Quantum Computing for Drone Collision Detection and Avoidance: A Systematic Mapping Study

Maria Eduarda W. M. Vianna, Alison R. Panisson, and Roberto Rodrigues-Filho

***Abstract*— As the use of unmanned aerial vehicles continues to expand, the demand for fast and accurate collision detection and avoidance solutions becomes increasingly critical. Traditional computing approaches face scalability challenges, with their complexity growing exponentially as the number of drones increases. This scenario highlights the potential of quantum computing to address such computationally intensive tasks, as its parallelism and ability to handle combinatorial optimization problems can significantly reduce the computational burden compared to classical methods. In this paper, we present preliminary findings from a systematic mapping study aimed at classifying and analyzing the most relevant quantum computing approaches applied to collision detection and avoidance. We provide an overview of the techniques employed, discuss their limitations, and outline emerging trends and future research directions.**

***Keywords*— Quantum Computing, Collision Avoidance, Drones.**

I. Introduction

Unmanned Aerial Vehicles (UAVs) [7] have seen increasing adoption across various domains, driven by their potential to enhance logistics, surveillance, agriculture, and environmental monitoring. Their applications include package delivery in remote areas [9], large-scale security operations [10], [2], hazardous site inspection [5], and crop health monitoring [12]. According to market data from Horizon[1], fully autonomous drones generated USD 6.4 billion in revenue in 2024, with projections reaching USD 16.9 billion by 2030.

As UAV deployments grow in complexity and scale, ensuring safe operation becomes increasingly challenging. One of the most critical issues is real-time collision detection and avoidance, especially in high-density environments. These tasks require responsive decision-making and efficient handling of dynamic obstacles [3], [1].

Traditional methods for UAV collision avoidance include geometric models based on position and velocity, force-field techniques, path planning algorithms, and sensor-based sense-and-avoid systems [14], [15], [13]. These approaches have shown effectiveness in controlled scenarios but often face limitations in dynamic or uncertain environments. AI-based methods, such as machine learning and reinforcement learning, improve adaptability but depend on large datasets and raise concerns around explainability, safety, and computational cost.

To address these challenges, quantum computing is emerging as a promising paradigm. Quantum algorithms offer advantages in solving large-scale optimization and decision problems, which are central to collision avoidance systems. In this context, quantum approaches may enable faster path planning, better scalability for multi-drone coordination, and more efficient processing of high-dimensional sensor data. Techniques such as quantum optimization and quantum machine learning show potential to overcome some of the limitations faced by classical systems, especially in scenarios where speed, uncertainty, and computational scale are critical.

This paper investigates how quantum computing techniques are being applied to UAV collision detection and avoidance through a systematic mapping study. We examine the current state of the literature to identify key trends, approaches, and challenges. Our contributions include: (i) a comprehensive overview of quantum-based methods applied to UAV collision avoidance, (ii) a classification of approaches based on how the problem is modeled and which quantum algorithms are used, and (iii) an analysis of recent trends, open problems, and future directions in this emerging area of research.

This paper is organized as follows: Sec. II reviews related work and positions our study; Sec. III describes the search protocol, research questions, and inclusion and exclusion criteria; Sec. IV explains our classification scheme; Sec. V presents the results; and Sec. VI concludes the paper.

II. Related Work

As quantum computing matures and becomes more accessible through platforms offered by major technology providers, its application to complex problems such as UAV collision avoidance is gaining attention. Despite this growing interest, our analysis reveals that only a limited number of studies focus specifically on this topic from a quantum computing perspective. Broader surveys on quantum computing exist, but we excluded them due to their general scope and lack of relevance to our specific research questions.

We identified three surveys that provide more focused insights. The first, by Rattan et al. [11], explores quantum computing in Advanced Driver Assistance Systems, discussing its use in perception, object detection, and decision-making, which are closely related to UAV safety. The second, by Landers [8], examines quantum technologies in space and aerial vehicles, highlighting applications in route planning, scheduling, and data analysis. The third, by Kumar et al. [6], reviews quantum technologies for drones and networks, including communication, cryptography, and control systems, and discusses the use of quantum finite automata for multi-drone coordination. Although none of these surveys focus directly on UAV collision avoidance, they form a valuable foundation. Our work builds on these efforts by addressing this gap through a focused and systematic mapping study.

Maria Eduarda W. M. Vianna e Alison R. Panisson, Departamento de Computação (DEC), Universidade Federal de Santa Catarina (UFSC), Araranguá-SC, e-mails: maria.vianna@grad.ufsc.br, alison.panisson@ufsc.br; Roberto Rodrigues-Filho, Departamento de Ciência da Computação (CIC), Universidade de Brasília (UnB), Brasília-DF, e-mail: roberto.filho@unb.br.

