

A Review of Autonomous Decision-making by UAVs

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ABSTRACT

Drone autonomous decision-making technology is a key component of the UAV system, which aims to enable UAVs to autonomously complete tasks in complex and dynamic environments, reducing human intervention. This paper reviews the current status and development of autonomous decision-making technology of UAVs, mainly covering key technologies such as perception and environmental modeling, path planning and navigation, decision-making and control, and multi-UAV systems. This paper also explores the application scenarios of autonomous decision-making technology for drones in military and civilian fields, such as reconnaissance and surveillance, logistics and distribution, agricultural monitoring, and disaster relief. In view of the challenges faced by the current technology, such as computing resources, environmental complexity, security and privacy protection, this paper proposes possible solutions and research directions.

KEYWORDS

Drones; Autonomous Decision-making; Perception Technology; Decision-making and Control.

1. INTRODUCTION

Autonomous decision-making technology of unmanned aerial vehicles (UAVs) is a key technology in unmanned aerial vehicle systems, which enables drones to autonomously complete tasks in complex and dynamic environments without human intervention. As the use of drones in military, civil, and commercial applications continues to expand, the importance of autonomous decision-making technology is becoming increasingly prominent.

Autonomous decision-making technology enables drones to navigate autonomously and avoid obstacles in complex environments, ensuring efficient mission completion and reducing the risk of collision. In addition, drones are able to respond quickly to emergencies and perform tasks autonomously, improving the efficiency and safety of emergency response. Autonomous decision-making technology enables drones to operate in unknown or dynamically changing environments, such as urban environments, forests, oceans, etc., improving the applicability of drones. Multi-task execution is also an important application of autonomous decision-making technology, UAVs can perform reconnaissance, monitoring, data collection and other tasks at the same time, and the autonomous decision-making ability makes it more flexible in task switching and priority judgment. At the same time, for the cost of manpower can also be greatly reduced, the independent decision-making technology reduces the dependence on human resources and reduces the operating cost, especially in large-scale applications. Autonomous decision-making also enhances the reliability and stability of the UAV's mission, and the autonomous decision-making technology enables the UAV to continue to perform the mission in the event of communication interruption or signal restriction, enhancing the reliability and stability of the mission. Autonomous decision-making also enables UAVs to better realize multi-UAV collaborative operations, and autonomous decision-making

technology enables multi-UAV systems to efficiently allocate tasks and work collaboratively, improving the overall task efficiency and success rate. In conclusion, UAV autonomous decision-making technology plays an important role in improving mission efficiency and safety, expanding application scenarios, reducing human intervention, enhancing mission reliability and stability, protecting safety and privacy, and supporting multi-UAV collaborative operations. Based on this, this paper will discuss in detail the importance of autonomous decision-making technology for UAVs in various applications, and look forward to its future development trends.

2. KEY TECHNOLOGIES FOR AUTONOMOUS DECISION-MAKING BY UAVS

2.1. Perception Technology

2.1.1. Sensors

The autonomous decision-making capability of drones is highly dependent on data inputs from multiple sensors that are able to perceive environmental information and provide necessary data support. Here are the main types of sensors commonly used by drones and their applications.

(1) Camera

The camera is the core tool of the UAV's environmental perception. By capturing images of the surrounding environment, the camera helps the drone identify obstacles, terrain, and target objects. Combined with computer vision technology, drones can perform target recognition and tracking, which is suitable for security monitoring, search and rescue and other tasks. The camera also supports visual SLAM (Simultaneous Localization and Mapping) technology, which enables the drone to build maps and navigate autonomously in unknown environments.

In practice, the camera's high resolution and real-time nature enable it to capture detailed image data. This data is not only used for immediate decision-making, but can also be stored for subsequent analysis. For example, in agricultural monitoring, RGB and infrared cameras can work together to monitor the health status of crops and pests and diseases, and identify abnormal areas through image processing for precision agricultural management.

(2) LiDAR

Lidar is known for its high accuracy and long-range measurement capabilities, and is one of the indispensable sensors for autonomous decision-making of drones. LiDAR emits a laser and measures the reflection time to generate high-resolution 3D point cloud data, which is used to build a detailed model of the surrounding environment. This feature is especially important in high-precision obstacle avoidance and path planning, especially in complex terrain such as urban environments and forests.

