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Comprehensive Review on UAV Efficient Path Planning Techniques for Optimized Applications

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Abstract

This literature review article compiles works that describe the use of bio-inspired algorithms in Unmanned Aerial Vehicle (UAV) motion planning. This review demonstrates the usefulness of the various frameworks by presenting the contributions and limits of each article. The optimization method also decreases the amount of inaccuracy in the system's convergence. Furthermore, this study discusses the assessment procedures and draws attention to the novelties and limitations of the explored methods. The paper wraps up with a detailed examination of the current difficulties and potential future research directions. This research will aid scholars in comprehending the state-of-the-art efforts made in UAV motion planning using a variety of optimization strategies.

Keywords: Path planning, Unmanned Aerial Vehicle (UAV); motion planning, drone, 3D reconstruction

1. Introduction

Communications, surveillance, photogrammetry, crisis management, and structural monitoring are just a few of the many fields that have benefited from the widespread use of Unmanned Aerial Vehicles (UAVs) during the last several decades [1]. UAVs and other intelligent vehicles have also made great strides toward completely autonomous operation in safe, confined spaces [2]. For vehicles to navigate complicated areas without human intervention, route planning remains one of the fundamental difficulties that must be solved [3]. Creating a viable route from a given starting point to a desired destination in real time is, in fact, one of the most difficult tasks [4]. Multiple algorithms are being developed and refined to determine the most efficient and cost-effective method of completing a task [5].

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3D reconstruction of large-scale complex objects with a high degree of detail (for example, cultural heritage documentation), an inspection of building sites, and Building Information Modeling (BIM), to mention a few, rely heavily on comprehensive datasets that fulfil the prescribed quality requirements. There have been several recent advancements in the sensor and platform industries that allow for the capture of high-quality pictures and point clouds. UAVs in particular are often utilised as platforms to transport sensors that collect data. To be more precise, multi-copters (referred to as UAVs for short) are quick, can acquire data autonomously, can fly at varied altitudes, and can go practically anywhere in the sky. Therefore, 3D reconstruction using UAVs is still a great technique to learn about the significance and form of both natural and artificial things. Figure 1 shows some of the specific future trend application drones.

Figure 1. Future trend drones

1.1 Methodology for Route Development

The optimum route, probabilistic completeness, and computing time of several UAV path planning techniques are compared in this review study. These characteristics are crucial for algorithms that plot out routes. The optimality property of a search algorithm ensures that it will find the best result. Probabilistic completeness is a feature of search algorithms that guarantees they will find a solution if one exists. Many strategies exist for determining the best route to take, including graph search, path planning based on random samples, and strategies drawn from biology [6-9].

A global route planning engine that makes use of historical environmental data may be used to generate a path plan. When the distance between the origin and the destination is short, regional route planning is the best option. Based on the collected data about the surroundings, global path planning may determine the most efficient and effective route to take.

The first step in creating an ecological map is collecting data of the surrounding ecosystem, followed by preliminary route design. Since it is dependent on global environmental data, global route planning cannot address issues that arise in real time. Large amount of computing power is required for international route planning. On the other hand, global route planning falls under the category of static programming [9 - 13], whereas local path planning is a part of the dynamic programming family.

The topic of route planning has generated a sizable body of published work. Currently, the most common methods for doing route planning are graph-based, population-based, and distributed.

1.2 Motivation

While UAVs have been the subject of much research, there are still several obstacles in their way. Choosing UAVs with mission-appropriate route planning is one of the biggest challenges faced by all researchers. Then, works have generated precise motion control and perfect route formation, as well as using sound navigation and communication methods to keep one step ahead of any hazards and prevent any untoward incidents. In addition to validating the product, concerns of regulation and the human-machine interaction must be addressed.

2. Related Works

The researchers Ali et al., [14] created a cluster-based approach that enabled cooperative movement and UAV swarm optimization. Greater convergence and longevity were also seen. Control and route planning using a hierarchical clustering technique was proposed by Shafiq et al. [15]. It rapidly determined the cheapest and most efficient route to take. For cooperative route planning, it provided the best possible global answer in the shortest possible time. Together with Duan [16], he analysed flying and landing concerns, and proposed a new PIO to fine-tune ADRC's settings. Liang et al., [18] devised a best landing path for micro-UAVs.