[1]https://www.grandviewresearch.com/horizon/statistics/drone-market-outlook/technology/fully-autonomous/global

III. Systematic Review

This work follows the systematic review guidelines proposed by Kitchenham et al. [4]. In this section, we present the search protocol that forms the foundation of our approach, designed to promote transparency and reduce bias. By following the outlined steps, future researchers should be able to replicate our process and reproduce the same findings.

A. Research Questions

The following research questions guided our investigation.

(RQ1) What quantum-based approaches have been used to address collision avoidance in unmanned aerial vehicles?
(RQ2) How are these quantum approaches applied to solve the collision avoidance problem in unmanned aerial vehicles?
(RQ3) What are the predominant quantum approaches in this domain?

B. Bibliographic Databases

Google Scholar was selected as the bibliographic database because quantum computing is an emerging, fast-changing field where peer-reviewed literature on specific topics like collision avoidance remains limited. Its ability to aggregate content from multiple sources, including IEEE Xplore, arXiv, and Springer, increases the chances of capturing a broader range of relevant studies. In such areas, preprints and non-peer-reviewed papers are often necessary to reflect the latest developments. Google Scholar also offers practical benefits: it is freely accessible and includes various document types such as books, theses, conference papers, and journal articles. To ensure the quality and consistency of the results, all retrieved materials were manually filtered, as described in Sec. III-D.

C. Search Keywords

We selected keywords related to *collision avoidance* while avoiding terms that could bias results toward specific subareas. For example, using "*quantum computing trajectory planning*" might overemphasize a niche topic. Our aim was to identify which components of the collision avoidance process are most frequently addressed when quantum computing is applied. The selected keywords are listed in Table I.

The fourth keyword was chosen to capture research on quantum networks, which the first two keywords did not sufficiently cover. "*Quantum drones*" was included based on preliminary Google Scholar searches, where it emerged as a potentially novel and growing area of interest.

Search Keywords
(1) *Quantum Computing Collision Avoidance*
(2) *Quantum Computing Autonomous Vehicles*
(3) *Quantum Computing UAV Collision*
(4) *Quantum Networks Anticollision uav*
(5) *Quantum drones*

TABLE I: List of selected search keywords.

D. Inclusion and Exclusion Criteria

This survey includes primary research papers published up to July 2025 that address collision avoidance in UAVs or autonomous vehicles. Given the limited number of quantum computing studies focused specifically on UAVs, we expanded the scope to include autonomous vehicles, particularly works related to navigation, obstacle detection, path planning, or coordination among agents. We also included studies involving communication systems that directly support collision avoidance, especially in multi-agent or swarm scenarios.

To ensure relevance, we excluded reviews, theses, books, book chapters, and technical reports. Papers with a broad focus that mention quantum computing without applying it to autonomous navigation were not considered. We also excluded works on sustainability or mission planning unrelated to obstacle avoidance, and studies on secure communication unless directly tied to collision coordination. Finally, quantum-inspired algorithms that use quantum metaphors, such as Quantum Particle Swarm Optimization, were excluded. Only studies grounded in genuine quantum principles or models were included, even if they were implemented on simulators rather than executed on actual quantum hardware.

IV. Classification Scheme

After analyzing the selected papers, we observed that the proposed solutions could be grouped into distinct quantum-based approaches. Although many of the works employed hybrid strategies, combining classical and quantum techniques, the categorization in this study prioritizes the quantum component as the primary criterion. That is, each paper was classified according to the dominant quantum methodology it employed, regardless of classical auxiliary methods. The resulting classification encompasses the following categories:

- **Quantum Optimization:** papers that focus on finding optimal solutions to the collision avoidance problem of autonomous vehicles using quantum algorithms.
- **Quantum Machine Learning:** papers that address collision avoidance by learning from past data using Quantum Machine Learning algorithms.
- **Quantum Reactive Control:** refers to the use of quantum circuits or algorithms to govern the real-time behavior of autonomous physical systems based on sensor inputs or predefined conditions. It focuses on reactive decision-making and control logic, rather than data-driven learning.
- **Quantum Communication and Cryptography:** papers focused on the efficient communication between autonomous vehicles for collision avoidance.
- **Quantum Architecture:** a quantum-based computational infrastructure that enables collision avoidance for autonomous vehicles

V. Results

A. Quantitative Analysis

The main approach for collision avoidance using quantum computing is **Quantum Machine Learning**, with 18 papers identified. Close behind is **Quantum Optimization**, with 15 papers. Together, these two categories represent 84.6% of the papers considered relevant for this specific problem (see Fig. 1). Although several papers could fit into the category of **Quantum Communication and Cryptography**, only 3 were included after filtering for close relevance to collision avoidance, as indirect connections were excluded according to the exclusion criteria (Sec. III-D). Following that, both **Quantum Reactive Control** and **Quantum Architecture** had only one paper each. The latter often included approaches that, like cryptography, were considered too distant from the survey's scope to be included.

