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REVIEW ARTICLE

Task offloading and trajectory control techniques in unmanned aerial vehicles with internet of things – An exhaustive review

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Abstract

Objectives: This article reviews and provides an exhaustive examination of task offloading and trajectory control techniques in unmanned aerial vehicles (UAVs) integrated with internet of things (IoT), highlighting their significance and impact on the UAV ecosystem. The paper begins by introducing the fundamental concepts of UAVs, IoT, and their integration, emphasizing the potential benefits and challenges of this union. Subsequently, it delves into an extensive exploration of task offloading, a critical aspect that optimizes UAV operations by distributing tasks between the UAV and edge/cloud computing resources. Various task offloading strategies, including computation offloading, data offloading, and control offloading, is discussed in detail, elucidating their role in optimizing resource utilization, energy efficiency, and real-time decision-making in UAVs.

Methods: The review comprehensively covers trajectory control techniques, which are essential for ensuring UAVs can navigate through dynamic environments safely and efficiently. This study outlines the use of IoT technologies, such as GPS, sensors, and communication networks, to enable precise trajectory planning, obstacle avoidance, and adaptive path adjustments. It also discusses the integration of machine learning and AI algorithms for autonomous UAV navigation, taking into account environmental factors, mission objectives, and real-time data from IoT sources. The paper further discusses the challenges and potential security concerns associated with IoT integration in UAVs, as well as the emerging trends and future prospects of this dynamic field. It emphasizes the need for standardized protocols and robust cybersecurity measures to ensure the reliability and safety of UAV-IoT systems.

Findings: This exhaustive review offers a comprehensive understanding of the synergistic relationship between UAVs and IoT, shedding light on the task offloading and trajectory control techniques that empower these autonomous aerial vehicles. By leveraging IoT technologies, UAVs are poised to continue transforming industries and driving innovation in ways previously unimaginable, making this interdisciplinary field an area of great promise and significance.

Keywords: Unmanned aerial vehicles, Task offloading, Trajectory control, Internet of Things.

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Introduction

Technological and scientific advances in recent years have led to significant changes in all branches of human knowledge. In the military environment, these changes provoked an evolution in the concept of defense. In addition to the use of all available technological means, there was a great concern, on the part of the United States and its allies, to reduce the number of losses of human lives on both sides of the war, mainly of the Arab civilian population,

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and with this to reduce negative repercussions on world public opinion. An example of this fact is the massive use of Tomahawk cruise missiles to carry out missions to destroy enemy targets. In addition, there was the large-scale use of unmanned aircraft for typical reconnaissance and espionage missions in areas of potential risk to allied pilots.

The use of unmanned aircraft and cruise-type missiles is of such importance that it is considered a strategic issue for countries that have this technology. So much so that this subject is currently the focus of advanced studies and research by the world scientific community. However, scientific research carried out in Brazil in this area is still in its embryonic phase and the results in the country are still quite modest when compared to the state of the art of these technologies in developed countries. This fact is largely due to the resulting high costs, the small number of professionals who have the knowledge and the lack of political will in the current context of national defense.

Within this focus, it is now necessary to establish certain priorities to be followed by research and teaching bodies in order to reach, in the long term, a sufficient critical mass so that one can have the greatest probability of success in the development, and even even in the acquisition of autonomous systems for unmanned aircraft, allowing the inclusion of Brazil in the universe of nations that have this technology of high strategic value.

The great success of cruise-type missiles and unmanned aircraft reflects the high degree of evolution in control, guidance and navigation techniques. The scientific community has been developing increasing efforts in this area. Recently, more attention has been paid to the problem of intelligent control, especially with advances in artificial intelligence technology, such as rule-based systems, fuzzy logic, and research in neural networks, which provide great evolutionary leaps in planning and management tasks mission. A great deal of effort has gone into making unmanned aircraft more capable and with less need for detailed user instructions. However, the lowest level of control, which corresponds to attitude control, is fundamentally necessary for unmanned aircraft, no matter how intelligent these vehicles may be.

