Original Research Article

Research on safety situation awareness and prediction technology of low-altitude traffic system integrating multi-source environmental perception data

Yifei Niu
Communication University of China, Nanjing, Nanjing, Jiangsu, 211199, China

Abstract: Aiming at the problems in low-altitude airspace operation such as heterogeneity and redundancy of multi-source perception data, insufficient perception accuracy in complex scenarios, and difficulties in predicting situation trends, this paper conducts research on low-altitude traffic safety situation perception and prediction by integrating multi-source environmental perception data. Data cleaning and fusion are realized by establishing a unified spatio-temporal benchmark; an air-space-ground collaborative perception network is constructed to improve perception stability; and scientific situation prediction is achieved based on airspace operation rules. The research forms a set of implementable safety management and control strategies, which effectively improve the safety of low-altitude operation and airspace utilization efficiency, and provide technical support for traffic management of low-altitude unmanned systems.
Keywords: low-altitude traffic; multi-source perception; situation perception and prediction

1. Introduction

The rapid development of the low-altitude economy has promoted the large-scale operation of unmanned aerial vehicles. The existing air traffic management modes are difficult to adapt to the complex operating environment of low-altitude airspace. Problems such as heterogeneous multi-source perception data, limited scenario perception accuracy, and lagging prediction of traffic situation restrict the safety and efficiency of low-altitude operation. Constructing a safety situation perception and prediction system integrated with multi-source environmental perception data has become the core demand of low-altitude management and control. Focusing on the practical problems in low-altitude traffic operation, this paper conducts research on data fusion, perception improvement and situation prediction, and proposes feasible technical strategies, so as to provide references for improving low-altitude safety management and control capability and supporting the orderly development of the low-altitude economy.

2. Analysis of low-altitude traffic safety situation problems

Low-altitude traffic perception data include BeiDou positioning, Automatic Dependent Surveillance-Broadcast (ADS-B), airborne radar, meteorological monitoring, geofencing, UAV remote identification and other sensing terminals. Various sensor devices show significant differences in sampling frequency, spatio-temporal reference, data format and communication protocol. The Unmanned Aircraft System Traffic Management (UTM) system only realizes basic data collection and lacks standardized preprocessing procedures, making it difficult to regulate redundant, noisy and conflicting data. Meanwhile, inconsistent interface specifications of various business platforms lead to great difficulties in data interconnection and fusion. Urban building occlusion, electromagnetic interference and high-density flight environments easily reduce the stability of perception equipment and cause target tracking deviation. The linkage between Air Traffic Management (ATM) and UTM systems is weak, resulting in deviations in risk identification under complex scenarios[1]. Low-altitude traffic flow is highly dynamic and random, and existing analysis modes cannot adapt to the evolution characteristics of traffic flow. The insufficient capabilities of real-time situation assessment and trend prediction fail to provide effective support for airspace scheduling and risk prevention and control.

3. Countermeasure strategies for low-altitude traffic safety situation

3.1. Optimization strategy for cleaning and fusion of multi-source perception data

To address the heterogeneity and redundancy of low-altitude multi-source perception data, taking BeiDou Fuxi grid code as the unified spatio-temporal benchmark, this paper completes coordinate normalization, time synchronization and unit unification of various data including BeiDou positioning, ADS-B, airborne sensors, meteorological monitoring and remote identification, realizing spatio-temporal alignment of all-element data. There are obvious differences in sampling frequency and positioning accuracy among various perception devices, with specific parameters shown in **Table 1**. A three-level data cleaning rule is constructed to eliminate duplicate messages, verify abnormal mutation values and filter noise interference, reducing the proportion of invalid data. Standardized data interfaces and protocol conversion mechanisms are adopted to break the data interaction barriers of UTMISS, FIMS, CIS and other systems. Data aggregation and correlation matching are completed according to airspace grid units; edge nodes conduct real-time data preprocessing while central nodes realize feature fusion of multi-source data, forming a standardized and high-quality low-altitude situation dataset to provide available and reliable data support for subsequent perception and prediction[2].

Table 1. Key parameters of low-altitude multi-source perception.

Perception Type	Sampling Frequency / Hz	Positioning Accuracy / m
BeiDou Positioning	10	0.5
ADS-B	2	3
Airborne Sensor	50	0.2
Meteorological Monitoring	0.2	5

3.2. Improvement strategy for accurate situation perception in complex airspace

In complex low-altitude operation environments, an integrated air-space-ground collaborative perception network realizes overall deployment of global perception resources. BeiDou positioning, airborne detection, ground monitoring and inter-aircraft communication form a unified perception system, and airspace structure completes perception coverage matching in accordance with layered, classified, domain-divided and grid-based rules[3]. In environments with urban building occlusion and electromagnetic interference, cross verification of multi-source information is realized, and equipment operation data support stable recognition of target status. Special perception areas are set for UAV clusters and mixed manned-unmanned flight scenarios, with real-time collection of data including position, altitude, speed, heading and flight intention. Geofencing and airspace boundary conditions are incorporated into the basis of situation judgment for timely identification of abnormal flight behaviors. The global perception link maintains uninterrupted operation, risk points are locked and tracked in real time, and safety situation data are output continuously and stably[4].The specific process is shown in **Figure 1**.