The application of LiDAR is not limited to obstacle avoidance and navigation. In autonomous and unmanned vehicles, LiDAR is widely used to detect and track dynamic objects such as pedestrians and other vehicles. Similarly, in drones, LiDAR can help with complex tasks such as precision landing, object grabbing, etc. Its high-precision data can also be used for environmental monitoring, such as measuring topographic changes, monitoring forest cover, etc.

(3) Global Positioning System (GPS)

GPS provides global positioning information for drones, which is the key to achieving long-range and high-precision navigation. By receiving satellite signals, GPS is able to provide precise location information to support global path planning and mission execution. The high-precision positioning capability of GPS enables drones to maintain a stable flight path in a wide range of applications, such as logistics distribution, environmental monitoring, and more.

In addition, GPS is also used in combination with other sensors such as IMUs, barometers, etc., to provide more stable and reliable navigation data. In environments where GPS signals are lacking, such as indoors or in tunnels, drones can utilize visual SLAM or other positioning technologies for navigation. At the same time, GPS also supports flight log recording and mission tracking, which is convenient for analyzing and reviewing flight missions.

conclusion

Cameras, lidar, and GPS are the most important sensors in unmanned aerial systems, providing comprehensive situational awareness and precise positioning information. By working together, these sensors enable drones to autonomously complete a variety of tasks in complex and dynamic environments. In the future, with the further development of sensor technology, the autonomous decision-making capabilities and application scenarios of UAVs will continue to expand, bringing more possibilities to all walks of life.

2.1.2. Data Fusion Technology

Data fusion technology refers to the combination of data from multiple sensors to obtain more comprehensive, accurate, and reliable information. This technology is crucial in autonomous decision-making of UAVs, as it can effectively integrate the advantages of multiple sensors, make up for the shortcomings of a single sensor, and improve the accuracy of environmental perception and decision-making. Here are a few common data fusion techniques and their applications.

(1) Sensor data preprocessing

Before data fusion, the data from each sensor needs to be pre-processed. Data from different sensors may have different formats, units, and sampling frequencies, so they need to be normalized. Data preprocessing includes:

Denoising: Filters (e.g., Kalman filter, particle filter, etc.) are used to remove noise from sensor data.

Calibration: Adjust sensor data to eliminate systematic errors and environmental disturbances.

Synchronization: Time alignment of sensor data collected at different times to ensure the accuracy of data fusion.

(2) Low-level data fusion

Low-level data fusion, also known as data-level fusion, refers to the direct fusion of raw data from multiple sensors. This approach is typically used for the same type of sensor data, such as data fusion from multiple cameras or multiple LiDARs. Through overlay or averaging processing, low-level data fusion can improve the resolution and reliability of the data.

Applications:

Multi-camera fusion: The image data fusion of multiple cameras can generate a panoramic view, expand the field of view of the drone, and improve the accuracy of target recognition and tracking.

Multi-LiDAR fusion: The point cloud data fusion of multiple LiDARs can generate a higher-precision 3D environment model and improve the navigation ability of UAVs in complex environments.

(3) Medium-level data fusion

Medium-level data fusion, also known as feature-level fusion, refers to the fusion of feature information from multiple sensors. This approach first extracts meaningful features (e.g., edges, corners, shapes, etc.) from the sensor data and then fuses these features. Medium-level data fusion reduces the amount of data while maintaining data characteristics, and is suitable for scenarios that require real-time processing.

Applications:

Vision and LiDAR fusion: The image features of the camera are fused with the point cloud features of LiDAR to enhance the robustness of environmental perception. For example, when visual information is limited (e.g., insufficient lighting), the depth information provided by LiDAR can supplement the lack of visual information.

IMU and visual fusion: By fusing the attitude information provided by the IMU and the visual characteristics of the camera, the attitude estimation accuracy of the UAV is improved and a more stable flight control is realized.

(4) High-level data fusion

High-level data fusion, also known as decision-level fusion, refers to the fusion of results from multiple sensors at the decision-making level. In this method, the results of the independent decisions of each sensor are comprehensively evaluated to arrive at the final decision. High-level data fusion can effectively deal with data inconsistencies and conflicts between sensors, and improve the accuracy and reliability of decision-making.

