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# A Review on Collision Avoidance Systems for Unmanned Aerial Vehicles

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***Abstract*—The unmanned Aerial Vehicles (UAV) concept has attracted the attention of both academia and industry as an alternative to reduce the traffic congestion limitation. To coordinate the UAVs located in the sky, also called drones, the concept of the Internet of Drones (IoD) was introduced as overall coordination of UAVs in the sky. IoD paradigm offers a wide range of applications mainly targeting the military and civilian environments. Some of those applications include transportation, agriculture-based systems, entertainment, weather monitoring, healthcare systems, and road hazards monitoring. However, once an area is highly congested by a various number of drones, dynamic or statics obstacles can hinder the overall performance of drones. In order to avoid those obstacles, one of the proposed solutions is to apply collision avoidance techniques while the drones are on duty. In this paper, we present a brief survey of collision avoidance systems for the internet of drones. We have reviewed the current literature review ranging from the year 2010 to 2021. This work has taken into consideration two main frequently used databases in academia: Xplore for IEEE and ScienceDirect for Elsevier. After article selection, some articles were retained and discussed. A detailed discussion and analysis of selected articles were made while most of the techniques used in collision avoidance systems include video-based systems and swarm-based intelligence approaches. Furthermore, the paper discusses the different approaches which are used to design collision avoidance systems. Finally, this paper provides concluding remarks and future research orientation that will mainly focus on AI-based algorithms applied in collision avoidance systems.**

***Index Terms*—Internet of Things, Unmanned Aerial Vehicles (UAV), Internet of Drones, Prediction, Collision avoidance.**

## I. Introduction

By definition, an unmanned aerial vehicle (UAV) commonly known as a drone, is an aircraft without a human pilot onboard [20]. UAVs are a component of an unmanned aircraft system (UAS), which includes additionally a ground-based controller and a system of communications with the UAV. On the other hand, the Internet of Drones (IoD) consists of many drones that can communicate and share information in the perspective of monitoring or reporting an event that has occurred in a certain place or region. Drones are also defined as aircraft-based devices that can fly or operate with passengers [6]. The Internet of drones is applicable in a multitude of areas mostly in the civilian environment. Those areas of applications include traffic monitoring, packets or good delivery, accident detection systems, agriculture inspection, and monitoring systems, emergency and rescue-based systems. Drones are also widely used in the military domain with many applications and events already documented in the literature.

For the last decades, there is a growing usage of drones for consumer-based applications such as entertainment-based systems or delivery-based systems. Many drones are used in the civilian domain and one of the most popular is the quadrotor DJI Phantom 4 pro. DJI 4 Pro has become very popular due to its characteristics such as price affordability, small size, easy and simple design, and ability to hover in place [15]. Accordingly, the number of accidents for drones has been widely reported.

Thus, drones must complete their mission while achieving maximum mission safety. However, to achieve the safety of drones, it is important to have efficient and effective collision avoidance techniques or protocols that can be applicable for static environments or dynamic environments.

The obstacles can be divided into two main categories: static obstacles and dynamics obstacles. The first category of static obstacles is fixed entities that are located in known places. These can be building, electric equipment, or any other equipment. The second category of obstacles is dynamics obstacles and consists of objects that can suddenly appear on the pathway of a drone and their location can change. Either dynamic or static, these obstacles have to be detected during the mission of a drone. Collision avoidance systems are assumed to have an efficient detection mechanism that can detect both the speed and the direction of dynamic obstacles while having complete knowledge of static obstacles.

In this paper, we present a brief survey of collision avoidance systems for the internet of drones and our contribution is three folds:

- We first describe the existing elements that affect the performance of the internet of drones mostly the collision avoidance system.
- We later describe the procedure that was used to choose and select the articles that were considered in this work.
- We provide thorough analysis through a systematic review of selected articles by emphasizing the used techniques, research goals, used techniques along with findings, followed by the future research directions

The rest of this paper is organized as follows. We present the related works on collision avoidance systems on the internet of drones in Section II. Section III discusses the selection procedure used for the articles that were discussed in the brief

