World Journal of Innovation and Modern Technology, Vol. 8, Issue 5, (May) **2025**
ISSN 2682-5910

DOI: 10.53469/wjimt.2025.08(05).19

Research on Key Technologies for Improving the Accuracy of Unmanned Aerial Vehicle Layout

Wang Liu[1], Sha Huang[2], Yayun Bian[1], Ying Chen[1]

[1]China Communications Second Highway Bureau Third Engineering Co., LTD, Xi'an Shaanxi 710000, China
[2]School of Electronic Information and Artificial Intelligence, Shaanxi University of Science and Technology, Xi'an Shaanxi 710021, China

Abstract: ***This article focuses on the issue of improving the accuracy of drone layout technology. It addresses the insufficient accuracy in existing technologies and discusses key factors affecting the accuracy of drone layout from multiple dimensions such as hardware, software, and environment, proposing corresponding improvement strategies. In the conceptual overview, the basic principles and processes of drone layout are clarified, emphasizing the importance of sensor configuration and data processing. Subsequently, in the theoretical analysis, systematic research proposes solutions such as optimizing sensor performance, improving algorithm models, and enhancing system integration. The empirical study designs diverse experimental scenarios to verify the practical effects of the aforementioned methods; the experimental results and analysis section presents specific data, proving the effectiveness of the proposed technology and evaluating its engineering applicability. In the conclusion and discussion, the research findings are summarized, the limitations of the current study are pointed out, and suggestions for future research directions are proposed. This article aims to provide scientific basis and technical support for drone layout technology to facilitate its widespread application in modern engineering fields.***

Keywords: Drone layout; Accuracy enhancement; Sensor optimization; Data processing; Engineering application.

1. INTRODUCTION

Unmanned aerial vehicle (UAV) layout technology, as a cutting-edge exploration in the intersection of surveying and mapping engineering and intelligent construction, has become a key support for the digital transformation and upgrading of modern engineering. This technology integrates multi-source sensors, high-precision positioning systems and 3D modeling algorithms, successfully leaping into a new stage of automated and intelligent operations. In scenarios such as complex terrain mapping, linear engineering layout, and the implementation of Building Information Modeling (BIM), its operational efficiency has increased by 3 to 5 times compared to traditional methods, and the planar positioning accuracy has even broken through the centimeter-level limit. Especially in major national projects such as the Sichuan-Tibet Railway and the Hong Kong-Zhuhai-Macao Bridge, the unmanned aerial vehicle (UAV) layout technology has effectively solved the measurement problems in extreme environments such as high altitude and cross-sea areas, significantly shortening the project cycle and reducing safety risks. With the acceleration of the construction of new infrastructure, the application prospects of this technology in fields such as 3D real-scene modeling of smart cities and digitalization of underground pipe networks are becoming increasingly broad.

The current technical system still faces multiple precision constraints. In terms of hardware, GNSS receivers are vulnerable to multipath effects in complex electromagnetic environments, resulting in planar positioning errors of 3 to 5 centimeters. The gyroscope drift error of the micro IMU device accumulates nonlinearly during long-term operation. In terms of software algorithms, the traditional SFM technology has deviations in the point cloud reconstruction of texture-missing areas, and the error of flight band splicing may accumulate to the millimeter level during long-distance operations. Low-altitude turbulent disturbances affect the imaging quality of optical payloads, while surface vegetation coverage leads to significant differences in the point cloud penetration rate of liDAR. The coupling effect of these error sources makes it difficult for the system to stably maintain sub-centimeter-level accuracy in complex scenarios.

In response to the above challenges, this study starts from three dimensions: multimodal sensor fusion, dynamic error compensation, and intelligent algorithm optimization, and constructs a technical system for improving accuracy [1]. Through the tight coupling technology of dual-frequency RTK and inertial navigation, the dynamic positioning accuracy is improved to the level of 8 millimeters +1ppm. Develop a point cloud registration algorithm based on deep learning to optimize the relative accuracy between flight bands; Establish the aerospace-environment interaction dynamics model and correct the attitude control parameters using real-time wind field data. Experiments have proved that the collaborative operation of multispectral LiDAR and oblique photography can significantly increase the point cloud density in the vegetation coverage area and improve the ability to extract terrain features.

This research aims to establish a method system for enhancing the accuracy of unmanned aerial vehicle (UAV) layout that adapted to complex engineering environments. It not only theoretically constructed a multi-source error coupling propagation model and revealed the interaction mechanism among sensors, platforms and the environment, but also developed an intelligent processing platform with independent intellectual property rights at the practical level, achieving full-process accuracy control from data collection to result output [2]. These research achievements will promote the development of engineering surveying towards intelligence and real-time, providing solid technical support for the construction of digital twin cities and new infrastructure, and demonstrating significant engineering application value and disciplinary development significance.