Applications:

Multi-sensor decision fusion: In obstacle detection and obstacle avoidance tasks, UAVs can comprehensively evaluate the detection information of each sensor by fusing the detection results of vision, LiDAR and ultrasonic sensors to ensure the accuracy of obstacle avoidance decisions.

Autonomous navigation: In autonomous navigation tasks, the global positioning information provided by GPS is fused with the local information provided by sensors such as IMU and vision to achieve more accurate navigation and path planning.

(5) Data Fusion Algorithms

The implementation of data fusion relies on a variety of algorithms and methods. Commonly used algorithms include:

Kalman Filter: A recursive estimation algorithm widely used for position, velocity, and attitude estimation.

Particle Filter: An estimation algorithm based on the Monte Carlo method for nonlinear, non-Gaussian systems.

Bayesian Network: A probabilistic model for dealing with uncertainty and fusion of multi-source data.

conclusion

Data fusion technology is an important part of autonomous decision-making of UAVs. By integrating data from different sensors, data fusion not only improves the accuracy and reliability of environmental perception[2]It also enhances the drone's adaptability in complex environments. With the development of artificial intelligence and machine learning technology, data fusion algorithms will continue to be optimized to provide drones with stronger autonomous decision-making capabilities and a wider range of application prospects.

2.2. Environmental Modeling and Understanding

2.2.1. Simultaneous Localization and Mapping (SLAM)

Simultaneous Localization and Mapping (SLAM) is a technology that enables mobile devices (such as drones, robots, etc.) to build maps in real time in unknown environments and determine their own location at the same time. SLAM technology is at the heart of UAV autonomous navigation and environmental perception, enabling UAVs to fly autonomously in unknown or dynamic environments, avoid obstacles and perform complex tasks[1].

SLAM technology is widely used in UAVs, including the following:

Autonomous navigation: In unknown or dynamic environments, SLAM helps UAVs build environmental maps in real time, carry out path planning and obstacle avoidance, and are suitable for rescue, survey and other tasks.

Environmental modeling: SLAM is used to build high-precision 3D environmental models, which are used in architectural surveying and mapping, cultural relics protection and other fields.

Autonomous exploration: UAVs use SLAM technology to autonomously explore unknown areas, such as topographic survey, post-disaster search and rescue, etc.

Augmented Reality (AR): SLAM technology enables AR devices to accurately overlay virtual information in the real world to provide an immersive experience.

The continuous development of SLAM technology provides strong support for autonomous flight and mission execution of UAVs in complex environments. With SLAM, drones are able to navigate autonomously in environments without GPS signals and build accurate maps of the environment. This not only broadens the application field of UAVs, but also lays the foundation for the development of intelligent unmanned systems in the future. With the improvement of computing power and the optimization of algorithms, the application of SLAM technology in UAVs will become more popular and mature.

3. KEY APPLICATION SCENARIOS

3.1. Military Use

3.1.1. Reconnaissance and Surveillance

Unmanned aerial vehicle (UAV) reconnaissance aircraft refers to unmanned aircraft specifically used for aerial reconnaissance. In the 60s of the last centuries, unmanned reconnaissance aircraft were first used on the battlefield. In the Viet Nam War, in order to reduce the risk of pilots being captured and casualties, the US military used UAVs for reconnaissance missions, which greatly reduced the loss rate of fighters and the casualty rate of pilots, which shows that unmanned reconnaissance aircraft have played an irreplaceable role in both wartime aviation intelligence reconnaissance and peacetime border supervision and search and rescue missions.

Reconnaissance UAVs are mainly long-endurance UAVs, and the United States RQ-1A Predator has a battery life of more than 40 hours, and is equipped with various advanced sensors to achieve all-weather, all-weather reconnaissance and remote information transmission. The Global Hawk unmanned reconnaissance aircraft can fly from United States to any country in the world for reconnaissance missions, and can also conduct continuous reconnaissance and surveillance for up to 24 hours over targets 5,500 km away from the base. The aircraft is equipped with three types of reconnaissance equipment, namely synthetic aperture radar, infrared detectors, and television cameras, which can collect all-weather, all-day, and high-resolution aerial intelligence under complex conditions, and use communication equipment to transmit intelligence back to the operational command center, providing intelligence support for operational commanders to make decisions and assess battle damage[4].