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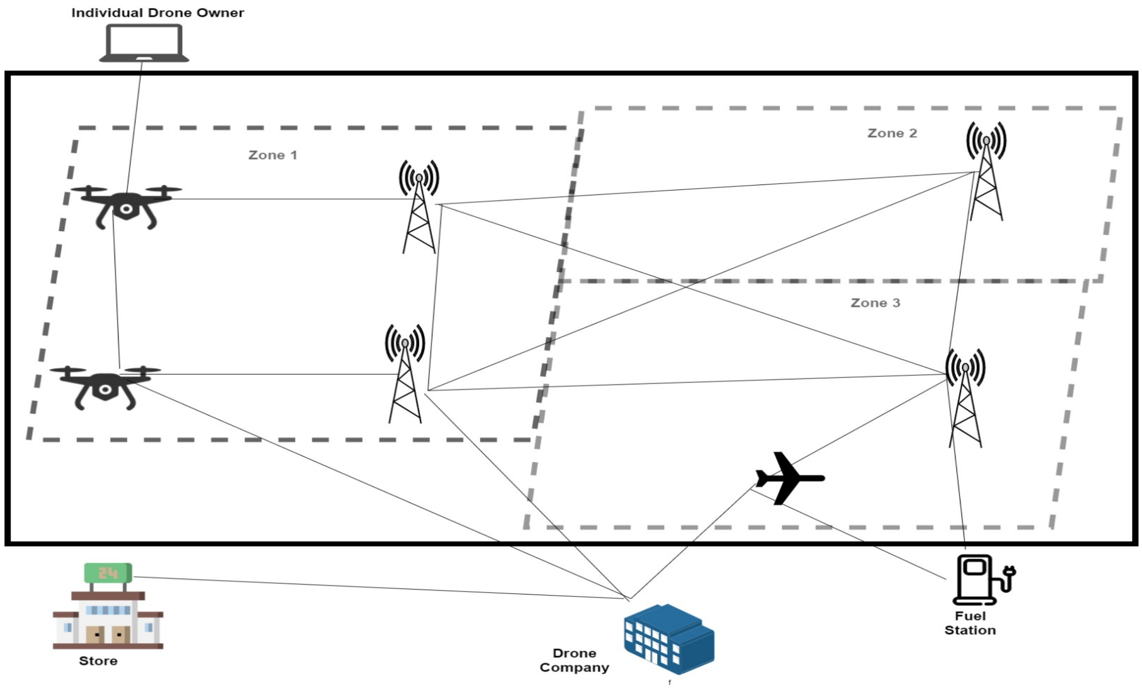


Fig. 1: Internet of drones architecture

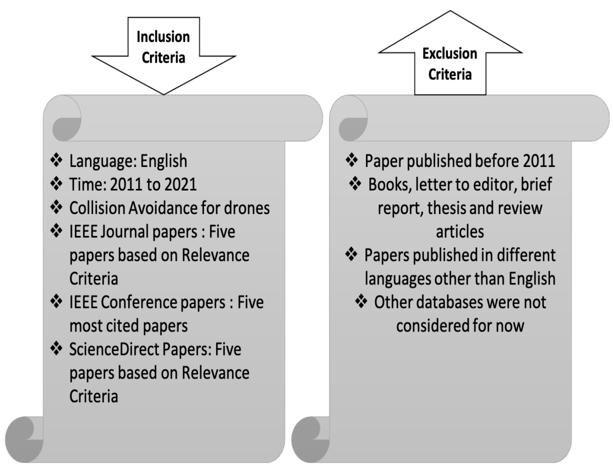


Fig. 2: Article Selection Process

survey. Section IV discusses the various design approaches for collision avoidance systems. Section V draws the concluding remarks and future work.

## II. Literature Review

In the section, we present mainly the procedure that was used for articles selection. In addition, we discussed several articles on existing work that attempted to provide surveys on collision avoidance-based techniques on the Internet of drones.

Among the existing work, there are a number of references that surveyed on collision avoidance systems.

In [14], Guan et al. discussed a survey of safety separation management and collision avoidance approaches of civil UAS operating in the integrated national airspace system. In their work, the authors tried to make a review of the UAS separation management and key technologies used in collision avoidance systems within the integrated airspace. Their work mainly focused on the current situation of UAS Traffic Management (UTM), safety separation standards, detection system, collision risk prediction, collision avoidance, safety risk assessment, etc., as well as an analysis of the bottlenecks that the current researches encountered and their development trends.

In [7], Huang et al. presented an overview of various approaches for multi-UAV collision avoidance under several classifications based on the algorithm used, frameworks designed, and their main features.