Dynamic Operational Environments

Dynamic operational environments present characteristics that vary constantly and, for this reason, become difficult to control. Organisms immersed in these environments may have adaptation as an essential characteristic for their survival, i.e., the ability of an organism to alter its own behavior may prove crucial for it to modify its way of acting in the face of adversity. In other words, every time an environment changes, the organism present in it must be able to adapt to such changes.

The need for adaptation is an increasingly necessary reality in the design of new systems (Krupitzer *et al.*, 2015, Kavitha *et al.*, 2023). It is desirable that the system itself be able to adjust itself through the management of its resources, or at least have the ability to be adjusted. Adaptation is a factor that requires the ability to change the configurations of a system, i.e., adaptation has reconfiguration as a requirement. For a system to be adaptive and able to achieve management control, it first needs to be reconfigurable.

The reconfigurability of a system is associated with how much the characteristics of a system can change, i.e., how flexible its configurations are. Any system that has the ability to reversibly change state is considered a reconfigurable system (Lyke *et al.*, 2015). In this sense, digital systems (e.g., personal computers) can be considered reconfigurable systems, as they have the ability to return to their original state. Likewise, a random access memory (RAM) card, whose bits change state to store different types of information, is also characterized as a reconfigurable system. Systems of this type can present different levels of complexity. A reconfigurable system can be as simple as a digital clock or as complex as a network composed of hundreds of computers, where the interconnection multiplies the severity of the system as a whole. In addition, such systems may have associated knowledge that involves different disciplines and techniques, such as reconfigurable matter and digital and analog electronic systems (Lyke *et al.*, 2015).

Non-reconfigurable systems, in turn, are not necessarily inferior in all respects when compared to reconfigurable systems. The latter may present loss of performance due to overload in subsystem control, increased design complexity and reduced reliability (Lyke *et al.*, 2015). Furthermore, the mere fact that a system is able to modify itself does not make it more capable of performing a task, nor is it a guarantee of greater efficiency. In this context, the uses that a system can make through its possible configurations is directly associated with its adaptability.

In this way, adaptability can be understood as the ability of a system to explore and manage its configuration domains and, thus, use them with a certain objective (Salehie & Tahvildari, 2009). Although reconfigurability and adaptability are terms with similar meanings, there is a difference between them. While reconfigurability is related to the flexibility of a given system, adaptability is related to the uses that can be made of that flexibility.

When a system has the ability to change in response to an operating environment, it is called self-adaptive (Krupitzer *et al.*, 2015). Being, here, an operational environment is defined as any object observable by the system (Salehie & Tahvildari, 2009). Self-adaptive systems are related to self-management characteristics, such as self-configuration, self-healing, self-optimization and self-protection, i.e., the area of adaptive systems studies characteristics that a system may or may not have. For example, a router can optimize packet transfer by modifying its internal settings (self-optimization), or a backup technique present on a computer's hard disk can recover files after some type of failure (self-healing).

These systems may have advantages in terms of user comfort and operational efficiency. Self-adaptive systems present increasingly desired characteristics, since they are capable of automatically adjusting their settings, i.e., they are capable not only of executing a task but also of modifying its internal parameters while executing it (Krupitzer *et al.*, 2015). A computer capable of entering a power-saving mode when idle is more suitable than a computer that does not. As well as a hybrid aircraft capable of modifying the structure of its wings and rotors to perform vertical flights or horizontal flights where it is most convenient (Heredia *et al.*, 2012, Gao *et al.*, 2018).

Self-adaptive systems can be compared to autonomous systems, considering self-adaptation as a way of providing autonomy to the system. However, while the first is related to the characteristics that a system has, the second is associated with the level of dependence on human operators to function correctly (Krupitzer *et al.*, 2015), SAE International]. Autonomy can then be understood as a scale, in which the lowest level is composed of systems completely dependent on human beings and the highest level is composed of completely independent systems.

