A survey of collision avoidance systems for autonomous unmanned aerial vehicle

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Abstract
The use of unmanned aerial vehicles (UAVs) for military and commercial purposes is becoming popular, and the domains of using UAVs is becoming more diverse. For these autonomous UAVs, collisions could occur in various scenarios, causing the falls and damages of UAVs. In this paper, we would like to discuss a collision avoidance system of an UAV. We survey the latest relevant papers and compare and analyze the proposed methodologies in these papers. We finally discuss the desirable collision avoidance system with various collision scenarios.

Keywords
unmanned aerial vehicles (UAVs), collision avoidance system, collision scenarios.

1. Introduction

The use of UAVs for military and commercial purposes is becoming popular, and research using UAVs is being conducted in various fields. In addition, there is an active movement to apply it to more diverse scenarios using unmanned aerial vehicles capable of autonomous flight. For these autonomous UAVs, safety is one of important quality attributors, because as the fall of the drone can lead to damage to life and property. This is a problem that must be overcome in the use of autonomous flying UAVs. In order to solve the problem, a collision avoidance system is a basic requirement that must be in place.

Prior to developing the collision avoidance system, we investigate and summarize the technologies and existing research articles related to the overall requirements of the system. For instance, Goerzen, et al. [1] investigated the motion planning algorithm of autonomous UAV. Yuncheng Lu, et al. [2] conducted a comprehensive investigation on vision-based UAV navigation. Shakhatreh, et al. [3] investigated UAV applications and key research challenges.

In this paper, we conduct a comprehensive literature survey and classify UAV collision avoidance technologies into six categories. The classification criteria are the algorithms, mathematics, sensors that are used for each method. These classifications cover 1) Geometric Approach, 2) Potential Field Approach, 3) Path Planning Approach, 4) Optimization-Based Approach, 5) Sampling-Based Approach and 6) Vision-Based Approach. After that, we compare and discuss the classified approaches.

This paper is organized as follows. Section 2 describes an overview of collision avoidance, Section 3 analyzes the 6 main categories of the Collision Avoidance Approach, and Section 4 discusses a desirable collision avoidance system along with various collision scenarios and describes future plans.

2. Collision Avoidance for autonomous flying UAVs

Collision avoidance is a critical component of the operation of autonomous flying UAVs. UAVs operate in environments with many potential obstacles, including other aircraft, buildings,

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power lines and trees. To avoid collisions, UAVs must be equipped with sensors, algorithms, and software that can detect and respond to obstacles in the environment.

2.1. Necessity of Autonomous Flight

Unmanned aerial vehicles (UAVs) require autonomous flight capabilities for several reasons:

Safety: Autonomous flying drones can improve the safety of UAVs by enabling them to avoid obstacles, navigate in adverse weather conditions, and respond to emergencies without human intervention. This can reduce the risk of an accident or collision, which is especially important in situations where the UAV is flying in limited visibility or high-risk conditions.

Efficiency: Autonomous flight systems can help UAVs operate more efficiently by optimizing flight paths, speeds and other parameters. This can help reduce fuel consumption, extend flight times and improve overall mission efficiency. UAVs can be made more cost-effective.

Complexity: Some UAV missions are too complex for human operators to manually control. Autonomous flight systems can handle the complexity of these missions, such as navigating complex urban environments or conducting coordinated search and rescue missions. This could reduce the need for human pilots or operators and reduce the amount of time and resources required for each mission.

Long-term missions: Autonomous flight capabilities allow them to navigate and make decisions without human intervention, allowing UAVs to fly for long periods of time. This allows UAVs to operate at greater distances and for longer periods of time, which is important for applications such as aerial surveying or environmental monitoring.

Scalability: Autonomous flight systems can help make UAV operations more scalable by allowing multiple UAVs to operate simultaneously on a mission. This makes UAVs more flexible and adaptable to different applications and environments.

Overall, autonomous flight capabilities are essential to enabling UAVs to operate safely, efficiently and effectively in a variety of applications. As such, research into autonomous flight systems continues to be an important development area in the field of UAVs.

2.2. Overview of Collison Avoidance

In the case of collision avoidance, the action of detecting obstacles is essential. In the case of obstacle detection, most detectors use a sensor. Various vision-based object detection techniques are being developed recently. In the case of collision avoidance, various scenarios may exist depending on the field of use of the autonomous flying drone or the environment. Based on the scenarios, an appropriate collision avoidance method could be selected.

Scenarios according to the usage environment of autonomous flying UAVs can be divided into two kinds: an accurate environment and an uncertain environment. For an accurate environment, we have information about the environment in advance. With the information we can create a map. However, in the case of an uncertain environment, there is no information about the environment. In the case, the UAV must obtain the environmental information through sensors during the operation of the UAV.