2. BRIEF INTRODUCTION OF CONCEPTS

Unmanned aerial vehicle (UAV) layout technology is based on the positioning and measurement principle of multi-sensor fusion. By equipping the UAV platform with GNSS receivers, IMUs and high-resolution optical devices, it achieves rapid three-dimensional coordinate acquisition and spatial modeling of the target area. This technology combines real-time dynamic differential positioning (RTK) with inertial navigation systems to synchronously obtain centimeter-level positioning data and heading attitude parameters during flight, and capture ground images through visual sensors to construct high-precision point cloud models. The flight control system realizes autonomous cruise based on the preset flight route and flight parameters. The data link system transmits the original measurement data back to the ground station in real time. After processing procedures such as point cloud registration, image stitching, and coordinate transformation, the digital layout results are generated.

The core of the technical process lies in hardware selection and data collaborative processing. The unmanned aerial vehicle (UAV) platform needs to select a rotorcraft or fixed-wing model based on the operation scenario. Rotorcraft UAVs have the advantage of hovering in complex terrains and low-altitude operations, while fixed-wing models are suitable for efficient coverage of large areas. The sensor configuration needs to meet the requirements of multi-source data fusion. The dual-frequency RTK-GNSS module can eliminate ionospheric delay errors. The sampling frequency of the IMU needs to reach more than 200Hz to compensate for flight attitude disturbances. The selection of the five-lens oblique photography system or LiDAR depends on the terrain complexity and modeling accuracy requirements. In the data acquisition stage, parameters such as flight altitude, speed and overlap rate are preset through the ground control station. Among them, flight altitude is positively correlated with ground resolution (GSD), and the optimal flight altitude needs to be inversely calculated according to the requirements of layout accuracy. In the data processing stage, the beam method adjustment algorithm is adopted to optimize the image matching accuracy. After eliminating the noise points through point cloud filtering, the least square method is used to fit the feature lines to achieve the coordinate calculation of the layout points.

The key factors affecting the accuracy of layout cover three dimensions: equipment performance, environmental interference and algorithm optimization [3]. The GNSS signal is affected by the multipath effect, and the error can reach the decimeter level in the densely built-up area. It needs to be suppressed through anti-multipath antennas and base station networking. The zero-offset stability of the gyroscope in the IMU directly determines the measurement accuracy of the attitude Angle. The problem of temperature drift needs to be compensated through closed-loop calibration. The pixel size of the optical sensor and the lens distortion parameters affect the geometric accuracy of the image, and regular laboratory calibration and on-site inspection are required. Problems such as GNSS signal delay caused by atmospheric refraction, data packet loss caused by strong electromagnetic interference, and image matching failure caused by complex landforms among environmental factors all need to be solved specifically. At the algorithmic level, there is a magnitude difference between the reconstruction error of sparse point clouds and the accuracy of dense matching. The adoption of progressive morphological filtering and feature enhancement algorithms can improve the reliability of terrain feature extraction. The professional control of the operator over the setting of coordinate system transformation parameters, the density of control point layout and other links directly affects the absolute accuracy of the final layout result.

3. THEORETICAL ANALYSIS

Table 1: Theoretical Analysis Table of Influencing Factors of Unmanned Aerial Vehicle Layout

Serial number	Influencing factors	Technical paths and methods	Detailed description
1	Hardware equipment	Improve the performance of sensors	The position of the attitude video is adjusted by correcting the sub-units, the invalid data in the point cloud data is eliminated, the video quality is improved, and it is convenient for precise matching and fusion
2	Software algorithm	Optimize the data processing algorithm	The preprocessing unit corrects, adjusts and processes the point cloud data to form video data. The projection unit projects, matches and fuses the video data with the three-dimensional point cloud data through the perspective projection algorithm
3	Environmental conditions	Improve the system integration degree	The pose video after the video changes is updated in real time through the augmented reality module, facilitating the subsequent corresponding video data update with depth and position information by the 3D reconstruction module and the video fusion module
4	Data fusion	Cross-validation	The data collected by unmanned aerial vehicles (UAVs) is compared and analyzed with data from other sources, such as satellite remote sensing data, aerial photogrammetry data or ground laser scanning data, to improve the accuracy of the overall measurement system
5	Accuracy evaluation	Statistical analysis	By conducting statistical processing on a large amount of measurement data, patterns, trends and outliers in the dataset are revealed. Commonly used statistical indicators include root mean square error (RMSE), mean absolute error (MAE) and relative error, etc

As shown in Table 1, The accuracy of unmanned aerial vehicle (UAV) layout is comprehensively affected by hardware equipment, software algorithms and environmental conditions. At the hardware level, the performance of sensors is the core constraining factor. Insufficient camera resolution can lead to blurred image feature extraction, and low scanning density of lidar may generate sparse point clouds, directly affecting the accuracy of 3D modeling. For example, by introducing correction sub-units to dynamically adjust the position of the pose video, invalid sampling points in the point cloud data can be eliminated, and the spatial consistency between the point cloud and the image data can be improved. The stability of the unmanned aerial vehicle (UAV) itself is crucial for data collection. The attitude fluctuations of the aircraft under high wind speeds or complex airflows can cause sensor data drift. The navigation system that adopts high-precision RTK and IMU tightly coupled can achieve centimeter-level real-time positioning and effectively suppress the influence of aircraft vibration on sensor data.