A classification of dependent/independent systems can actually express decision-making imposed in specific environments. For example, the J3016 standard, published by SAE International, proposes a scale with 6 levels of autonomy for on-road cars, as follows:

Level 0

The driver is fully responsible for managing all subsystems of the vehicle, such as the accelerator, steering and brake. The system can only assist the driver with momentary warnings and assistance.

Level 1

The system helps the driver with the management of one of the car's subsystems, such as activating the brake or accelerator, whenever necessary.

Level 2

The vehicle system is capable of assisting the driver with more than one subsystem at the same time, such as applying the brakes and steering the car so that it does not leave the road.

Level 3

The system, under specific conditions, is able to manage all its subsystems without needing a human driver. However, whenever the conditions are not satisfied, the control is transferred to the driver, which makes it a necessary condition to operate the vehicle.

Level 4

The system is able to operate in certain environments without depending on a driver, i.e., vehicle control is no longer transferred to the driver. In this case, all instruments controlled by the driver, such as the steering wheel and pedals, become unnecessary.

Level 5

There are no more environment restrictions for system operation. At this level, as well as at level 4, the vehicle is only driven by the driver if he decides to do so.

Autonomous systems can present numerous advantages in relation to the reliability of task execution or even in timely decision-making. Systems of this nature can integrate the human/machine interface in the search for better safety, economy and well-being conditions. A system with a high level of autonomy is desirable not only for cars but for a wide range of applications (Corke *et al.*, 2011). However, the development of an autonomous system is far from being a simple task due to factors that are related to the system itself. When it is dynamic, the variables involved add up and increase the complexity of the control, requiring a greater capacity of the system as a whole.

In general, mobile autonomous systems, whether land, water or air, must be able to travel a trajectory to perform their mission (Corke *et al.*, 2011)]. Thus, they must be assisted by peripheral mechanisms in order to receive specific information for proper decision-making. For this, such systems must be able, through sensors designed for these purposes, to navigate safely through unknown environments.

Unmanned aerial vehicles (UAVs) have been widely studied in recent years, considering the diffusion of their applications in different areas. Also known as drones, UAVs benefit from the absence of a pilot on board, which allows them to be used in difficult-to-access environments. In addition, they dispense with a control cabin and the equipment contained therein, making them more compact and lighter. Despite not being a recent invention (Nonami, 2007), it was only in the last few decades that UAVs became popular and began to draw attention for their potential use in various types of applications (Otto *et al.*, 2018).

In 2018, for example, a UAV was used for the first time to rescue two drowning individuals off the coast of Australia (Šašak *et al.*, 2019). And, in 2019, also for the first time in history, a UAV was used to transport organs between two hospitals. Applications even extend to other areas, such as monitoring physical infrastructure, such as electricity towers, roads, oil and gas pipelines, monitoring land use, and transporting goods (Otto *et al.*, 2018).

Task Offloading in UAV

Task offloading refers to the process of transferring tasks from a mobile device, such as a UAV, to a remote cloud server or another device in the network. In UAV operations, task offloading can be used to improve mission efficiency, conserve energy, and reduce latency.

There are several types of tasks that can be offloaded from a UAV, such as image processing, data analysis, and computation-intensive tasks. By offloading these tasks to a more powerful server, UAVs can complete complex tasks more quickly and accurately than they would be able to do on their own. Additionally, by offloading tasks to a remote server, UAVs can conserve battery life and extend their operational time.

There are several factors to consider when implementing task offloading in UAV operations. These include:

Network connectivity

The quality of the network connection between the UAV and the remote server is a critical factor in task offloading. Poor network connectivity can result in delays, increased latency, and reduced efficiency.

Task characteristics

The characteristics of the task being offloaded, such as the computation requirements and the amount of data to be transferred, should be taken into account when deciding whether to offload the task or perform it locally on the UAV.

Energy consumption

Offloading tasks can reduce the energy consumption of the UAV, but the energy required to transfer data to and from the remote server should also be taken into account.

