Theory and Practice of Science and Technology
2025, VOL. 6, NO. 8, 37-39
DOI: 10.47297/taposatWSP2633-456907.20250608

A Survey of Autonomous Obstacle Avoidance Technology for UAVs

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ABSTRACT
Autonomous obstacle avoidance technology for UAVs refers to the ability of unmanned aerial vehicles (UAVs) to automatically detect and avoid obstacles without human intervention. This technology is a crucial component of UAV applications, greatly enhancing their safety and reliability by reducing human error-related accidents. Currently, UAV autonomous obstacle avoidance has become one of the most prominent research areas, with significant achievements made by scholars both domestically and internationally. This paper provides a comprehensive review of the current state of research on UAV autonomous obstacle avoidance technologies worldwide, aiming to offer references and insights for related research.

KEYWORDS
UAVs; Obstacle avoidance sensors; Computer vision; Obstacle avoidance methods

1 Introduction

Autonomous obstacle avoidance technology is one of the hot topics in UAV research today. As UAV technology continues to advance, UAVs are being increasingly applied in various industries, such as logistics, agriculture, and environmental monitoring. In these fields, UAVs often need to fly in complex environments, where obstacles are abundant. As a result, autonomous obstacle avoidance is essential to prevent collisions, ensuring the UAV's safe and reliable operation. Research on UAV autonomous obstacle avoidance technology is crucial for expanding the potential applications and improving the operational efficiency of UAVs. This paper provides an overview of the development trends in this field, based on domestic and international research.

2 Research background and significance

International research on UAV autonomous obstacle avoidance began in the 1990s, with early work focusing primarily on sensor-based algorithms. Although domestic research in China started later, it has made considerable progress in recent years. With the development of computer vision, deep learning, and other related technologies, the field has evolved rapidly. Current research, both domestically and internationally, is primarily focused on the following three areas:

· Sensor-based obstacle avoidance algorithms: This approach uses sensors such as lidar and ultrasonic sensors to gather environmental data. A pre-programmed algorithm then uses this data to guide the UAV around obstacles. While this method provides real-time environmental information, it is often limited by the high cost and maintenance of the sensors, as well as their poor adaptability to complex environments.

· Computer vision-based obstacle avoidance algorithms: This method relies on cameras to capture images of the surrounding environment. Computer vision algorithms process these images to enable the UAV to avoid obstacles. A key advantage is the lack of additional sensor hardware, making it suitable for a wide range of complex environments. However, its performance is highly sensitive to factors like lighting conditions and obstructions.

· Deep learning-based obstacle avoidance algorithms: This approach employs deep learning to model the UAV's environment. The model then predicts the location and shape of obstacles, facilitating avoidance. This method's strengths include its ability to automatically learn environmental features and its strong generalization capability. The main drawbacks are the high demand for large datasets and significant computational resources.

UAV autonomous obstacle avoidance is a complex and crucial field that integrates multiple disciplines. While international research has broadly focused on sensor-based, computer vision, and deep learning algorithms, domestic research has largely concentrated on the first two. As technology continues to advance, we can expect this field to become increasingly mature and refined.

3 Current state of research

In the review of sensor-vision-based obstacle avoidance technologies, Zeng Ganmin, Tang Wenqi, and Ming Rui (2019) highlighted that obstacle avoidance is a key component of UAV autonomous flight technology, which includes obstacle detection and path planning. They described obstacle avoidance systems based on LiDAR, ultrasonic sensors, and monocular cameras, as well as map-based navigation systems. The authors emphasized the practical application of multi-sensor integration to enhance obstacle avoidance capabilities. Mao Yiming (2021) proposed a UAV obstacle detection and avoidance method that combines LiDAR and monocular camera data. By constructing a motion model to predict obstacle boundaries, the method plans Dubins paths. Mao also developed a deep learning-based image recognition system for identifying specific obstacles and implemented this system on an embedded platform for onboard obstacle avoidance. Furthermore, he introduced a multi-UAV cooperative avoidance method that employs the Vicsek model for information sharing and a modified artificial potential field method for distributed collaborative avoidance.

Lü Qian, Tao Peng, Wu Hong, Hu Xiangyang, and Zhang Aihan (2021) presented a UAV autonomous flight and obstacle avoidance technique based on unscented Kalman filtering. This method integrates multiple onboard sensors to collect UAV flight status and environmental information, combined with monocular camera target detection algorithms to enable obstacle avoidance and precise navigation through predefined obstacle zones. Simulations on the Airsim platform, as well as real-world experiments, showed that the UAV could successfully complete the task in simulated environments, although some parameter adjustments were required to ensure real-world effectiveness. Long Hang (2021) developed a quadrotor UAV platform for indoor obstacle avoidance, based on LiDAR positioning. The system is designed for GPS-denied environments and utilizes onboard computational control as input for the flight controller. The research also included dynamic modeling, attitude control, position estimation, and the implementation of the Cartographer algorithm for indoor localization. The effectiveness of the dynamic obstacle avoidance algorithm was validated through both simulation and real-world tests.

Cao Yirong (2021) investigated how UAVs can autonomously avoid obstacles in complex environments while utilizing LiDAR for environmental sensing. The research focused on global path planning and local avoidance within a LiDAR-based autonomous obstacle avoidance system. The study incorporated hardware and software design, simulation platform construction, improvements to the RRT algorithm, and the application of the 3DVFH algorithm. The UAV demonstrated effective autonomous obstacle avoidance in complex environments, validating the proposed methods.