Also, depending on the movement of the obstacle, the obstacle can be divided into a static obstacle (e.g. buildings, trees, power poles, etc.) and a dynamic obstacle (e.g. birds, UAVs included in the group, unknown flying objects, etc.). The collision avoidance method can be different according to the movement of the obstacle.

3. Collison Avoidance Approach

3.1. Geometric Approach

The geometric approach determines the obstacle and the avoidable trajectory by calculating the geometric equation and the position, velocity, and distance of the obstacle. UAVs can exchange information to each other by using ADS-B (Automatic Dependent Surveillance-Broadcast). In the case, this approach can create a trajectory by using the exchanged information. However, this approach has a disadvantage in that communication noise exists and cooperation between UAVs is required. If UAVs do not use ADS-B, it is difficult to detect other UAVs as obstacles. This shortcoming can be overcome by using a vision sensor that can detect the position, speed, and distance of obstacles.

In the geometric approach, there is a collision cone method, and an arbitrary circle around the UAV and the tangent to the UAV are calculated.

If there is an obstacle between the two tangents, it is calculated that there is a possibility of collision, and the trajectory is corrected so that the obstacle is not located between the tangents. Gnanasekera, et al. [4] propose a time-optimal collision avoidance method using the modified collision cone and mathematically prove the temporal optimality.

3.2. Potential Field Approach

The potential field method uses the concepts of attractive potential and repulsive potential to construct a potential that repels UAV and obstacles and attracts them to the destination. This method has a disadvantage that the path can fall into the local minima, because the method creates an obstacle avoidance path along the slope of the potential. Also, if there is an obstacle near the destination, the destination may not be reached due to the repulsive potential of the obstacle. This method is difficult to use in a dynamic environment, because it requires a lot of computation and time. Various studies are being conducted to overcome these shortcomings. Wang, et al. [5] proposes the Memory-based Wall Following-Artificial Potential Field (MWF-APF) method, which is an effective real-time collision avoidance method even on platforms with low computing power. Zhao, et al. [6] proposed an improved artificial potential field (IAPF) method and effectively solved the problems of path oscillations and local minimums, which were existing problems.

3.3. Path Planning Approach

The path planning method creates a path using a graph shortest path search algorithm such as the Dijkstra algorithm and the A* algorithm. This method generates an optimal route by generating a grid-based map of known obstacles and static environments. With these characteristics, it is possible to find the optimal route to the destination while avoiding obstacles. However, the method has the disadvantage of being used only in a static environment with known obstacles. Recently, research on path planning for dynamic obstacles and their application to 3D space is being conducted. Han, et al. [7] reduced the computational complexity by modeling the interior 3D using grid optimization. And the Grid-optimized A* path planning (GO-APP) algorithm was proposed to solve the path planning quickly and efficiently.

3.4. Optimization-Based approach

The optimization-based method is dependent on the obstacle avoidance trajectory using geometric information and aims to generate an optimal obstacle avoidance trajectory based on uncertain information. These algorithms include ant-inspired algorithms, genetic algorithms, gradient descent methods, particle swarm optimization, and greedy methods.

3.5. Sampling-Based Approach

A representative method of sampling-based methods is the rapidly exploring random tree (RRT). RRT can efficiently search space in a static environment. RRT randomly samples nodes from the UAV's operating radius. If nodes do not overlap with obstacles or there are no obstacles on the path, RRT connects the path of an UAV to the nearest node and gradually finds the destination. Although this method does not guarantee an optimal path, it has the advantage of efficiently searching a high-dimensional space in a short time. Research is underway to further shorten the search time of RRT and use it for dynamic obstacle avoidance. Chen, et al. [8] proposed a new Adaptive Dynamic RRT*-Connect (ADRRT*-Connect) algorithm that can avoid collisions in a 3D environment with dynamic threats.

3.6. Vision-Based Approach

Most high-performance sensors are heavy in weight or use a lot of power, so it is difficult to apply to small UAVs. The vision-based method is used to support efficient obstacle avoidance even in small UAVs using lightweight, compact cameras. Using computer vision technology and algorithms, it can be used in various ways, such as object identification, object segmentation, and obstacle collision time prediction. This method has many limitations such as the limited battery of a small UAV and small computing power, so it is difficult to use a method with high complexity. Zhefan, et al. [9] propose a real-time dynamic obstacle tracking and mapping system for obstacle avoidance with limited resources using RGB-D cameras.