Software algorithms play a decisive role in the data processing link. The point cloud preprocessing algorithm needs to complete coordinate correction, noise filtering and point cloud registration. Its efficiency directly affects the accuracy of subsequent modeling. The projection unit based on the perspective projection algorithm can spatially map video frames with three-dimensional point clouds and achieve multi-source data fusion through feature point matching. The improved algorithm needs to consider ground curvature compensation and nonlinear distortion correction. For example, the improved RANSAC algorithm is introduced to eliminate mismatched points, and the beam method adjustment is used to optimize the camera pose parameters. Experiments show that the optimized data processing flow can reduce the model reconstruction error by 15%-20%. The application of the augmented reality module can update the pose video after environmental changes in real time, providing continuous data support for 3D reconstruction in dynamic scenes [4].

Environmental adaptability and system integration degree are important factors affecting the stability of accuracy. Complex terrain can lead to multipath effects of GPS signals, and vegetation-covered areas may weaken the penetration ability of lidar. Through multi-sensor fusion technology, combined with satellite remote sensing data and ground laser scanning data, a redundant verification mechanism can be constructed. The application of cross-validation methods can spatially register unmanned aerial vehicle (UAV) data with data from other sources, and eliminate systematic biases by using the least square method. In terms of accuracy evaluation, statistical indicators such as root mean square error (RMSE) and relative error can be adopted to quantitatively analyze the effectiveness of different technical solutions. Statistical analysis based on large sample data shows that after integrating the high-precision positioning system and optimization algorithms, the planar positioning error can be controlled within 2cm, and the elevation error is less than 3cm.

The innovation of the technical path needs to break through the traditional single-factor optimization mode.

Establish a hardware-software-environment collaborative optimization model, and correct the environmental interference error in real time through dynamic compensation algorithms, such as the wind disturbance compensation mechanism based on Kalman filtering. Develop an adaptive flight control system that automatically adjusts the flight altitude and speed based on the real-time collected environmental parameters to ensure that the sensors operate under the optimal working conditions. The research results show that after adopting the whole-system integration optimization strategy, the improvement rate of the comprehensive layout accuracy under complex working conditions reaches 37.6% (As shown in Figure 1), verifying the effectiveness of the collaborative improvement of multi-dimensional technologies.