3. Intelligent Path Scheduling

There are a few works that provided video-based techniques for avoiding collisions. Both [17] and [10] tried to automate the process of generating drone trajectories, such as the photographs taken during the battle, so that the data collected from the drones could be utilized to create a high-resolution 3D model for use in collision avoidance software. The comparison of future intelligent path scheduling with traditional path planning is shown in figure 2. Methodologically, their primary approaches followed these steps:

- Estimating scene geometry,
- Planning camera trajectories,
- Executing the resulting trajectories.

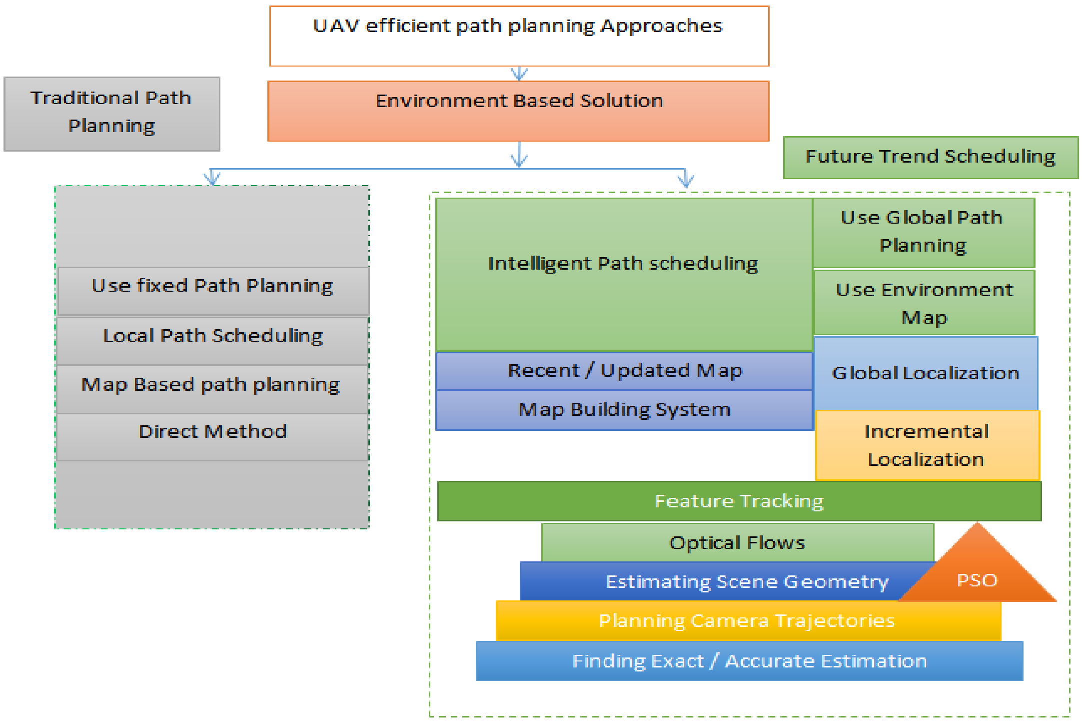

Figure 2. Future trend path scheduling Vs Traditional path planning

They then used the revolution to get extensive coverage of the incident. They also came up with an algorithm that takes in data about the scene's shape from many perspectives.

When these algorithms were combined, the robots were able to implement collision systems that allowed them to safely navigate around hazards.

3.1 Step by Step path planning through samples

Through the search inside configuration space, data from a collision detector is sampled and used to influence the next steps. To ensure that the configuration is legitimate and yields results that match the desired configuration, the route does a collision check to determine whether it is feasible or not. While the benefits of a random method to solving complicated problems are clear [19], since collision testing is only conducted when absolutely required, the algorithm is left in the dark as to whether the object even exists in the configuration space or not [20]. Detailed descriptions, applications, and enhancements to algorithms that use samples are being examined [21]. Sampling-based algorithms are more promising than graph-based ones in a complex and realistic situation due to their simplicity in representation and computation [6, 22]. Rapidly exploring Random Trees (RRT) and Probabilistic Road Mapping (PRM) are two popular sampling-based route planning techniques.