Security

Task offloading involves transferring sensitive data from the UAV to a remote server, so security protocols must be in place to protect the data from unauthorized access.

Overall, task offloading can significantly enhance the capabilities of UAVs by enabling them to perform complex tasks more efficiently and effectively. By taking into account factors such as network connectivity, task characteristics, energy consumption, and security, UAV operators can optimize their task-offloading decisions and complete their missions successfully.

Task Offloading in UAV with IoT

Task offloading is a technique in which a task is divided into smaller subtasks, and these subtasks are assigned to different computing resources for execution. The main purpose of task offloading is to improve the performance of the system by reducing the processing time and resource consumption. UAVs and the IoT can be used together to implement task offloading.

UAVs can act as mobile edge computing devices, and they can fly to different locations to perform various tasks. These tasks can range from monitoring and surveillance to delivery of goods and services. The IoT can provide the necessary connectivity and infrastructure to support the task offloading process. IoT devices can be used to gather data from sensors and transmit it to the UAVs for processing.

To implement task offloading in UAV with IoT, the following steps can be taken:

- *Identify the tasks that need to be offloaded*: Identify the tasks that can be offloaded from the UAV to IoT devices. These tasks should be computationally intensive and require a significant amount of processing power.
- *Select the appropriate IoT devices*: Select the appropriate IoT devices that can be used for offloading the tasks. These devices should have the necessary processing power and connectivity to communicate with the UAV.
- *Establish a communication network*: Establish a communication network between the UAV and the IoT devices. This network should be reliable and secure to ensure that the data is transmitted securely.
- *Offload the tasks*: Offload the identified tasks to the selected IoT devices. The UAV should monitor the progress of the tasks and retrieve the results once the tasks are completed.
- *Analyze the results*: Analyze the results obtained from the offloaded tasks and make any necessary adjustments to the system.

Task offloading in UAV with IoT can significantly improve the performance of the system by reducing the processing time and resource consumption. This technique can be used in various applications such as surveillance, monitoring, and delivery of goods and services.

Navigation and Position Estimation

One of the features that make UAVs useful in many applications is the wide use of sensors. Different types of sensors can be used for different purposes. In closed environments, there may be a need to perform 3D mapping of the environment, object detection and obstacle avoidance. For this, ultrasound sensors, laser and stereo and monocular cameras can be used (Al-Kaff *et al.*, 2018).

The research area that studies the use of imaging sensors, such as photographic cameras, to scan and perceive environments is called computational vision. In this area, the image is the input data through which real-world features are extracted (Hwang & Narendra, 1992). In UAVs, its applications include not only position estimation but also 3D modeling, surveillance and reconnaissance, inspection of structures, and obstacle avoidance, among others (Al-Kaff *et al.*, 2018, Kanellakis & Nikolakopoulos, 2017). That way, it can be said that the use of computer vision in UAVs brings significant contributions to increase their capabilities. For example, using the concept of visual servo control, vertical takeoff and landing on a target, navigation of high voltage lines, stabilization in a circular orbit and autonomous landing on a mobile platform were proposed (Al-Kaff *et al.*, 2018).

However, regardless of the application, it is imperative that drones are able to navigate accurately through the environment in which they are immersed. Thus, a piece that plays a fundamental role is the navigation system onboard the aircraft. In robotics, navigation and position are terms that have different meanings. The first encompasses not only the science of a body's position but also the planning and management of the route taken by it, avoiding possible obstacles and collisions. The second explores the estimations of the position and velocity of the body in relation to a point, or plane, of reference. Thus, it can be said that position estimation is a subset of navigation (Groves, 2013).

