The Application and Future Prospects of Drone Vision Technology in the Railway Industry

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Abstract. With the continuous expansion of the railway transportation scale, traditional inspection methods are increasingly unable to meet the safety inspection requirements of railway facilities and their surrounding environments. Drone vision technology, with its unique advantages, has been widely applied in the railway industry. This paper comprehensively reviews the current application status of drone vision technology in various aspects of railway inspection, deeply analyzes the challenges it faces, and looks ahead to its future development trends, aiming to provide references for promoting the intelligent inspection of the railway industry.

Keywords: Railway; Drone Inspection; Vision Technology; Development Trends

Introduction

Railways play a vital role in a country's economic development as a major artery of transportation. With the continuous expansion of the railway network and the increasing density of train operations, the maintenance and inspection tasks of railway equipment have become more arduous. Traditional manual inspection methods are not only inefficient and labor-intensive but also have issues such as blind spots and being restricted by environmental factors, which makes it difficult to ensure the efficient and safe operation of railway transportation. The rise of drone technology has brought new opportunities for railway inspection. Drones equipped with various vision sensors can achieve comprehensive and high-precision inspections of railway facilities and their surrounding environments, effectively making up for the shortcomings of traditional inspection methods and becoming an important driving force for the intelligent development of the railway industry.

1 Overview of Drone Vision Technology

1.1 .Types and Characteristics of Drones

Drones come in a wide variety of types. According to the configuration of the flight platform, they can be divided into fixed-wing drones, unmanned helicopters, multi-rotor drones, parafoil drones, flapping-wing drones, and unmanned airships, etc. [1]. Fixed-wing drones have strong endurance, good wind resistance, high flight speed, and can reach high altitudes. They are suitable for large-area and long-distance railway inspection tasks, such as inspecting railway lines in remote mountainous areas. Composed of wings, fuselage, empennage, landing gear, and power plant, they have diverse take-off methods to meet different scenario requirements. Multi-rotor drones, on the other hand, possess high mobility and flexibility and can hover in the air, facilitating fixed-point operations and close-range inspections of complex areas. For example, when inspecting railway bridges in urban areas, they can flexibly move among buildings to obtain accurate data. In the railway inspection field, these two types of drones are most widely used, and their complementary advantages can meet the needs of diverse inspection tasks.

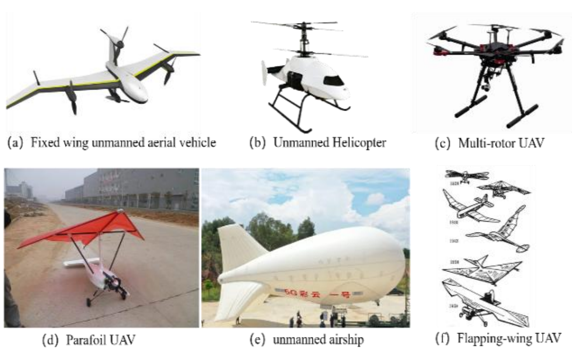

Figure 1 Schematic diagram of UAV type

1.2 Equipped Devices and Vision Technologies

During railway inspection operations, drones commonly use sensors such as infrared thermal imaging, visible-light imaging, and LiDAR [2]. Visible-light imaging sensors are widely applied. They can acquire high-resolution images, clearly presenting the detailed features of railway facilities and facilitating the inspection of equipment appearance by inspectors. With the development of vision technology, techniques such as image analysis, target detection and segmentation, image restoration and enhancement, target tracking, binocular and multi-camera vision, multi-source fusion vision, 3D point cloud and 3D reconstruction, and remote sensing and aerial image analysis have been extensively used in the railway industry. For instance, 3D reconstruction technology can create 3D models of railway facilities, providing an intuitive basis for accurate inspection and assessment; multi-source fusion vision technology combines data from different sensors to more comprehensively reflect the information of the detected targets, improving the accuracy and reliability of inspections.

2 Applications of Drones in Railway Inspection: Disaster Prevention and Control

In alpine, high-altitude, complex mountainous, and special dangerous sections along railway lines, drone inspection technology plays an irreplaceable role in disaster prevention and control. It can improve inspection efficiency and accuracy, reduce the workload and danger for personnel. By establishing 3D models from photographed images, drones can conduct investigations of geological disasters such as landslides, dangerous rockfalls, and debris flows [3]. In 2022, Zheng Lang et al. used drone surveying and mapping during the emergency response to the "8·14" landslide in