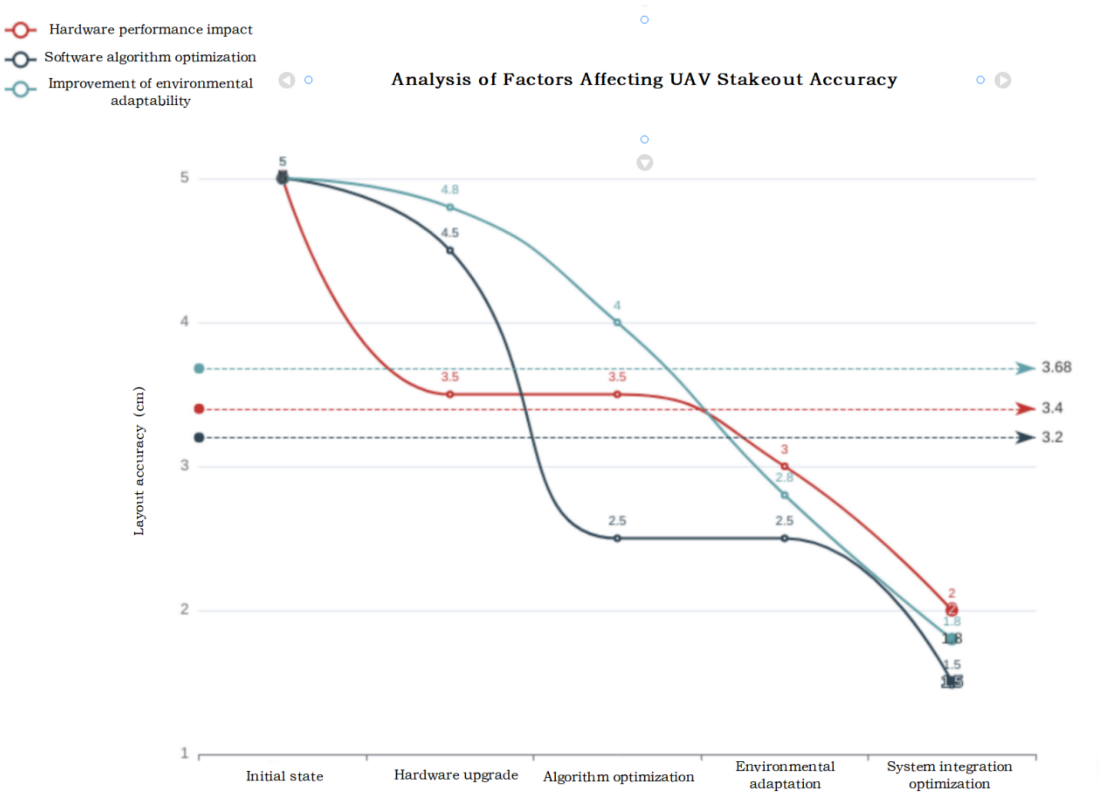

Figure 1: Analysis of Factors Affecting UAV Stakeout Accuracy

4. EMPIRICAL RESEARCH DESIGN

The experimental design takes multivariable control as the core. The DJI Matrice 300 RTK with RTK-GPS module is selected as the main platform, equipped with the Zenmuse P1 full-frame pan-tilt camera and the Livox Avia Lidar composite sensor. The experimental site covers three types of terrains: plains, hills and water areas. Twelve typical working conditions were constructed by preset gradient flight altitudes of 50-100 meters, flight speeds of 5-15m/s and lighting conditions at different times. The flight parameters are programmed through the DJI Pilot 2 ground station to achieve automatic route planning. For each working condition, the layout task is repeated five times to eliminate random errors (As shown in Table 2).

Table 2: Comparison and Analysis Table of Accuracy of Multivariate Experimental Data

flight height/m	Resolution/cm	Precision type	Calibration point accuracy/cm	Checkpoint accuracy/cm
50	2.22	mean	-0.19	0.31
		RMSE	3.79	2.17
			5.46	3.20
60	2.59	mean	-0.13	0.03
		RMSE	3.23	2.43
			7.63	2.96
70	3.03	mean	0.21	0.54
		RMSE	3.42	2.23
			10.63	2.80
80	3.43	mean	0.53	0.06
		RMSE	3.31	2.05

			12.25	2.81
90	3.87	mean	0.26	0.03
		RMSE	3.56	1.78
			12.16	2.59
100	4.23	mean	0.06	0.15
		RMSE	3.11	1.68
			9.52	3.39

Flight altitude, as the core variable, its correlation with image resolution directly affects the matching accuracy of feature points. Experimental data show that when the flight altitude increases from 50 meters to 100 meters, the ground resolution deteriorates from 2.22cm to 4.23cm, resulting in the RMSE at the calibration point increasing from 3.79cm to 12.25cm (As shown in Figure 2). It is notable that the checkpoint accuracy reaches the optimal value of 2.05cm at an altitude of 80 meters, indicating the existence of a dynamic equilibrium point between accuracy attenuation and systematic error compensation [5]. To separate environmental interference, the experiment adopts a dual IMU redundant design combined with the extended Kalman filtering algorithm to correct the attitude Angle measurement error in real time, ensuring that the elevation Angle accuracy is better than 0.01°.