Initially, UAVs were equipped with sensors for position and orientation estimation, in which GPS and INS were generally used (Kanellakis & Nikolakopoulos, 2017) As these systems are susceptible to errors, data fusion has become a promising alternative to increase accuracy and increase reliability, in addition to extending the possibilities for alternative systems, such as those based on imaging sensors. In this sense, different position estimation approaches based on computer vision techniques have been proposed (Balamurugan *et al.*, 2016, Al-Kaff *et al.*, 2018, Kanellakis & Nikolakopoulos, 2017). Position estimation techniques, in which approaches based on computer vision are contained, can be divided into two large groups (Groves, 2013):

Estimated navigation

The original expression is dead reckoning, probably derived from deduced reckoning, and can be defined as calculating the current position of a body based on its advance from a previous position. Therefore, it can be said that, in estimated navigation, the relative position, and not absolute, of a vehicle is obtained. This group includes position estimation techniques that seek to calculate the speed and orientation performed by the body, such as odometry, for example, in which the number of rotations performed by the wheel of a vehicle is counted and multiplied by its diameter. When computer vision techniques are used to obtain the relative movement of a body, the position estimation system is also called visual odometry. The biggest disadvantage of the techniques in this group is the rapid increase in the inaccuracy of the estimated position due to the errors that accumulate with each new movement performed by the vehicle.

Absolute positioning or fixed positioning

This category encompasses systems for estimating the position in which the calculation is performed based on the identification of information external to the body. Such information can be artificial signs or natural structures present in the environment. Furthermore, it may be necessary to compare this information with pre-existing information saved in a database to infer the position of the vehicle. In the maritime area, for example, the so-called visual navigation is defined as the estimation of the position of a vessel from the visual recognition of structures present on the earth's coast (Yan *et al.*, 2010). Despite not presenting an accumulation of partial errors in the calculation of the position, as with dead reckoning, this group depends on previous information about the environment so that it is possible to recognize it. Furthermore, external information may be purposely modified or mistakenly recognized when compared with pre-existing internal information, leading to a false estimation of the vehicle's position.

When external instruments are not available to help a vehicle estimate its position, the two groups, here called estimated navigation and fixed positioning, can be understood as subgroups of another larger group, called simultaneous localization and mapping (SLAM), which, in free translation, it means simultaneous localization and mapping (Cadena *et al.*, 2016). As the name implies, the idea is to simultaneously estimate the position and map the environment in which the vehicle is inserted. In SLAM, a vehicle that does not have access to previous information about an environment can start its exploration using dead reckoning techniques while building a map collecting information from the environment. When the vehicle returns to a previously visited location, the new information collected can be compared to the previously created map using a fixed positioning technique. In cases where a location is revisited, so-called loop closure occurs, a key feature of SLAM. If circuits are not closed, SLAM is reduced to estimated navigation. And if a map of the environment is available before starting navigation, estimated navigation becomes an auxiliary tool to make the system more robust and less susceptible to failures. As the closing of circuits occurs by recognizing a part of the environment when revisited by the vehicle, it can also be called region recognition (Cadena *et al.*, 2016).

Autonomous Control Architecture

Unmanned vehicles can be classified according to their level of autonomy, that is, according to their ability to react to the environment, into three classes:

- Autonomous
- semi-autonomous
- Remote controlled

Autonomous vehicles must be able to react to their environment in an intelligent way. This intelligence can be attached to the vehicle or can be remotely communicated through a free space link.

In any case, the area of basic interest is flight control and its various relative functions that must be performed by a UAV in order to fulfill its mission with favorable results. The main functions are as follows:

- Navigation;
- Guiding;
- Stability and control;
- Communications;
- Remote intelligence;
- Fault tolerance.

Navigation will have to be carried out under subsonic conditions with high maneuverability or even in supersonic conditions. The on-board computer and sensors will have to allow the UAV to reach the point in space with sufficient precision in the right time to effectively fulfill the mission imposed on it. For this, the inertial navigation unit must include accelerometers and gyroscopes to provide accelerations and angular velocities of its three orthogonal axes, which together with a GPS receiver will provide information to the aircraft control and stability system. Fundamental to the flight control system is the development of control laws, which can either be derived from classical control theory or modern control, non-linear control theory or knowledge-based systems.