3.2 Artificial Neural Networks

An ANN is a technique that simulates biological brain networks. The structure of a biological brain network and the process by which it reacts to external stimuli have been abstracted to create a mathematical model. ANN has led to the creation of a wide variety of models, including the Hop Field Network, the ART Network, and the Kohonen Network [23-26]. In this concept, numerous basic processors (sometimes called neurons or nodes) are linked together to form a larger network. Its computational power is constrained by just two simple restrictions; processing units only receive signals at regular intervals and it communicates with one another through signals.

The ANN model combines data processing and storage, and it has great fault tolerance, the ability to train on its own, and the capacity for parallel distributed processing. Since ANN is so effective at handling parallel systems with many moving parts, it is often employed to address intractable issues in mission-critical programmes.

3.3 Particle Swarm Optimization (PSO) Algorithm

Particles in the N-dimensional space indicate each possible solution to the optimization issue. Direction and velocity of a particle are set by its fitness function and its speed. At their own pace, particles go in the direction of the best particle. Due to its low computational cost, high search speed, and limited number of tuning parameters, PSOs have found widespread usage in robot route planning. For mobile robots' worldwide journey planning, a PSO algorithm with assured convergence was developed. The approach was explained as ‘encoding’ the route between the initial and final locations as individual particles. The initial population was generated in a subset of the active zone that was segmented according to the locations of barriers, allowing a particle to seek for its best route inside a more constrained region.

3.3.1 Problems with Unmanned Aircraft Systems

Swarm intelligence was used in many approaches to solve the problem. Among these is a proposal, to dynamically deal with the duality of control made by the authors of [27]. The suggested plan centered on modifying thin-plate spline algorithms to reduce swarm formation distortion and find pathways around obstructions. Similarly, several authors have utilised this strategy to focus on intensive monitoring of certain types of obstructions.

3.3.2 Genetic algorithm approach

In 1975, American professor J. Holland introduced the concept of a Genetic Algorithm (GA). It is an intelligent search algorithm that uses an analogy to the process of biological evolution to zero down on the best possible answer. A genetically encoded starting population is the basis for GA, and this population may either be created at random or be chosen for its unique characteristics. Generalized adaptiveness makes use of commonplace procedures including selection, replication, crossing, and variation [28,29].

Due to the complexity of the 3D terrain's course, a multi-objective genetic algorithm-based planning strategy was proposed. This method evaluated the resulting route based on many criteria, including its overall length, its slope, and its level of security. Large-scale uniform initialization was used to ensure that the track does not get trapped in a loop. The austerity operator was then used to eliminate the iteration's circles.

3.4 Sparse A∗ Search

Many research suggested an enhanced version of the A algorithm, called the Sparse A Search (SAS) algorithm. In order to speed up the basic A* algorithm and solve more issues in less time for planning, the region and the nodes are confirmed by visibility. The amount of computing complexity is reduced, and the search efficiency is increased, using this approach.

It also has the ability to dynamically weigh the quality of the route against the amount of time it will take [25, 26]. Path planning in 3D settings is a popular application for SAS.

4. Comparative Observations

4.1 Synopsis of Skill in Route Planning

This research explores three graph search algorithms that may be used to discover the shortest route in planning, have acceptable performance, and can be used to carry out online real-time path finding. Due to its dependence on the number of nodes, Dijkstra's method is unsuitable for large and high-dimensional regions from a run-time perspective. A*, which was developed to fix Dijkstra's flaws, benefits from the heuristic approach. When a new circumstance arises, D* is put through a cycle of rapid-repair remedies. The results show that both the RRT and PRM algorithms work well for addressing high-dimensional route planning problems using the sampling-based technique. They are able to reach probabilistic completeness, but not in the most efficient way possible in terms of both computing time and route. Among the many types of biologically inspired algorithms, GA is the most directly influenced by evolutionary theory, while PSO and ACO take their cues from swarm intelligence. Therefore, GA is a viable option for swiftly locating answers in a large search area and receiving them in a short amount of time.

