100	100< H_m <120	
1	Dangerous Areas	0~ H_m	0~ H_m	0 ~ H_m
2	Warning Areas	H_m ~ H_m +20	H_m ~120	H_m ~ H_m +20
3	Safe Areas	H_m+20~120	None	H_m+20 ~ 1000

Note：H_m denotes the post-fuzzification elevation of Grid



(Dangerous zone, Warninig zone, Safe zone)

Figure 8. Diagram of safety altitude classification.

3. Experiment and Analysis

3.1 Experimental Area and Data

3.1.1 Overview of the Experimental Area: Shanghai is located at the front of the Yangtze River Delta, with a unique geographical location: it borders the East China Sea to the east, Hangzhou Bay to the south, Jiangsu Province and Zhejiang Province to the west, and the estuary of the Yangtze River to the north. It serves as a key junction between the Yangtze River Basin and the eastern coastal regions.

In terms of topographic and geomorphic features, except for a small number of scattered hilly landform units in the southwestern part of Shanghai, the entire area is dominated by flat plains. The average elevation of the region is approximately 4 meters, with small topographic relief. This provides basic topographic conditions for low-altitude development, but also intensifies the dominant impact of buildings and structures on the low-altitude environment.

As a core megacity on China’s eastern coast, Shanghai has a high level of urbanization and strong spatial function agglomeration. Key functional areas such as its central urban area, sub-centers, and the Five New Cities have all formed high-density building clusters centered on super high-rise buildings. Such building clusters not only result in low-altitude environments characterized by "high building density, strong spatial obstruction, and complex three-dimensional interconnection", but also impose significant spatial constraints on the physical avoidance and signal transmission of UAV flights, creating a low-altitude flight environment with high complexity.

From the perspective of policy orientation, the Shanghai Municipal People's Government has clearly put forward the strategic goals of "building one of the first batch of national inter-provincial general aviation pilot cities for low-altitude operations, developing into a national comprehensive demonstration and leading area for the low-altitude economy industry, and accelerating the construction of an internationally influential 'City in the Sky'" (General Office of Shanghai Municipal People's Government, 2024). This plan regards low-altitude safety management as the core prerequisite for the development of the low-altitude economy. Against this strategic background, there is an urgent need to construct a digital 3D spatial datum for UAV low-altitude flight safety that adapts to the spatial characteristics of megacities. Through standardized and precise spatial constraint data, it provides technical support for the airworthiness safety management and control of low-altitude UAVs, thereby meeting the core demand of Shanghai’s high-quality low-altitude economy development for a safety support system.

3.1.2 Available Data:

(1) Digital Surface Model
The DSM data produced from the 2025 aerial photogrammetry was used. This data was generated from airborne laser point clouds (5 points/m²) acquired by the Leica Country Mapper-S aerial camera, with a grid spacing of 0.5 meters and an elevation accuracy of 0.2 meters. It can be used to extract elevation information.

(2) Digital Orthophoto Map

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The DOM data produced from the 2025 aerial photogrammetry was used. Acquired by the Leica Country Mapper-S aerial camera, this data has a resolution of 0.1 meters and a horizontal positional root mean square error of 0.4 meters. It can be used to assist in viewing ground feature conditions.

(3) Basic Topographic Map
Topographic map data from the Shanghai Basic Topographic Map Database was used. This data details basic geographical features on the earth’s surface, including residential areas, facilities, and roads. It can be used to assist in identifying ground features such as high-voltage power towers and radio transmission towers.

(4) Other Data
Other available data includes areas such as airport clearance areas, military control areas, and major immovable cultural relics.

3.2 Data Processing and Result Presentation

Based on the methodology for constructing the low-altitude flight safety zone proposed in Chapter 1 of this paper, multi-source basic geographic information data within the Shanghai municipal administrative area (including DSM, Digital Line Graphic (DLG), DOM, and thematic data of controlled areas, etc.) was used as the core data source to carry out the calculation and construction of safety zone grid data. During the specific implementation process, the following key technical steps were carried out in sequence:

(1) Spatial division of the operation area and construction of a regular vector grid. Combined with the spatial characteristics of Shanghai and the accuracy requirements for safety assessment, the division of the entire operation area and the generation of the basic grid (100 m × 100 m) were completed.

(2) Extraction of parameters for the highest point of ground features within grid units. Based on DSM data, an elevation extreme value recognition algorithm was used to calculate and output the plane coordinates (X, Y) and elevation value (Z) of the highest point of surface buildings and structures within each grid unit.
(3) Inversion of elevation parameters for high-voltage towers and transmission lines. Combined with DLG vector elements and DOM image texture features, the spatial location interpretation of high-voltage towers and transmission lines was completed. Their 3D parameters were obtained through the method of "tower elevation correlation + line surface elevation assignment", and vector surfaces for linear and discrete electromagnetic interference sources were constructed.