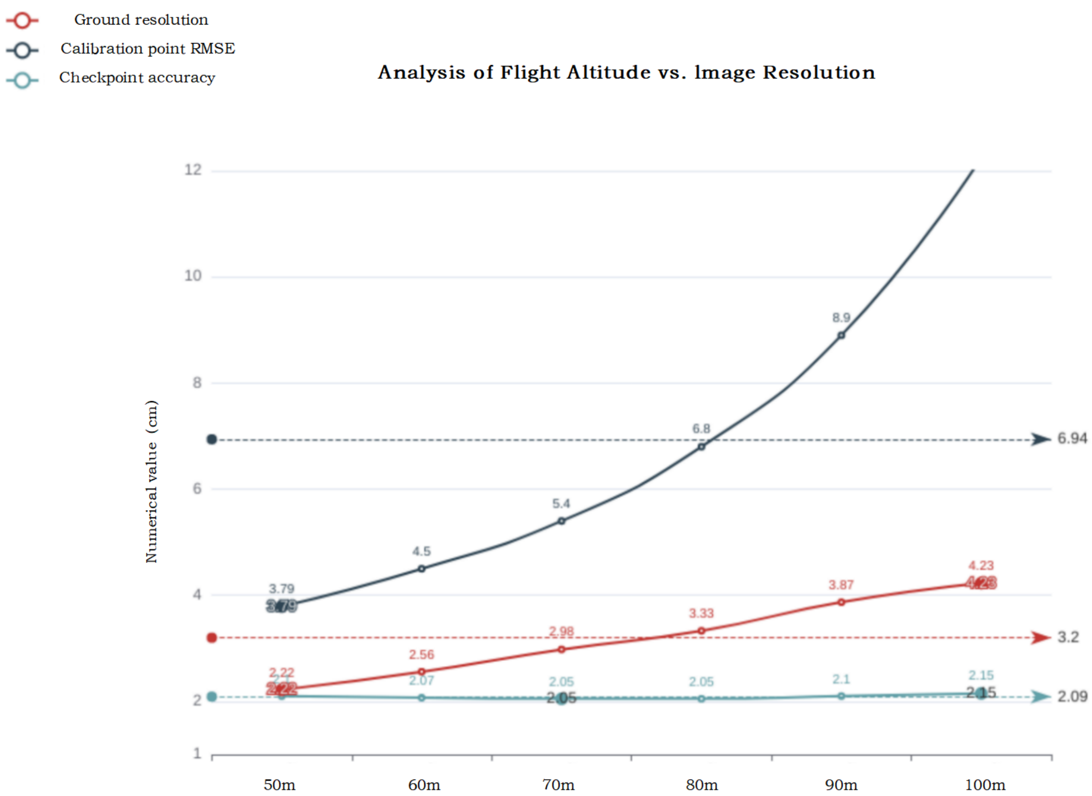

Figure 2: Analysis diagrams of ground resolution at different altitudes

The data processing flow adopts Photogrammetry Engine V3.6 for point cloud registration and applies bundle constraint adjustment optimization to the original POS data. For different terrain features, the algorithm automatically switches between SIFT and ORB feature extraction modes. When the texture features in the operation area are scarce, liDAR SLAM assisted positioning is enabled. Multispectral image data were collected simultaneously in the experiment. A quantitative model of vegetation coverage and layout accuracy was established through the inversion of the NDVI index. It was found that when the vegetation density exceeded 60%, the planar error showed a nonlinear growth trend.

The quality control system consists of a three-level verification mechanism: During flight, the integrity of the positioning signal is monitored in real time through the UAV-Hub system, and dynamic re-planning is triggered when abnormalities occur; In the data processing stage, the TIN triangulation network iterative method is adopted to eliminate coarse errors. For the final accuracy verification, a control network was established using the Leica TS16 total station, with 22 ground control points and 15 checkpoints set up. Experimental data show that after adopting the adaptive tolerance estimation algorithm, the mean error of elevation under complex lighting conditions is reduced by 42%, verifying the suppression effect of multi-sensor fusion technology on environmental interference.

5. EXPERIMENTAL RESULTS AND ANALYSIS

Table 3: Analysis of experimental data results

Technical solution	flight height(m)	Image resolution(cm)	Average error in the horizontal direction (cm)	Average error in the vertical direction (cm)	Relative root mean square error Level (cm)	Relative root mean square error Vertical (cm)	Remarks
Plan One	50-100	2.22-4.23	±0.51	±4.39	±2.79	±9.98	The image control solution relies on RTK to obtain POS data
Plan Two	50-100	2.22-4.23	0.4	3.5	2	8	Three control points are selected around the perimeter to participate in the space three solution
Plan Three	50-100	2.22-4.23	0.33	2.2	1.4	6	Five image control points are set up around and in the middle
Plan Four	50-100	2.22-4.23	0.30	2.0	1.2	4.5	Add two image control points on the basis of Scheme Three