Table 1. Synopsis of Skill in Route Planning

Method	Effective Techniques	Optimal Path	Application	Overall Efficiency
ANN	Intelligent Path Scheduling	Yes	Solution of complex & optimal high dimensional dataset through shortest path	Greater
Particle Swarm Algorithm	Sampling Based Searching	Yes	Solution of complex high dimensional datasets	Good
Genetic Algorithm	Biological Search Based	No	Optimal Path selection in lower dimensional datasets	Moderate
Sparse A* Search	Graph Search Based	No	Find Shortest Path Arrangement	Fair

However, PSO's quick convergence speed becomes an issue as the environment grows more complex; it can still give route optimality and completeness, making it suited for problems with constantly changing landscapes and discovering many solutions. Finally, ACO works best for issues with a clear beginning and end point. It may provide a thorough strategy well-suited to problems calling for certain answers. Table 1 contains various methods for appropriate applications, summarizing the characteristics observed for each method, including optimum route, probabilistic completeness, and application domains.

4.2 Effective Route Planning using PSO

UAVs are used as aerial gateways to gather uplink data from ground IoT devices within the framework of the ever-growing and expansive IoT network. Since IoT devices are unable to send data over a great distance, using an aerial gateway may help cut down on energy consumption, but the UAV also has its own limitation in terms of battery capacity, which can cut down on flying duration. The UAV has to arrange its flight path in a manner that offers it the shortest route and reduces travel time so that it can observe all the necessary locations in a short amount of time.

4.3 Analysis and Forecasting

Existing algorithms are far from being the last word on perspective and route planning, and there is a lot of intriguing work to be done in this area. Current difficulties in perspective and route planning methods are discussed, pointing the way for further study.

Without any knowledge of the scene or object beforehand, model-free methods often use NBV to swiftly move in a path that reduces the model uncertainty. Though this works well for swiftly gaining an overview of a situation, their local search approach inside a non-linear goal function may get trapped in local minima. Therefore, it cannot ensure that the whole object, including all its intricacies, will be covered. Also, stereo or depth cameras are used in the majority of model-free approaches for 3D data gathering. The platform must move to a suitable distance from the target. While this method is doable for interior uses and smaller objects, it may be impractical for large-scale 3D restoration projects. However, the explore-and-exploit algorithms benefit from global improvements in coverage and accuracy of findings, if they are given prior knowledge of the general geometry, which in turn leads to better results and less bumpy pathways.

Unfortunately, most of the current explore-and-exploit methods do not allow for live input from the data collecting device; therefore, the calculated postures remain static. Consequently, given the existing computing capability of onboard processing units, it might be an attractive avenue for future research to refine the global design of the poses and update them locally depending on the input from the captured photographs. With the advent of ubiquitous cloud computing and lightning-fast data transport through technologies like 5G, this concept may finally become a practical reality. This might potentially serve as a stopover between two flying missions (exploration and exploitation), which normally need more than one visit to the location.

As with most engineering endeavours, comparing the project as intended with the actual state of the project might be a promising new approach. But even if everything goes according to plan, there are still a lot of additional factors that might change the result. Predicting the MAV's motion and state, the quality of the result may be challenging for a number of reasons, including hardware constraints, weather conditions, the complexity of the object, and the link between the sensor and the item.

Further, certain lower elements of the structures cannot be effectively recorded and recreated owing to safety considerations, such as the lowest controllable flying height. It can be said, the majority of current practices are optimized for calm circumstances and fail to account for the impact of wind and other environmental variables.

5. Conclusion and Future Plans

Some techniques for UAV route planning are provided in this study. The algorithm speaks about being placed in a certain category and identifies with its sources of inspiration. In addition, for the sake of clarity, the short procedures of each are summed up. Both the benefits and drawbacks of each algorithm are briefly discussed. This work compares several route planning algorithms with regards to their optimum path, probabilistic completeness, and computing time, and how well they do when applied to various scenarios. It is determined that different algorithms are suited to various route planning issues based on their individual characteristics. Even if the original or main algorithm lacks certain qualities, it may be possible to solve complicated issues by improving the algorithm and integrating it with additional approaches. PSO's rapid result connecting several sites is also shown.

When it comes to comparing and determining the best motion planning and optimization algorithms, the area is as deep as it is wide. However, more research and less exploitation of many obstacles and opportunities are required to deploy the numerous UAV systems in an acceptable manner. Because of this, several swarm-based intelligent optimization methodologies will be modelled for 3D-path planning strategies that are both accurate and efficient.

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