Tahir et al. [13] analyzed the core characteristics of swarming drones and the public awareness levels with respect to these swarms. This study showed that the swarms of drones are a fundamental part of the future agenda. Thus emphasizing the need for strong and robust avoidance systems.

Aggarwal et al. [1] paper focused on path planning for unmanned aerial vehicles (UAVs) in order to find an optimal path between source and destination. The main objective of path planning techniques is not only to find an optimal and shortest path but also to ensure a collision-free environment for the UAVs. It is important to have path planning techniques to calculate a safe path in the shortest possible time to the final destination.

Based on the aforementioned literature, the overall research on effective collision avoidance systems is still in the early stages, thus the need to provide a more comprehensive study on the topic.

In this work, various databases were extracted to achieve an accurate review. Those databases are mainly Xplore for IEEE-

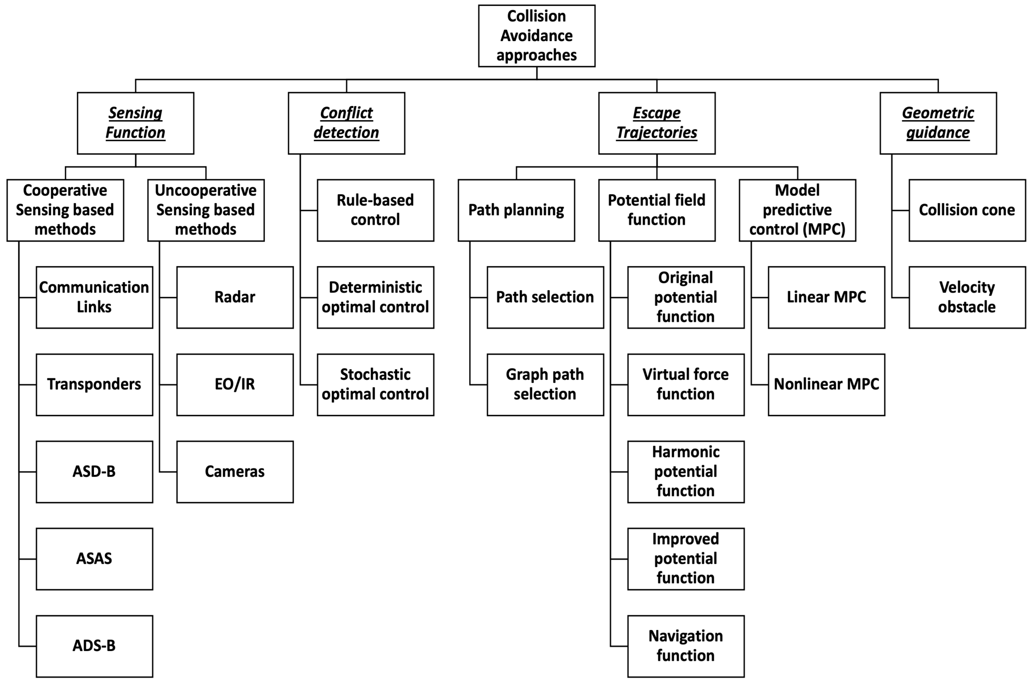


Fig. 3: Design Approaches for Collision Avoidance Systems

based articles and Science-direct for Elsevier-based articles. Other libraries including Springer, ACM, Google Scholar, Wiley digital library will be used for the future work of this article. This is mainly due to the number of page limitations. In order to select the articles, the following keywords including "internet of drones", "unmanned aerial vehicles", "collision avoidance system". The selection procedure is illustrated in Fig. 2

The outcome of 45 research articles was taken into consideration. As shown in Fig. 2 those research articles were chosen or taken into consideration based on inclusion and exclusion criteria. Concerning the exclusion criteria, only qualified articles were chosen. However, book chapters and from book, thesis, and other summary reports were excluded. Other available articles including Journal editorials, newsletters, or papers that were not in English were excluded. After reviewing all collected articles, only 15 papers were retained for in-depth analysis and study.