Aidai Village, Ganluo County, providing scientific basis for disaster prevention and control [4]. In 2018, Wang Dong et al. used drone oblique photogrammetry technology to explore new methods for monitoring dangerous rocks on the high-slope at the exit of the Ji'ermu Tunnel on the Chengdu-Kunming Railway [5]. In 2020, Wang Song et al. conducted surface modeling of the collapse in the Shexingcun section of the Qinghai-Tibet Railway using drones to evaluate the collapse range [6]. To address the limitations of local data management of drone oblique photogrammetry technology, in 2021, Fu Kun et al. independently developed an online publishing platform for drone-based oblique photogrammetry data files, which can meet the long-term monitoring requirements for high-position rock mass collapses on the Chengdu-Kunming Railway [7]. In 2021, He Peng et al. conducted 3D point-cloud reconstruction and real-scene modeling of the data obtained by drone oblique photogrammetry at the Hejiacun Station in Zhangjiajie to simulate the trajectory of dangerous rockfalls and ensure railway transportation safety [8]. In the same year, Zhou Fujun designed and developed a low-altitude aerial survey geological interpretation software system, improving the railway survey efficiency in alpine and mountainous areas [9]. In 2022, Shi Yuefeng et al. constructed a multi-level flood-control system combined with drones, providing strong support for railway flood-control management [10].

2.1 Challenges Faced by Drone Vision Technology in Railway Applications

2.1.1 Lack of Unified Technical Standards and Specifications

Currently, in the application of drone vision technology in the railway industry, there is a lack of unified technical standards and specifications. Drones produced by different manufacturers vary in performance parameters, data interfaces, and communication protocols, and data-processing software also differs. This makes it difficult to achieve compatibility and collaborative work between different devices and software in actual inspection operations. This not only increases the difficulty and cost of system integration but also affects the accuracy and reliability of inspection data, hindering the large-scale promotion and application of drone inspection technology [11].

2.3 Uneven Performance of Drones

The quality of drones on the market varies greatly. Some drones have deficiencies in stability, endurance, and anti-interference ability. In the railway inspection environment, complex situations such as electromagnetic interference and severe weather may be encountered. Drones with poor performance are prone to flight failures, resulting in interrupted data collection, reduced data quality, or even safety accidents. To ensure transportation safety, railway departments have strict restrictions on the flight of drones along railway lines. For example, the operation of some drones is prohibited within a 500-meter radius of railway lines, which limits the application scope of drone vision technology to a certain extent [12].

2.4 Difficulty in Data Processing and Analysis

The drone vision data obtained from railway inspections is massive and includes various types, such as visible-light images, infrared thermal-imaging data, and LiDAR point-cloud data. How to efficiently process and analyze these data to extract valuable information is a major challenge. Existing data-processing algorithms still need to be improved in terms of accuracy, speed, and adaptability and are difficult to meet the dual requirements of real-time performance and accuracy. In addition, more perfect solutions are needed for data storage and management to ensure data security and traceability [13].

3 Development Trends of Drone Vision Technology in the Railway Industry

3.1 Standardization and Normalization of Technology

In the future, the railway industry will strengthen the standardization and normalization construction of drone vision technology, formulating unified technical standards and operating specifications. These will cover aspects such as drone selection, performance requirements of equipped devices, data collection and processing procedures, and quality control standards. Through standardization construction, the compatibility and interoperability between different devices and software can be improved, system integration costs can be reduced, and the orderly development of drone vision technology in the railway industry can be promoted [14].

3.2 Research and Development of High-Performance Drones

In response to the special requirements of railway inspections, more investment will be made in the research and development of high-performance drones. Drones with stronger stability, longer endurance, higher anti-interference ability, and precise positioning capabilities will be developed to adapt to the complex railway inspection environment. At the same time, the lightweight, miniaturization, and intelligence levels of drones will also continue to increase, enabling them to move more flexibly among railway facilities for more efficient and accurate inspections [15].

3.3 Intelligent Data Processing and Analysis

With the continuous development of artificial intelligence and big-data technology, intelligent data processing and analysis will become the core competitiveness of drone vision technology in the railway industry. Using algorithms such as deep learning and machine learning, automatic analysis and intelligent diagnosis of railway inspection data can be achieved, which can quickly and accurately identify equipment defects, potential geological disasters, and other issues and conduct risk assessment and prediction. By establishing a big-data platform and deeply mining and analyzing historical inspection data, scientific decision-making basis can be provided for the maintenance and management of railway facilities, realizing the transformation of railway inspections from passive detection to active prevention [16].

Conclusion

Drone vision technology has achieved remarkable results in the railway industry. It has played an important role in the inspection of high-altitude equipment and environments, ground-level equipment and environments, and disaster prevention and control, effectively improving the efficiency and quality of railway inspections and ensuring the safety of railway transportation. However, currently, this technology still faces challenges such as non-unified technical standards, uneven drone performance, and difficult data processing. Looking ahead, by promoting the standardization and normalization of technology, developing high-performance drones, and advancing intelligent data processing and analysis, drone vision technology will be more widely and deeply applied in the railway industry. It will inject strong impetus into the intelligent development of the railway industry and help China's railway cause reach new heights.

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