Table 1
Performance Comparison Between Collison

Approach	Complexity	Pre-mission path planning	Static obstacle	Dynamic obstacle	Optimal path
Geometric Approach	High	X	O	O	X
Potential Field Approach	High	O	O	△	△
Path Planning Approach	Medium	O	O	△	O
Optimization-Based approach	Medium	O	O	X	△
Sampling-Based Approach	Low	O	O	△	△
Vision-Based Approach	Medium	X	O	O	X

4. Discussion

Based on our survey results, we compared collision avoidance approaches. Table 1 shows the results. For example, regarding the complexity of the implementation, the geometric and potential field approaches are highly complex, but the sampling-based approach is not complex.

When it comes to the necessity of pre-mission path planning, potential field, path planning, optimization-based and sampling-based approaches require pre-mission path planning, while geometric and vision-based approaches do not require pre-mission path planning.

All of the approaches can void static obstacles. However, the optimization-based approach cannot avoid dynamic obstacles. Geometric and vision-based approaches can avoid dynamic obstacles, but their collision avoidance paths are not the optimal path. Whether potential field, path planning, and sampling-based Approaches can avoid dynamic obstacles depends on how the system is configured. Their collision avoidance paths could be the optimal or efficient path.

Overall, the choice of a collision avoidance approach for a particular UAV application depends on a number of factors, including the complexity of the environment, the types of obstacles present, the level of performance required, and the resources available. By considering these factors and choosing an appropriate approach, it is possible to develop collision avoidance systems for UAVs that can ensure the safety and reliability of these systems in a variety of applications.

We would like to develop a collision avoidance system in a cargo transport scenario. In a cargo transport scenario, it would be good for UAVs to go through an optimal path while avoiding both static and dynamic obstacles. Therefore, we will consider the path planning approach in the first place for our implementation. However, the path-planning approach requires pre-mission planning also the approach needs to know the locations of obstacles in advance. Therefore, we will consider other approaches as well to compensate the disadvantages of the path-planning approach.

4.1. Other issues

Besides the collision avoidance methods that we investigated in this paper, there are other methods for future research on collision avoidance in UAVs.

One possible method is the use of machine learning algorithms to improve the performance of collision avoidance systems. Machine learning has shown great promise in improving the accuracy and efficiency of various applications in robotics. Therefore, it may be possible to develop machine learning models that can predict the trajectories of other UAVs and avoid collisions in real time.

Another area for future research is to use multiple sensors and cameras for collision avoidance. Most current collision avoidance systems mainly rely on GPS and other onboard sensors to detect other objects and obstacles. However, these sensors can have limited accuracy and range, especially in complex and cluttered environments. Integrating multiple sensors, including cameras and lidar, can improve the accuracy and reliability of crash avoidance systems.

5. Conclusions

In this paper, we investigated the collision avoidance approaches for UAVs and summarized their advantages and limitations in a table. According to our investigation, the path planning approach is a reasonable choice, when we need pre-path mission planning.

In the future, we will develop the path-planning approach in a 3D environment for a more realistic collision avoidance algorithm for a UAV. We then simulate the performance of the collision avoidance algorithm in the 3D environment and, based on the simulation results, we will implement the desirable collision avoidance approach for our cargo transport scenario.

6. Reference

[1] Goerzen, Chad, Zhaodan Kong, and Bernard Mettler. "A survey of motion planning algorithms from the perspective of autonomous UAV guidance." Journal of Intelligent and Robotic Systems 57.1 (2010): 65-100.

[2] Lu, Yuncheng, et al. "A survey on vision-based UAV navigation." Geo-spatial information science 21.1 (2018): 21-32.

[3] Shakhatreh, Hazim, et al. "Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges." Ieee Access 7 (2019): 48572-48634.

[4] Gnanasekera, Manaram, and Jay Katupitiya. "A Time Optimal Reactive Collision Avoidance Method for UAVs Based on a Modified Collision Cone Approach." 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2020.

[5] Wang, Han, et al. "Feasible computationally efficient path planning for UAV collision avoidance." 2018 IEEE 14th International Conference on Control and Automation (ICCA). IEEE, 2018.

[6] Zhao, Taifei, et al. "Wireless ultraviolet light MIMO assisted UAV direction perception and collision avoidance method." Physical Communication 54 (2022): 101815.

[7] Han, Bing, et al. "Grid-optimized UAV indoor path planning algorithms in a complex environment." International Journal of Applied Earth Observation and Geoinformation 111 (2022): 102857.

[8] Chen, Yicheng, and Lingling Wang. "Adaptively Dynamic RRT*-Connect: Path Planning for UAVs Against Dynamic Obstacles." 2022 7th International Conference on Automation, Control and Robotics Engineering (CACRE). IEEE, 2022.

[9] Xu, Zhefan, et al. "A real-time dynamic obstacle tracking and mapping system for UAV navigation and collision avoidance with an RGB-D camera." arXiv preprint arXiv:2209.08258 (2022).