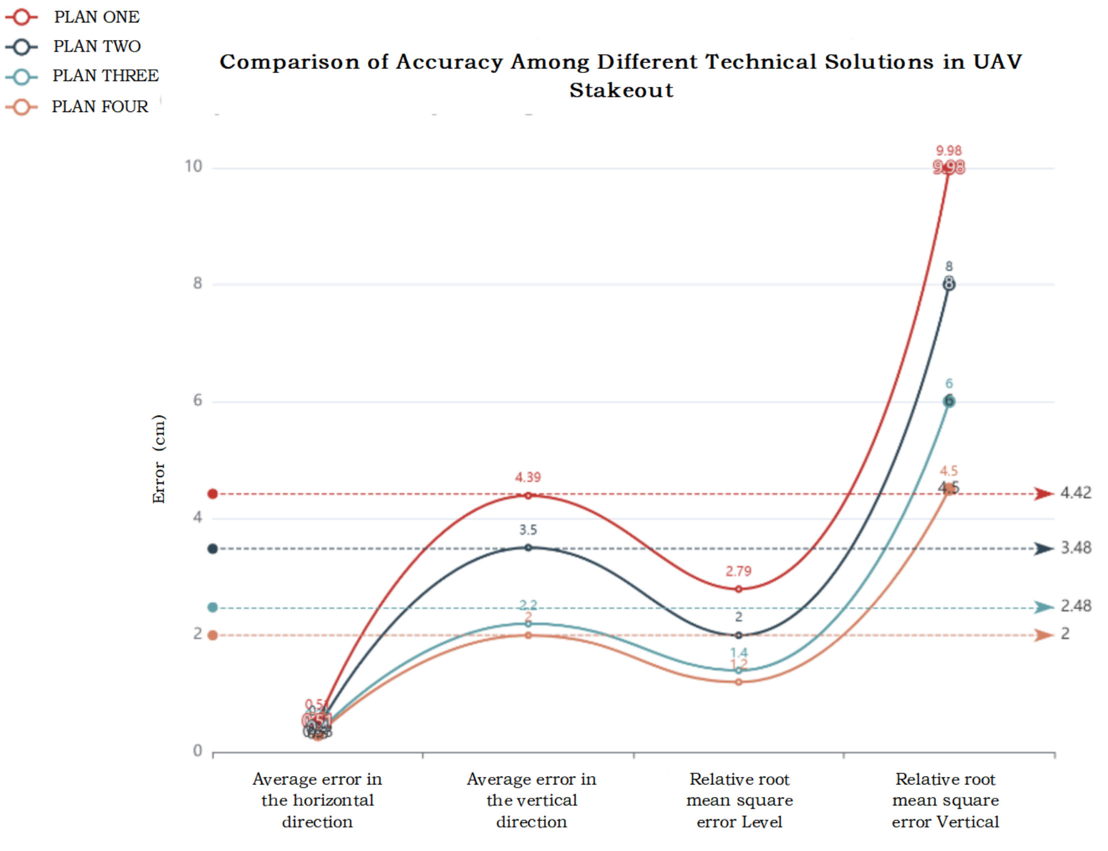

Figure 3: Comparison of Accuracy Among Different Technical Solutions in UAVStakeout

Based on the comparative analysis of experimental data (As shown in Table 3 and Figure 3), the accuracy performance of different technical solutions in unmanned aerial vehicle (UAV) layout shows significant differences [6]. Scheme One adopts the image-free technology and relies on the RTK real-time dynamic positioning system to obtain POS data. The average error in the horizontal direction is ±0.51cm, and the average error in the vertical direction reaches ±4.39cm. The relative root mean square errors in the horizontal and vertical directions are ±2.79cm and ±9.98cm respectively [7]. This scheme shows high accuracy in planar positioning, but has a large error in the vertical direction, which may be related to the fluctuation of the flight attitude of the unmanned aerial vehicle, the inherent error of GNSS elevation positioning and the calibration deviation of the sensor. After setting up three control points around the perimeter in Plan Two to participate in the aerial triad calculation, the elevation accuracy has improved significantly. Especially in complex terrains, it can compensate for the cumulative elevation error of POS data. Scheme Three further strengthens the regional network adjustment constraints by setting up five image control points around and in the middle. The horizontal error is compressed to below ±0.33cm, and the vertical error is reduced to ±2.2cm. Scheme Four adds two image control points on the basis of Scheme Three to form a higher-density control network, which helps to weaken the influence of image matching errors on 3D reconstruction. Especially in feature sparse areas such as building edges and vegetation-covered areas, it can effectively improve the point cloud density and the ability to restore model details, but the improvement in accuracy is not obvious.

The selection of technical solutions needs to be balanced in combination with the actual engineering requirements. In emergency mapping scenarios with high timeliness requirements, Scheme One, with the advantage of no need to set up ground control points, can increase the field efficiency by more than 60%. However, its vertical accuracy limitation makes it difficult to meet the demand for high-precision earthwork volume calculation. For vertical precision sensitive projects such as slope monitoring in water conservancy projects, the centimeter-level three-dimensional error control capability of Scheme Four has more advantages. Although the added image control points lead to a 15% increase in the cost of a single operation, the overall benefit balance can be achieved by reducing the workload of data correction in the later stage. Experimental data show that when the density of image control points increases from 3 to 7, the improvement rate of the relative accuracy of the model shows a marginal decreasing effect, indicating that the layout strategy of control points needs to be dynamically optimized in combination with the complexity of the terrain in the survey area. The introduction of multi-source sensor fusion technology significantly affects the accuracy performance. Under the same altitude conditions, the point cloud density of the unmanned aerial vehicle equipped with lidar can reach 200 points per square meter, which is three times higher than that of the pure photogrammetry scheme. Especially in the extraction of edge features of ground objects, it has obvious advantages and can control the layout error of linear ground objects within ±1.2cm.