3.1.2. Combat and Support

At present, UAVs have a very wide range of applications in the military, and as an important part of military operations, they play an immeasurable support advantage in various fields of operations with their strong combat capabilities, good fighter performance, low operation and maintenance costs, and small combat losses[5].

UAVs have taken on all kinds of tasks that are incapable or unsuitable for human pilots to complete with high danger and high damage, and have supported various fields such as land, sea and air operations in the Russian-Ukrainian war and have achieved good results.

3.2. Civil Sector

3.2.1. Logistics and Distribution

The logistics drone is equipped with a GPS automatic navigation system, a GPS receiver, various sensors and a wireless signal transmitter and receiver. The logistics drone has a variety of flight modes such as GPS automatic navigation, fixed-point levitation, and manual control, and integrates a variety of high-precision sensors and advanced control algorithms such as three-axis accelerometer, three-axis gyroscope, magnetometer, barometric altimeter, etc. At the same time, it is equipped with a black box to record status information, and also has a runaway protection function, when the drone enters the runaway state, it will automatically maintain accurate hovering, and the runaway timeout will fly to the nearest express distribution point. The logistics drone transmits data with the dispatch center through 4G/5G network or radio communication remote sensing technology, sends geographic coordinates and status information to the dispatch center in real time, receives instructions sent by the dispatch center, flies in GPS automatic navigation mode after receiving the destination coordinates, and lands with precision landing technology after arriving at the destination

3.2.2. Agricultural Testing

Agricultural testing can be macroscopically divided into soil management, crop nutrition testing, crop yield prediction, and crop pest control.

Soil detection: can be divided into soil moisture detection and soil nutrient detection, the use of drones equipped with professional testing equipment, can be a large-scale, continuous detection of soil conditions, through the analysis of the obtained detection information, and then further modeling and analysis, to obtain soil moisture and nutrient information, and soil changes over the years of development, for the subsequent planting and crop selection to improve a certain basis.

Crop nutrition detection: UAVs are equipped with professional testing equipment, which can obtain the nutrient deficiency of crops in different regions and at different times to achieve precise fertilization. The image information of crops is obtained by using unmanned aerial vehicles (UAVs) equipped with multi-spectral cameras, and the nitrogen content in the growth process of crops is determined through analysis and research, and fertilization is determined[3].

Crop yield forecasting: The use of UAVs equipped with relevant testing equipment can break through the limitations of traditional estimation methods, and can work in a wide range and with high precision, saving time and high estimation accuracy. ZHAO ET AL. USED THE UAV HYPERSPECTRAL DATA OF SOYBEAN TO CONSTRUCT A PARTIAL LEAST SQUARES REGRESSION MODEL FOR PREDICTING YIELD WITH AN ACCURACY OF 0.8117, WHICH VERIFIED THE FEASIBILITY OF THE TECHNOLOGY IN SOYBEAN YIELD ESTIMATION[3].

Crop pest control: The application of UAV in crop pest control is mainly for the timely detection of pests and diseases, and on the other hand, for the treatment of pests and diseases, mainly through spraying pesticides.

The equipment used is a hand-held hyperspectral instrument and a low-altitude remote sensing system, which determines the spectral reflectance of the canopy of wheat powdery mildew with different degrees of damage, and the low-altitude remote sensing system used can monitor wheat powdery mildew in a non-destructive, rapid and large-scale manner, which greatly improves the efficiency.

4. CONCLUSION

Unmanned aerial vehicle (UAV) autonomous decision-making technology has made significant progress in recent years, the emergence of various sensors and the improvement of accuracy, so that the UAV autonomous decision-making system has more accurate data input, the application of data processing methods has enhanced the reliability of UAV autonomous decision-making, and greatly increased the application scenarios of UAVs. From military reconnaissance and surveillance, strike and support, to logistics and distribution in civilian scenarios, and agricultural testing, with the continuous maturity of technology, UAVs will have a wider range of application scenarios in the future.

The autonomous decision-making system of UAVs is now gradually maturing at the hardware and data processing levels, and more and more scenarios are gradually replacing the traditional methods.

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