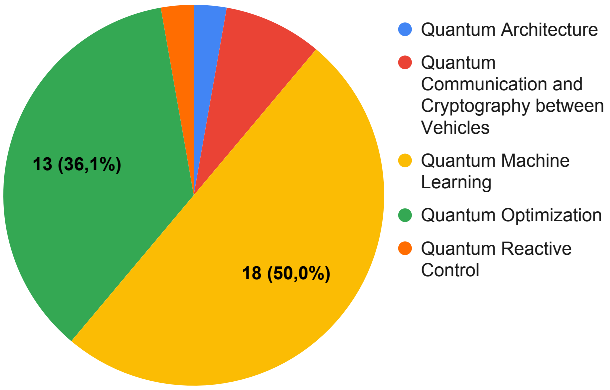

Fig. 1: Number of papers per identified categories. Quantum Machine Learning appears in the majority of the papers (50%).

To gain a comprehensive understanding of the application of **Quantum Machine Learning** to the collision avoidance problem in unmanned aerial vehicles, the field can be systematically categorized into several subcategories: **Quantum Neural Networks**, **Quantum Reinforcement Learning**, **Quantum Support Vector Machines**, **Quantum Clustering**, and **Quantum Federated Learning**. Fig. 2 presents the distribution of papers employing each of these approaches, noting that individual papers may fall into multiple subcategories. Among the analyzed works, **Quantum Neural Networks** was the most frequently utilized, appearing in 17 papers. This was followed by **Quantum Reinforcement Learning** with 5 papers, **Quantum Support Vector Machines** and **Quantum Clustering** with 3 papers each, and **Quantum Federated Learning**, which appeared in only one study.

Regarding **Quantum Optimization**, the field can likewise be organized into distinct methodological subcategories: **Quantum Variational Methods**, which employ parameterized quantum circuits optimized through a classical feedback loop, **Quantum Annealing**, which solves problems by guiding a quantum system toward its lowest-energy state, and **Other Quantum Optimization Techniques**. Fig. 3 illustrates the distribution of papers applying each of these approaches, with some studies encompassing more than one category. Among the reviewed literature, **Quantum Variational Methods** emerged as the most prevalent, featuring in 7 papers. This was followed by **Quantum Annealing**, which appeared in 4 studies and other quantum optimization techniques, also employed in 4 papers.

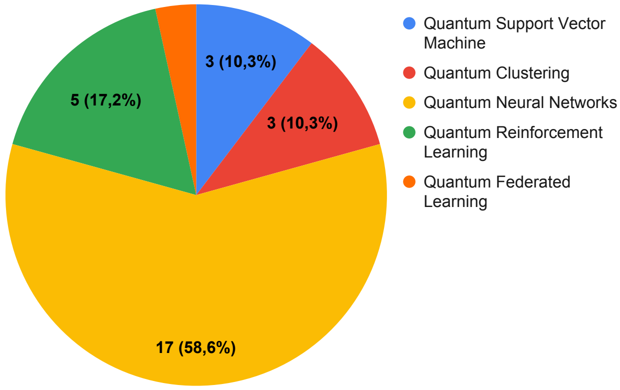

Fig. 2: Quantum Machine Learning subcategories. Quantum Neural Networks are the most applied approach.

Since the other categories did not have expressive representation, there are no subcategories considered for them. However, regarding **Quantum Communication and Cryptography**, all approaches explored quantum entanglement as a property, using it either to ensure secure communication or to enable coordinated communication among multiple agents. The only paper that fits into the **Quantum Reactive Control** category presents an autonomous flying robot vehicle that reacts to surrounding conditions using quantum logic. Finally, regarding the **Quantum Architecture**, it proposes quantum processing at the edge, thereby reducing latency in data processing and enabling more effective collision avoidance in autonomous vehicles.