6. CONCLUSION AND LIMITATIONS ANALYSIS

Through systematic theoretical analysis and empirical verification, this study has clarified the core technical path for improving the accuracy of unmanned aerial vehicle (UAV) layout. The experimental results show that the adoption of the high-precision GNSS-RTK positioning module can reduce the horizontal positioning error to the centimeter level and improve the vertical direction accuracy by approximately 35%. The multi-sensor fusion algorithm effectively compensates for the drift error of a single sensor by integrating the IMU inertial measurement unit and the visual SLAM data, reducing the trajectory calculation error by 42% in the dynamic flight scene. The geometric correction technology based on Ground Control Points (GCP) significantly improves image distortion. Experimental data show that when the deployment density reaches 25 GCP per square kilometer, the DOM plane accuracy can reach 0.03m. In terms of the optimization of the flight control system, the adaptive PID control algorithm reduces the attitude Angle fluctuation amplitude of the unmanned aerial vehicle (UAV) by 57% under wind disturbance of level 5, and improves the heading stability to ±0.5°. The point cloud registration algorithm controls the stitching error of the 3D model within the 2cm threshold by improving the ICP iterative strategy [8].

The current technological system still faces the challenge of insufficient adaptability to complex environments [9]. The track offset caused by the change of dynamic wind speed still fluctuates by 3-5cm, and the aerodynamic compensation algorithm needs to be further studied. The influence of multipath effect on GNSS signals increases the positioning error to 7cm in urban environments, and a new type of anti-interference antenna array needs to be developed. In terms of the timeliness of data processing, the operation time of the existing point cloud processing algorithms at the gigabit point scale exceeds 2 hours, and it is necessary to explore the GPU parallel acceleration architecture. Experimental data show that changes in lighting conditions reduce the success rate of feature matching in visual odometry by 28%, and there is an urgent need to develop a multispectral fusion perception system [10]. At the hardware level, the ranging accuracy and volume power consumption of micro lidar have not yet reached an engineering balance, which restricts the payload configuration of small unmanned aerial vehicles [11]. The existing research lacks depth in the collaborative mechanism of dynamic obstacle avoidance and layout operations, and it is necessary to construct a real-time path planning model based on reinforcement learning.

The limitations of the research are mainly reflected in the insufficient diversity of the experimental scenarios. The existing verifications are mostly concentrated in open areas, and the test coverage rate for complex terrains such as mountains and forest areas is only 23%. Dynamic environment modeling does not fully consider the influence of temperature and humidity gradients on the performance of sensors, resulting in deviations in the evaluation of algorithm robustness. It is suggested that the subsequent research establish a multi-dimensional environmental coupling experimental platform and construct a comprehensive evaluation system including meteorological parameters, electromagnetic environment and topographic features. Hardware improvement should focus on developing a multi-physics coupling compensation module, integrating a temperature-compensated gyroscope and an anti-magnetic interference accelerometer. The direction of algorithm optimization needs to be combined with the federated learning framework to enhance the ability of cross-scenario model transfer. At the engineering application level, it is suggested to formulate a classification standard for the accuracy of unmanned aerial vehicle (UAV) layout and establish a standardized operation system including equipment selection, flight parameters, and data processing procedures.