The UAV must be able to receive and send data that includes current position, mission specifications, area engagement coordinates and mission reconfiguration. The intelligence of this aircraft must be robust in order to allow the continuation of the mission until even under certain failures of onboard systems. Component reliability is the first level of security that enables the mission to be accomplished, in addition, robustness is configured by redundancy, self-repair and resource reallocation. Only with the deployment of this extra level of intelligence in the onboard computers of the aircraft will it be possible for a mission to be accomplished without human intervention. Under malfunction or damage situations, self-healing systems will have to be able to reallocate their priority functions to redundant subsystems or alternative sources. Reallocating critical tasks (eg attitude control) to redundant resources (reserve processors) will allow the mission to continue with minimal performance degradation. On the other hand, if redundant resources are not available, critical tasks may overtake less critical ones, even if there is greater performance degradation, which may still result in mission success.

In order to reach this level of intelligence, a whole control architecture is necessary that allows the accomplishment of these tasks. The systems architecture of most intelligent autonomous vehicles is hierarchically or functionally based, or it can be defined parallel or behaviorally. Hierarchical forms often have three or more layers of abstraction. In this type of approach there is a hierarchical decomposition of the main problem into smaller and easier problems to be solved (Chandler & Pachter, 1998).

The hierarchical architecture is basically composed of four layers, as shown in Figure 1.

At the highest layer of the control architecture, mission planning/management works, which operates according to global mission specifications, producing secondary objectives or tasks to achieve a certain objective.

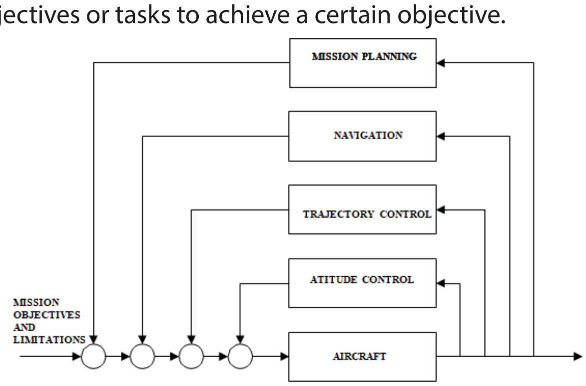

Figure 1: Control architecture based on hierarchical decomposition.

In the layer immediately below is the local navigation module, which uses a detailed map to evaluate an obstacle-free trajectory, defining where the aircraft should go. The information about altitude and orientation determined in the navigation module are essential for the trajectory control module, as they allow the determination of the error in relation to the desired references. Typically, these references are specified via waypoints (points with desired altitude and orientation for the vehicle).

Optimal flight paths for military operations must take into account several parameters including aircraft limitations and minimization of exposure to enemy threats. Thus, trajectories are functions of mission requirements (time of arrival, point of arrival, etc.), aircraft performance limitations (amount of fuel, power limits, etc.) and hostile environment. With that, it is necessary to make a previous optimization of trajectories, using cost functions that include effects of time, risks and final position (Vian *et al.*, 1988).

Path planning for autonomous vehicles is a fundamental problem and extensive research efforts have been made toward this subject (Latombe, 1991, Hwan & Narendra, 1992). One of the most used first methods is the potential field approach (Sundarrajan *et al.*, 2023). The main feature of this method is its scalar potential field that represents both the repulsive force for obstacles and the attractive force for targets.

The advent of the global positioning system (GPS) provided a powerful tool to obtain accurate navigation data that provides accurate tracking of pre-established inertial trajectories (Sundarrajan *et al.*, 2023). Traditionally, guidance and navigation systems are designed separately, using well-established design methods for control and simple strategies such as line of sight (LOS) for guidance. (Kaminer, 1998) contains interesting studies on this topic. During the design phase, the control system is usually designed with a bandwidth large enough to follow the commands that are expected from the guidance system. In a new methodology is proposed in which the guidance systems and the control system are designed simultaneously.

At the next level, the task of maintaining the desired altitude and heading is the responsibility of trajectory control. This module has the function of processing trajectory data produced by the navigation system and comparing them with the aircraft data, generating the corresponding error signals and transforming them into desired altitude and direction commands.