## III. Domain of Applications for Collision Avoidance Systems

In this section, we provide a discussion of the articles that we surveyed. As shown in the table, we mainly focus on the topics which were covered, the research goals that were intended to handle, the methodology that was used, and the findings Due to page limitation, we have only discussed 15 articles and then we intend to provide more in future work. Based on the discussed paper, the avoidance systems are discussed in the following main directions

*1) Video based Systems:* Several works focused on providing collision avoidance systems using video-based solutions. In these work, [17] and [10] attempted to generate to automatically generate drone trajectories such as the imagery acquired during the flight, thus the image will later produce a high 3D model that can be used for collision avoidance systems. Their main techniques were mainly divided into the following steps: they first provided an estimation of the scene geometry to plan camera trajectories. Later on, they used the trajectory to cover the scene as thoroughly as possible. In addition, they made an algorithm that makes observations of scene geometry from a diverse set of viewing angles. The combination of all those provided algorithms allowed them to establish collision systems to avoid obstacles.

*2) Swarm Based Intelligence Systems:* Several solutions also relied on swarm-based intelligence systems. Among them, the authors in [19] proposed a solution to dynamically handle the duality of control. Their proposed scheme focused on adapting the thin-plate splines algorithms that would help to minimize deformation of the swarm's formation while providing solutions to avoid obstacles. Other papers used a similar approach targeting to have very close surveillance of obstacles

## IV. Design Approaches Collision Avoidance Systems

In this section, we present the existing design approaches for collision avoidance systems which are divided into two main categories. We first describe the main approaches under which the systems are constructed. Furthermore, we present the techniques and their underlying algorithms in each category. Fig. **??** gives a full description of those approaches and their techniques. The main collision avoidance approaches that will

Tab. I: Discussion of selected articles

| Study | Topic | Research Goals | Methodology | Findings |
|---|---|---|---|---|
| [19] | UAV and Swarm intelligence | Dynamically handle this duality of control | Formation-collision co-awareness by adapting the thin-plate splines algorithm to minimize deformation of the swarm's formation while avoiding obstacles | Simulation results show that the proposed methodology maintains the desired formation very closely in the presence of obstacles, while the response time and overall energy efficiency of the swarm are significantly improved. |
| [17] | Obstacle avoidance | To present a real-time onboard approach for monocular depth prediction and obstacle avoidance | Predict every video frame depth map and the corresponding confidence. The estimated depth map is transformed into Ego Dynamic Space (EDS) by embedding both dynamic motion constraints of a drone and the confidence values into the spatial depth map | Extensive experimental results on public data sets demonstrate that their depth prediction method is 1.8X to 5.6X faster than the state-of-the-art methods and achieves better depth estimation accuracy. |
| [11] | Collision avoidance | Design of a positive potential function to take into account the movement of obstacles | A controller was designed with hierarchical objectives using a behavioral-based approach. A null space-based controller is adopted, whose main objective is to ensure that the collision avoidance is achieved, whereas other objectives are projected onto the null space. | Develop a hierarchical control system that can perform trajectory tracking/location and obstacle avoidance tasks. In addition, obstacle avoidance applies to n obstacles. |
| [2] | Flying Swarm of drones | Flying Swarm of Drones Over circulant Digraph | Their method is fundamentally different from any known to date since it does not need sensors to avoid collisions between drones. In addition, the flight of drones does not have to be coordinated. | The authors presented a novel framework for collision-less flying of many drones without the need for collision-detecting sensors or flight synchronization. Their method presented an algorithm that was scalable to hundreds of drones and allows to fly all of them from a single ground station |
| [18] | Autonomous aerial vehicles | The paper provides a comprehensive review of collision avoidance strategies used for unmanned vehicles, with the main emphasis on unmanned aerial vehicles (UAV). | It is an in-depth survey of different collision avoidance techniques that are categorically explained along with a comparative analysis of the considered approaches w.r.t. different scenarios and technical aspects. | The paper provides a comprehensive review of collision avoidance strategies used for unmanned vehicles, with the main emphasis on unmanned aerial vehicles (UAV). |
| [4] | UAV and obstacles avoidance | To learn to navigate an Unmanned Aerial Vehicle (UAV) and avoid obstacles | Crash data set creation to optimize the UAV navigation | This simple self-supervised model is quite effective in navigating the UAV even in extremely cluttered environments with dynamic obstacles including humans. |
| [5] | Unmanned Aircraft Systems (UAS) | To develop a system that can identify/detect a UAS, which will subsequently enable countermeasures against UAS. | Identify a UAS through various methods including image processing and mechanical tracking. | UAS can be reliably distinguished from other objects using the SURF method. A third-party counter-UAS system, like an RF rifle, can readily be added to the system to disrupt its channel of communication. |
| [10] | Drones 3D Scanning | To automatically generate drone trajectories such that the imagery acquired during the flight will later produce a high fidelity3D model. | Using a rough estimate of the scene geometry to plan camera trajectories based on a mathematical model of scene coverage that demonstrates an intuitive diminishing returns property called sub-modularity | The method results in greater quality 3D reconstructions, geometrically as well as visually than baseline methods. |

be discussed in the next subsections include Sensing Function, Conflict detection, Escape trajectories, and Geometric guidance.