REFERENCES

[1] Maghazei, O., & Netland, T. (2020). Drones in manufacturing: Exploring opportunities for research and practice. Journal of Manufacturing Technology Management, 31(6), 1217-1235.
[2] Nouacer, R., Hussein, M., Espinoza, H., & Corradi, F. (2020). Towards a framework of key technologies for drones. Microprocessors and Microsystems, 75, 103073.
[3] Zhu, H., Nie, H., Zhang, L., Wei, X., & Zhang, M. (2020). Design and assessment of octocopter drones with improved aerodynamic efficiency and performance. Aerospace Science and Technology, 106, 106154.
[4] Duffy, J. P., Cunliffe, A. M., DeBell, L., & Sandbrook, C. (2018). Location, location, location: Considerations when using lightweight drones in challenging environments. Remote Sensing in Ecology and Conservation, 4(1), 7-19.
[5] Hussein, M., Nouacer, R., Corradi, F., Ouhammou, Y., & Castrillo, G. (2021). Key technologies for safe and autonomous drones. Microprocessors and Microsystems, 80, 103365.
[6] Zhu, Y. W. (2016). Research on key technologies of UAV systems. Journal of Beijing Institute of Technology, 36(S1), 12-18.
[7] Qiu, D. H. (2018). Research on key technologies of UAV takeoff/landing taxiing and shock absorption [Doctoral dissertation, Changchun Institute of Optics, Fine Mechanics and Physics, CAS].
[8] Fan, Y. J., & Zhang, Q. C.(2018). Key technologies of UAV aerial survey image matching. Electronic Measurement Technology, 41(5), 89-94.
[9] Hu, C. C. (2023). Research on deployment optimization of air-ground cooperative unmanned systems [Master’s thesis, Nanjing University of Information Science & Technology].
[10] Chen, F. Y. (2020). Research on image processing technology for UAV autonomous precision landing [Master’s thesis, Shandong University].
[11] Sun, H. (2018). Research on key technologies of UAV short-distance landing fault-tolerant control [Doctoral dissertation, Northwestern Polytechnical University].
[12] Li, J. D. (2020). Research on key technologies of UAV flight control systems. Technology Wind, 2020(3), 45-47.
[13] Sun, X. S., Liu, S. H., & Liu, L.(2020). Research on key technologies of UAV flight control systems. Wireless Internet Technology, 17(18), 23-25.
[14] Zeng, Q. (2019). Research on UAV-assisted cooperative communication key technologies [Doctoral dissertation, University of Science and Technology Beijing].
[15] Xu, H. W., Li, P., & Wang, X. (2018). Research on key technologies of UAV-borne air-to-ground missiles. Journal of Projectiles, Rockets, Missiles and Guidance, 38(4), 45-48.
[16] Dai, F. X. (2007). Research on key technologies of UAV-borne multispectral imager [Master’s thesis, Shanghai Institute of Technical Physics, CAS].
[17] Yuan, Y. J. (2019). Research and implementation of UAV image precise registration [Technical report, Shanghai Advanced Research Institute, CAS].
[18] Hou, X. Y. (2022). Research on key technologies of UAV target recognition and counting [Technical report, Shanghai Advanced Research Institute, CAS].
[19] Li, Y. (2018). Analysis of key technologies in UAV aerial remote sensing systems. Urban Geography, 2018(12), 156-157.
[20] Chen, Z. B. [陈在斌]. (2020). Research on key technologies of tilt-rotor UAV control systems [Doctoral dissertation, Changchun Institute of Optics, Fine Mechanics and Physics, CAS].
[21] Li, J. [李炯]. (2009). Research on microwave guidance technology for UAV landing systems [Master’s thesis, Institute of Electronics, CAS].
[22] Duan, Z. [段镇]. (2014). Research on key technologies of UAV flight control systems [Doctoral dissertation, Changchun Institute of Optics, Fine Mechanics and Physics, CAS].

[23] Zhao, G. J. [赵广健]. (2019). Research and practice of UAV equipment technology. Southern Agricultural Machinery, 50(15), 123-124.
[24] Cao, H. T. [曹洪涛]. (2022). Key technologies for radiometric consistency correction of UAV optical remote sensing [Doctoral dissertation, Aerospace Information Research Institute, CAS].
[25] Zhang, Y. [张郁]. (2018). Accuracy analysis of UAV low-altitude photogrammetry. Geomatics and Information Science of Wuhan University, 43(S1), 89-93.
[26] Pan, J. H., Zhang, S. B., & Wang, D. H. [潘计辉, 张盛兵, 王党辉]. (2018). Fault-tolerant technology research for flight control systems of high-altitude long-endurance UAVs. Journal of Northwestern Polytechnical University, 36(3), 456-461.
[27] Zhang, B. G. [张宝钢]. (2011). Key technologies for aeromagnetic data preprocessing of fixed-wing UAVs (Technical Report No. RS-2011-028) [Institute of Remote Sensing Applications, CAS].
[28] Teng, Y. K. [滕玉坤]. (2019). Research on key visual measurement technologies for UAV aerial refueling [Doctoral dissertation, Shenyang Institute of Automation, CAS].
[29] Wang, F., Qi, S. J., & Wu, X. L. [王锋, 祁圣君, 吴欣龙]. (2018). Research and prospects of UAV flight quality. Aerodynamic Missile Journal, 2018(5), 34-38.
[30] Zhao, W. W. [赵伟伟]. (2020). Research on formation and obstacle avoidance control for UAV swarms [Doctoral dissertation, Changchun Institute of Optics, Fine Mechanics and Physics, CAS].
[31] Wang, J., Zou, M., & Yang, Y. [王俊, 邹萌, 杨莹]. (2018). Technical discussion on UAV in large-scale mapping. Resources Guide, 2018(9), 45-47.
[32] Zhou, H. X. [周鸿翔]. (2019). Quality evaluation of UAV remote sensing orthophotos. Geomatics & Spatial Information Technology, 42(5), 112-115.
[33] Yu, Y. F., & Wang, L. [郁一帆, 王磊]. (2019). New trends in UAV technology development. Aerodynamic Missile Journal, 2019(6), 23-27.
[34] Wu, X. L. [吴欣龙]. (2019). Research on flight quality standards for UAV systems. Aeronautical Standardization & Quality, 2019(4), 23-26.
[35] Zhang, C. H. [张长海]. (2019). Research on UAV aerial remote sensing technology. North China Natural Resources, 2019(4), 89-91.
[36] Lai, C. X. [赖春晓]. (2021). Key technologies and engineering applications of UAV oblique photogrammetry. Architecture and Decoration.