Basically, autonomous vehicle guidance systems are of two types (Harris & Charnley, 1992):

- Continuous trajectory (TC) type, which controls the vehicle to follow a continuous line;
- Point-to-point (PP) method, which controls the vehicle to follow an intermediate objective point.

The main advantage of the TC type over the PP method is that the aircraft establishes a current point on the trajectory through smooth transitions, that is, it avoids large transitions arising from switching and large associated accelerations from one trajectory segment to another.

The innermost level of architecture based on hierarchical decomposition comprises attitude control and is responsible for optimally maintaining the stability of the aircraft through the action of the control surfaces.

Although each of these levels is important in the overall system operation, this work will focus more extensively on the layer corresponding to the vehicle attitude control, in order to study the design approach of robust controllers with gain tabulation.

(Harris & Charnley, 1992) reports that, for a given control architecture to enable the fulfillment of the intended missions, it is of fundamental importance that the autonomous vehicle is capable of:

- Sensing your environment as well as your internal states;
- Interpret this sensory information to refine your state vector.

UAVs use a wide range of sensors, including video, electro-optical, infrared, ultrasonic, laser, radio-frequency, inertial GPS, etc. Whatever sensors are used, it is essential to accurately model the sensor and its noise and to know its capabilities as well as its limitations for the required measurement tasks.

Trajectory Design Techniques in UAV

Trajectory design is a critical aspect of UAV operation, as it involves planning the path and speed of the UAV during its mission. There are several trajectory design techniques that can be employed to optimize UAV operations, including:

Waypoint-based trajectory design

This technique involves defining a series of waypoints that the UAV must visit during its mission. The trajectory between waypoints can be straight or curved, and the speed of the UAV can be adjusted at each waypoint to optimize mission efficiency.

Grid-based trajectory design

This technique involves dividing the mission area into a grid and defining the UAV's trajectory as a series of straight lines between grid points. The UAV's speed can be adjusted at each grid point to optimize mission efficiency.

Coverage-based trajectory design

This technique involves designing the UAV's trajectory to cover a specific area, such as a crop field or a search area. The trajectory can be optimized to maximize coverage while minimizing energy consumption.

Optimization-based trajectory design

This technique involves using optimization algorithms to determine the optimal trajectory for the UAV based on specific mission objectives, such as minimizing energy consumption, maximizing coverage, or avoiding obstacles.

Machine learning-based trajectory design

This technique involves training machine learning algorithms on data from past UAV operations to predict optimal trajectories for future missions. The algorithms can take into account factors such as weather conditions, terrain, and mission objectives.

Adaptive trajectory design

This technique involves designing the UAV's trajectory to adapt to changing environmental conditions or mission objectives in real time. For example, if the UAV encounters unexpected obstacles during its mission, it can modify its trajectory to avoid danger and continue its operation safely.

Overall, the selection of a trajectory design technique will depend on the specific mission objectives and environmental conditions. By utilizing one or a combination of these techniques, UAVs can optimize their flight paths, conserve energy, and complete their missions successfully.

Conclusion

In conclusion, task offloading and trajectory control techniques are crucial for improving the performance of UAV systems. Task offloading techniques can reduce the computational load on the UAV by offloading computationally intensive tasks to IoT devices, while trajectory control techniques can optimize the UAV's trajectory to minimize energy consumption and improve its overall performance.

The combination of task offloading and trajectory control techniques in UAV with IoT has shown promising results in various applications, such as surveillance, monitoring, and delivery of goods and services. However, there are still several challenges that need to be addressed, such as ensuring the security and reliability of the communication network between the UAV and the IoT devices, and developing efficient algorithms for task offloading and trajectory control.

Overall, the development and integration of task offloading and trajectory control techniques in UAV with IoT will continue to be an important research area in the coming years, as the demand for efficient and reliable UAV systems continues to grow in various fields.

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