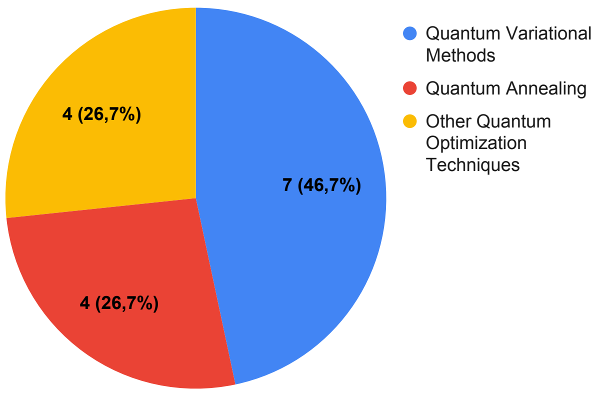

Fig. 3: Quantum Optimization subcategories. Quantum Variational Methods are the most applied methods.

B. Trends and Future Directions

The number of papers on quantum computing for collision avoidance in UAVs that fit our inclusion criteria has varied over the years, as shown in Fig. 4. Between 2019 and 2023, publication counts remained low, fluctuating between 1 and 3 papers per year. However, starting in 2024, the field experienced a sharp increase, with 11 papers published that year, followed by an even higher count of 14 papers in 2025 (data up to July). This surge highlights a recent and accelerating interest in the application of quantum computing to collision avoidance issue.

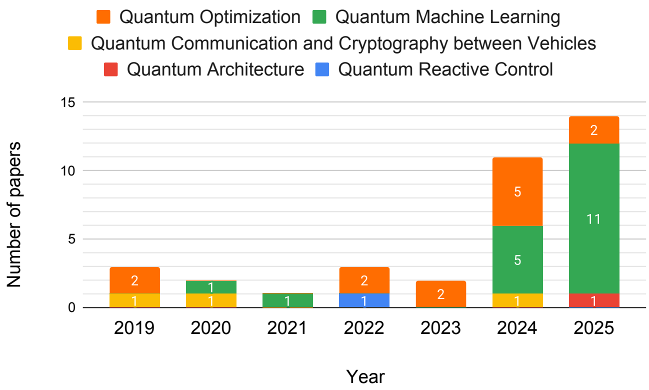

Fig. 4: Number of papers per year considering categories.

C. Threats to Validity

Quantum computing is an emergent field, and applying it to a specific problem, such as collision avoidance, while using targeted keywords (e.g., focused on drones or aerial vehicles), makes it difficult to find a large number of relevant papers. Thus, one limitation of this study is the small sample size, which restricts the understanding of the full range of possible approaches. Another important limitation is that many of the papers included have not been peer-reviewed. This affects the reliability and maturity of some proposed solutions, making it necessary to interpret the findings with caution.

VI. Final Remarks

This work presented a systematic mapping study on the use of quantum computing techniques for collision avoidance in unmanned aerial vehicles (UAVs). We defined and followed a systematic review protocol designed to answer three key research questions. For RQ1, *What are the quantum computing approaches applied to UAV collision avoidance?*, we identified two most popular categories: quantum optimization and quantum machine learning. For RQ2, *How are these approaches applied?*, we observed that both are typically used to model collision avoidance as an optimization problem, where the objective is to compute a collision-free trajectory using quantum algorithms. For RQ3, *What are the predominant approaches in this domain?*, we found that quantum machine learning, particularly quantum neural networks, is the most frequently adopted strategy.

Our study also reveals a recent surge of interest in this topic, with a significant concentration of publications in 2024 and the first half of 2025. In total, we identified 36 papers addressing the collision avoidance problem using quantum techniques, though only a subset focus specifically on UAVs. Most studies rely on simulations rather than actual quantum hardware, yet their results consistently suggest improvements over classical methods, particularly in terms of accuracy and convergence time. These findings indicate that quantum computing holds promising potential for advancing collision avoidance in UAV systems, although further work is needed to validate these approaches in real-world settings.

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Appendix

Table II, containing all selected papers, has been added to this appendix. Note that, in column **RQ3**, 'Yes' or 'No' indicates whether the employed approach falls under Quantum Neural Networks – the most popular approach.

TABLE II: List of selected papers on Quantum Computing to address the Collision Avoidance problem.