In the review of computer vision-based obstacle avoidance algorithms, Tan Yating (2021) discussed UAV obstacle avoidance strategies, suggesting a rapid A* algorithm based on safety distances for large obstacles to ensure safe distances and improve search speed. For small obstacles, the study employed stereo vision and a four-path adaptive window census semi-global stereo matching algorithm for real-time avoidance, improving the precision and speed of disparity calculations. In the review of deep learning-based obstacle avoidance algorithms, Jiang Weilai, Xu Guoqiang, and Wang Yaonan (2022) addressed the problem of UAV autonomous obstacle avoidance and target tracking. They introduced the multi-experience pool deep Q-network (MP-DQN), an extension of the deep Q-network (DQN). This algorithm optimizes reward function design and enhances the UAV's environmental perception capabilities, improving both obstacle avoidance and tracking success rates, as well as algorithm convergence. Simulation results showed that MP-DQN outperformed DQN and Double-DQN (DDQN) in terms of faster convergence, shorter tracking paths, and stronger environmental adaptability. Li Zhi (2023) proposed a study on obstacle avoidance in dynamic environments, applying operational research theories to path search, flight corridor generation, trajectory optimization, and emergency avoidance planning. The paper introduced innovative work in four areas: rapid path search algorithms, flight corridor generation based on arbitrary endpoint grid calculations, dynamic obstacle avoidance modeling, and emergency avoidance planning algorithms, all aimed at improving UAV safety and efficiency in complex dynamic environments. Wang Min (2019) proposed an autonomous obstacle avoidance algorithm for rotary-wing UAVs, analyzing obstacle threat points and calculating the minimum time-to-collision to determine desired speed and direction. This approach improves flight stability and safety, and under overload constraints, it bisects the available speeds to minimize penalties and determine the avoidance speed. MATLAB simulations demonstrated that this method leverages the hovering capabilities of rotary-wing UAVs to achieve autonomous obstacle avoidance. International research in the field of UAV autonomous obstacle avoidance has also made significant contributions. Hussein Mahmoud, Nouacer Réda, Corradi Federico, et al. (2021) emphasized that the development of UAV systems relies heavily on key technologies. They identified and categorized these technologies using cases from the COMP4DRONES project, which were divided into four categories: Uspace capabilities, system functions, payloads, and tools. The study highlighted how the project improved existing technologies to simplify UAV customization and ensure safe operations. This research underscores the systematic approach to constructing UAV technology frameworks abroad, where key technologies, including autonomous obstacle avoidance, are categorized and optimized through project-based practice, providing crucial support for UAV functionality.

This literature suggests that international research on UAV technology focuses on an integrated approach, starting with comprehensive project-level considerations and using real-world cases to optimize various operational technologies. This methodology enhances UAV system performance, with autonomous obstacle avoidance being a critical component to ensure safe operation. For instance, the Uspace capability category likely involves technologies for UAV-environment interaction, which play an essential role in accurate obstacle detection. The system function research may involve refining decision algorithms, sensor fusion, and other core functions necessary for autonomous obstacle avoidance. The research from the COMP4DRONES project provides a foundation for advancing UAV autonomous obstacle avoidance technology, which can guide future research to explore specific aspects of this technology, fostering safe and efficient UAV operations in complex environments. In summary, domestic scholars have focused their research on UAV autonomous obstacle avoidance technologies in areas such as sensor integration, path planning algorithms, and multi-UAV cooperative control. These studies have provided valuable theoretical foundations and practical experience for addressing UAV obstacle avoidance in complex environments, using methods such as LiDAR, computer vision, and deep learning. The majority of domestic scholars support the use of multi-sensor fusion and intelligent algorithms, emphasizing that advancing this field requires addressing algorithm optimization, system integration, and real-world implementation.

On the other hand, international research primarily focuses on reinforcement learning, dynamic environment path planning, and system safety analysis. These studies stress the importance of real-time data processing accuracy and reliability for effective autonomous obstacle avoidance. Although there are differences in research perspectives, both domestic and international studies ultimately aim to enhance UAV autonomy and intelligence. Practical research is generally focused on civilian and military UAVs, with significant overlaps with fields such as robotics and intelligent transportation. However, there is less research in sectors like medical rescue and post-disaster recovery. Overall, the research on perception, decision-making, and control mechanisms for UAV autonomous obstacle avoidance by scholars worldwide has provided rich theoretical insights and practical references for applications in UAV swarms, intelligent transportation, and other high-autonomy sectors. This body of work has contributed significantly to the theoretical and practical development of UAV autonomous obstacle avoidance technology.

4 Conclusion

The rapid development of UAV technology has made autonomous obstacle avoidance a crucial factor in enhancing UAV flight safety and efficiency. This review summarized various obstacle avoidance technologies, focusing on the application of sensors and algorithms, including LiDAR, ultrasonic sensors, and computer vision. A review of the domestic and international literature reveals that current research primarily focuses on obstacle detection, environmental perception, and path planning, forming a well-established theoretical framework and practical guidelines.

The integration of deep learning and artificial intelligence algorithms in obstacle avoidance systems has become a key area of interest. This integration improves UAVs' ability to adapt to complex environments and enhances their decision-making accuracy. The fusion of multiple obstacle avoidance technologies, such as multi-sensor data fusion, has provided effective solutions for real-time obstacle avoidance in dynamic environments. Despite significant progress, challenges remain in dynamic obstacle avoidance, complex environmental modeling, and multi-UAV collaboration.

Future research should focus on the exploration of novel obstacle avoidance algorithms, with an emphasis on practical effectiveness and versatility, to advance UAV autonomous obstacle avoidance technology and provide more reliable safety measures for UAVs in various operational tasks.

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