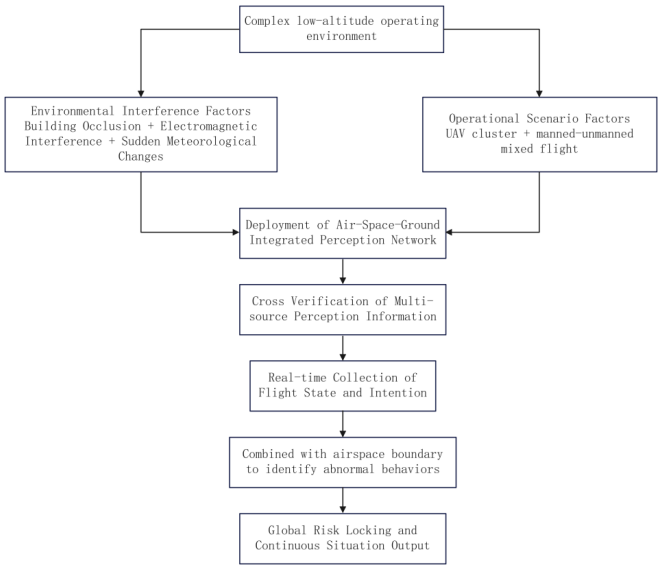

Figure 1. Flowchart of accurate situation perception improvement in complex airspace.

3.3. Improvement strategy for scientific prediction of low-altitude traffic situation

Based on real-time multi-source perception data, this paper systematically conducts traffic situation trend deduction combined with the historical operation rules of low-altitude airspace and airspace management regulations. Relying on the Bagua three-dimensional route network, traffic flow statistics and trend analysis are carried out for radial main routes and annular diversion routes to identify congestion-prone sections and potential conflict areas.Factors such as meteorological changes, dynamic airspace adjustment and emergency task insertion are all included in the research scope. The evolution trend of the airspace situation is determined from short-term, medium-term and long-term time dimensions, and relevant trend assessment conclusions are output. Corresponding airspace scheduling and diversion measures are activated according to the prediction results. Route allocation optimization and flight interval adjustment are completed before traffic surges, and avoidance areas are delineated in advance to prevent risk spread. This promotes the transformation of operational management from passive response to active prevention, and maintains the stable and safe operation of low-altitude traffic through standardized trend prediction and disposal mechanisms.

4. Conclusion

This paper studies the safety situation perception and prediction technology of low-altitude traffic based on multi-source perception data fusion, solving core problems such as data heterogeneity and redundancy, weak perception capability in complex scenarios and difficulty in situation trend prediction. By unifying the spatio-temporal benchmark, cleaning and fusing data, enhancing collaborative perception and standardizing situation prediction, implementable low-altitude safety guarantee strategies are formed. The research results can support the grid-based and layered management of low-altitude airspace, and have practical significance for improving UAV operation safety and airspace resource utilization efficiency. In the future, technical processes can be further optimized combined with actual operation data to promote the engineering application of the technology in scenarios such as urban low-altitude logistics and emergency rescue.

About the author

Yifei Niu, female, Han Chinese, native of Changchun, Jilin Province; Educational Background: Master's degree; Professional Title: Senior Engineer; Research Interests: Low-altitude safety, artificial intelligence, 5G.

References

[1] Chen X, Li S, Li M. A hybrid centralized-decentralized traffic control framework for unmanned aerial vehicles in urban low-altitude airspace [J]. Communications in Transportation Research, 2025, 5100195-100195.

[2] Anayatova R, Ryabchenko I, Tulekova G, et al. Psycholinguistics in Meeting the Challenges of Advanced Aeromobility and Organizing Safe Air Traffic in Low-Altitude Aviation [J]. PSYCHOLINGUISTICS, 2025, 37(2): 6-32.

[3] Li C, Zhao Z, Chen Y, et al. Modeling the Urban Low-Altitude Traffic Space Based on the Land Administration Domain Model—Case Studies in Shenzhen, China[J]. Land, 2024, 13(12): 2062-2062.

[4] Zhao Z, Zhang L, Zhou R, et al. A flight risk field model for advanced low-altitude transportation system using field theory [J]. Transportation Research Part A, 2024, 190104268-104268.

[5] Li X, Shi Y, Ma M. Research on industrial linkages and economic contributions of the low-altitude tourism industry: a case study of Zhengzhou [J]. Journal of Applied Economics and Policy Studies, 2025, 18(11): 96-106.