#	Title	RQ1	RQ2	RQ3
1	Variational Quantum Algorithm Applied to Collision Avoidance of Unmanned Aerial Vehicles	Quantum Optimization	Scheduling Takeoff Times	No
2	Quantum Algorithms Using Infeasible Solution Constraints for Collision-Avoidance Route Planning	Quantum Optimization	Path Planning	No
3	Q-Omni: A quantum computing and GPT-4o solution for Camel-Vehicle Collisions	Quantum Machine Learning	Obstacle Detection	Yes
4	A Quantum Computing Approach for Multi-robot Coverage Path Planning	Quantum Optimization	Path Planning	No
5	Swarm Robotics and Quantum Computing in Simulated Environments	Quantum Optimization	Path Planning	No
6	Towards Real Time Multi-robot Routing using Quantum Computing Technologies	Quantum Optimization	Path Planning	No
7	Q-Edge: Leveraging Quantum Computing for Enhanced Software Engineering in Vehicular Networks	Quantum Architecture	Infrastructure Optimization	No
8	Trajectory Planning for Automated Vehicles using Quantum Computing	Quantum Optimization	Path Planning	No
9	Nav-Q: quantum deep reinforcement learning for collision-free navigation of self-driving cars	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
10	Solving Drone Routing Problems with Quantum Computing: A Hybrid Approach Combining Quantum Annealing and Gate-Based Paradigms	Quantum Optimization	Path Planning	No
11	Q-ARDNS-Multi: A Multi-Agent Quantum Reinforcement Learning Framework with Meta-Cognitive Adaptation for Complex 3D Environments	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
12	Quantum algorithms for drone mission planning	Quantum Optimization	Path Planning	No
13	QDCNN: Quantum Deep Learning for Enhancing Safety and Reliability in Autonomous Transportation Systems	Quantum Machine Learning	Obstacle Detection	Yes
14	Quantum-Enhanced Hybrid Reinforcement Learning Framework for Dynamic Path Planning in Autonomous Systems	Quantum Machine Learning	Quantum-Enhanced Learning	No
15	CTD2020: Exploring (Quantum) Track Reconstruction Algorithms for non-HEP applications	Quantum Machine Learning	Path Planning	Yes
16	QNN-VRCS: A Quantum Neural Network for Vehicle Road Cooperation Systems	Quantum Machine Learning	Path Planning	Yes
17	Quantum Computing-Accelerated Kalman Filtering for Satellite Clusters: Algorithms and Comparative Analysis	Quantum Machine Learning	Trajectory Prediction	Yes
18	Quantum Annealing Applied to De-Conflicting Optimal Trajectories for Air Traffic Management	Quantum Optimization	Path Planning	No
19	Collision-free Path Planning in Multi-vehicle Deployments – A Quantum Approach	Quantum Optimization	Path Planning	No
20	Real-Time Collaborative Route Planning in Autonomous Vehicles by Leveraging Optimized Quantum Neural Networks	Quantum Machine Learning	Path Planning	Yes
21	Quantum Artificial Intelligence for Secure Autonomous Vehicle	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
22	Quantum Long Short-Term Memory-Assisted Optimization for Efficient Vehicle Platooning in Connected and Autonomous Systems	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
23	Hybrid Classical-Quantum Deep Learning Models for Autonomous Vehicle Traffic Image Classification Under Adversarial Attack	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
24	Quantum Neural Networks for Enhanced Motion Prediction in Autonomous Vehicles	Quantum Machine Learning	Trajectory Prediction	Yes
25	Fast Quantum Convolutional Neural Networks for Low-Complexity Object Detection in Autonomous Driving Applications	Quantum Machine Learning	Obstacle Detection	Yes
26	Design and Simulation of an Autonomous Quantum Flying Robot Vehicle: An IBM Quantum Experience	Quantum Reactive Control	Path Planning	No
27	Quantum Cooperative Robotics and Autonomy	Quantum Communication and Cryptography	Vehicles' Communication	No
28	Ridge Regressive Data Preprocessed Quantum Deep Belief Neural Network for Effective Trajectory Planning in Autonomous Vehicles	Quantum Machine Learning	Path Planning	Yes
29	A Novel Hybrid Quantum Architecture for Path Planning in Quantum-Enabled Autonomous Mobile Robots	Quantum Optimization	Path Planning	No
30	Cyberattack Defense in Smart Cities: Leveraging Quantum Neural Networks for Secure Route Planning in ADAS	Quantum Machine Learning	Vehicles' Communication	Yes
31	Design and analysis of parallel quantum transfer fractal priority replay with dynamic memory algorithm in quantum reinforcement learning for robotics	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
32	Dynamic Quantum Federated Learning for UAV-Based Autonomous Surveillance	Quantum Machine Learning	Quantum-Enhanced Learning	Yes
33	Optimizing Autonomous Cargo Transport with Quantum Algorithms and Satellite Image Fusion	Quantum Optimization	Obstacle Detection	No
34	SVQCP: A Secure Vehicular Quantum Communication Protocol	Quantum Communication and Cryptography	Vehicles' Communication	No
35	Quantum Network of Cooperative Unmanned Autonomous Systems	Quantum Communication and Cryptography	Vehicles' Communication	No
36	QUADRO: A Hybrid Quantum Optimization Framework for Drone Delivery	Quantum Optimization	Path Planning	No