(4) Obfuscation of elevation data. In compliance with the confidentiality management requirements for geospatial sensitive information, a corresponding algorithm was used to obfuscate the original elevation values, balancing data security and availability.

(5) Fusion of multi-factor grid data. Adopting the principle of "spatial topological overlay + priority of the highest elevation in overlapping areas", the grid data of three types of impact factors (building height, electromagnetic interference, and controlled areas) was integrated to resolve attribute conflicts.

(6) Classification of safety altitude levels. Based on the airspace filing status and policy constraint thresholds, the safety level assignment for each grid unit was completed.

Through the systematic implementation of the above steps, the construction of a standardized low-altitude flight safety zone grid dataset covering the entire Shanghai municipal administrative area was finally completed, providing a unified spatial data benchmark for subsequent safety assessment of low-altitude UAV flights and route planning (as shown in Figure 9).

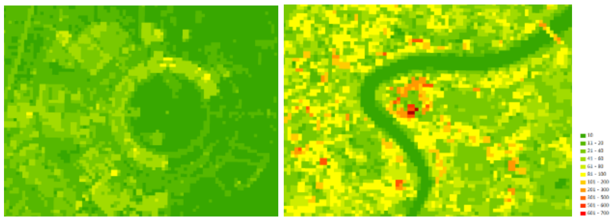

Figure 9. Examples of Shanghai low-altitude flight safety zones.

3.3 Analysis of Result Application

In response to Shanghai’s "Quantum Urban Spatiotemporal Intelligence" construction strategy, the city is actively advancing the development of the "Shencheng Huiyan" (Shanghai Smart Eye) intelligent perception system. This system has established a highly integrated intelligent UAV depot network that serves the refined management of Shanghai’s natural resources and the modernization of urban governance, featuring the technical capability to acquire digital remote sensing information of the earth’s surface in an all-weather and flexible manner.

However, under the scenario of the 120-meter flight altitude constraint in unfiled airspace, the accurate determination of the safe flight altitude for low-altitude surveying UAVs has become a core technical requirement. If this altitude threshold cannot be clearly defined, it may easily lead to physical collisions between UAVs and obstacles such as super high-rise buildings and high-voltage towers, thereby causing severe consequences including equipment damage, data loss, and even public safety incidents. The low-altitude flight safety zone grid dataset constructed in this paper can provide a targeted resolution of this technical bottleneck.

Before the implementation of actual flight missions, operators can import the vector data of the preset operation range into the supporting safety assessment platform. Based on the low-altitude flight safety zone data, the platform automatically calculates and outputs the safe flight altitude threshold for each grid unit in the survey area through spatial overlay analysis and risk threshold determination algorithms. Meanwhile, it generates differentiated recommended safe flight altitudes (e.g., the optimal flight altitude range for avoiding risk zones). This process provides standardized and precise support for the flight safety of actual UAV operations from a technical perspective, effectively reducing collision risks and aligning with the technical requirements for safe operations of the "Shencheng Huiyan" system.

This contribution has been peer-reviewed.
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4. Conclusion

This paper constructs a theoretical framework and technical system for the "Urban Low-Altitude Surveying UAV Flight Safety Zone". Based on multi-source real geographic information data in Shanghai, empirical testing and result development were conducted, and application verification was completed through on-site UAV flight operations, which systematically verified the technical advantages of this achievement in ensuring low-altitude flight safety.

Empirical results show that the low-altitude flight safety zone grid data results formed in this study can effectively support the flight safety management and control of low-altitude surveying UAVs. On one hand, it can accurately identify the spatial distribution and altitude constraints of potential safety hazards such as structures and electromagnetic interference sources in the survey area, significantly reducing the collision risk between UAVs and obstacles; on the other hand, its standardized data format and structured attribute information have the feasibility of being promoted and applied as industry-standard data products or technical paradigms, providing a reference for the safe operation of low-altitude UAVs in similar megacities.

For subsequent research and application optimization, two key directions are proposed. First, a dynamic update mechanism for the spatial data of the low-altitude flight safety zone should be established based on the dynamic change frequency of ground features and the adjustment cycle of airspace policies, and regular data iteration should be carried out to ensure the currency, accuracy and engineering practicality of the results. Second, combined with the differentiated safety assessment needs of key areas in Shanghai (such as urban central business districts, airport clearance areas and new city construction areas), the grid resolution of local areas should be further refined, and the multi-factor fusion algorithm and safety level determination model should be iteratively optimized.

Through the above optimizations, long-term and precise low-altitude safety support can be provided for Shanghai’s construction of a "National Comprehensive Demonstration and Leading Area for the Low-Altitude Economy Industry" and a "City in the Sky", thereby helping it achieve the strategic goal of becoming an "internationally influential benchmark city for the low-altitude economy".

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