### A. Sensing Function approaches

The sensing functions consist of the capability of a given UAV to collect traffic information within a given parameter surrounding the unmanned aircraft. There is a number of sensors that can be deployed on a UAV, which can be categorized into two groups: cooperative-based methods [12] and non-cooperative methods [16]. Cooperative-based methods comprise the collection of a number of metrics that categorize a UAV such as the current position, heading direction, speed, and others. The most commonly used devices are transponders, Airborne Separation Assistance Systems (ASAS), and Automatic Dependent Surveillance-Broadcast (ADS-B). ADS-B, for example, transmits information such as location, speed, and UAV identity from the UAV to other entities and ATC (Air Traffic Control).

Sensing the environment can be accomplished using a variety of non-cooperative traffic technologies, such as laser range finders, optical flow sensors, Electro-Optical/Infra-Red (EO/IR), radar systems, stereo camera pairs, or moving single cameras. Laser range finders are commonly used for obstacle detection and work well if they can be scanned.

### B. Conflict detection approaches

Since multi-vehicle systems vary greatly in type and mission, relying on a ground station and predefined trajectories is impractical. It has been suggested that the concept of self-separation (free flight) be used. However, due to the human reaction time delay, manual control is difficult to implement for the free flight task. Scientists are currently researching a conflict detection [3] and resolution approach to carry out the task. A rule-based approach, deterministic and stochastic approaches, and a protocol-based approach have all been proposed as solutions to conflict detection and resolution.

Rule-based control - By using this policy, which is a predefined rule basis, each vehicle in the system decides its control. But an unexpected event cannot be taken into account properly by the rule-based method.

Deterministic optimal control - Conflict resolution, on the other hand, maybe redefined as an optimization model when minimizing an objective function without colliding. Two solutions to this problem are available: deterministic controls and optimal stochastic controls. Vehicle dynamics can be described as regular differential equations for detergent control problems, so many numerical methods can be used to provide the optimal trajectory.

Stochastic optimal control - The state of the vehicle system is a stochastic method for stochastic control problems and the best possible trajectory is produced by solving a problem with optimization.

### C. Escape trajectories approaches

These approaches [8] consists of several techniques such as path planning, potential field function, and model predictive control (MPC).

Path planning methods seek the shortest path in a map or database graph where the edges of obstacles are already known. Escape trajectory approaches take into account known obstacle vehicle trajectories and find an airworthy path (free-route) for a controlled vehicle over a given time interval, i.e., planning a trajectory ahead of time. This method is further subdivided into two categories: path selection and graph path selection.

### D. Geometric guidance approaches

Geometric collision avoidance algorithms [9] have been developed in the past two decades, and maybe most suitable for collision avoidance in multi-vehicle systems because extensive analysis and prediction are not required. There are two methods for geometric guidance: one is the collision cone method, and the other is the velocity obstacle.

## V. Conclusion and Future Work

The concept of the Internet of Drones (IoD) provides many advantages that can be applied both in the military and civilian environments. Areas of applications such as transportation, agriculture-based systems, entertainment, weather monitoring, healthcare systems, and road hazards monitoring are very promising due to their main contribution to sustainable development. Nevertheless, there are dynamic or statics obstacles in the sky that can hinder the overall performance of drones on their missions. To avoid those obstacles can be achieved by applying collision avoidance techniques while the drones are on duty. In this paper, we presented a brief survey of collision avoidance systems for the internet of drones. We have reviewed the current literature review ranging from the year 2010 to 2021. We provided a discussion and analysis of selected articles, especially most used techniques including video-based systems and swarm-based intelligence approaches. Moreover, we presented the design approaches that serve as a building block for collision avoidance systems. In the future work, we intend to provide a detailed discussion of current literature by focusing on different AI and ML-based techniques.

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