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A brief review of concepts and technological solutions to perfom DAA functions in the context of SIMUA Project

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Abstract— **The Unmanned Aircraft System Traffic Management (UTM) is a "traffic management ecosystem" for uncontrolled operations that is separate from, but complementary to, the Air Traffic Management (ATM). In this scope, the operations' risk management is crucial to keep a safe integration of this manned and unmanned aircraft into a non-segregated airspace domain. Even more, "Detect and Avoid" functions and approaches must be established while dealing with multiple entities on this complex scenario. This paper provides a brief review of concepts and technological solutions to perfom DAA functions in the context of the project SIMUA - Safe Integration of Manned and Unmaned Aircrafts in non-Segregated Airspace, in regarding the main methods to be in compliance with the established research questions that scope project.**

Keywords— **Detect and Avoid, UTM, Unmanned Aircrafts**

I. INTRODUCTION

The SIMUA project consists in a "Safe Integration of Manned and Unmaned Aircrafts" in a non-segregated airspace domain [1]. In this case, the non-segregated airspace is limited by the UTM level as illustrated in Fig. 1. It is important to notice that the complexity of these drones operations will be related to technological capacities and Air Traffic management - in this scope, the effectiveness of drone operations is intrinsically linked to the efficient coordination and management provided by Air Traffic Management systems, ensuring safe integration, navigation, and communication within shared airspace.

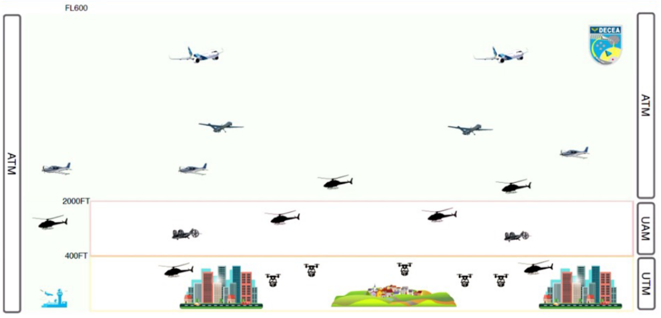

Fig. 1. UTM Flight Domain

The objective of this work is to evaluate the methods among the bibliographic references and make a global approach to gather the main techniques used in the field of "Sense/Detect and Avoid" - In the context of drone operations in a non-segregated airspace domain, the exploration of concepts and solutions related to Sense/Detect and Avoid functions serves the purpose of enhancing the autonomous capability of drones to perceive and react to other aircraft and obstacles in real-time. These functions enable drones to proactively detect potential collisions, avoid conflicts, and navigate safely, contributing to the overall safety and successful integration of drones into airspace shared with manned aircraft. By searching on these references we can draw a simple panorama, having thus the entire view of this Project's scope. In addition, this work aims to explore the concepts and technological solutions that can be developed or adapted to enable unmanned aircraft to perform DAA functions.

II. SCOPE OF RESEARCH

The use of Unmanned Aircraft Systems (UAS) is growing rapidly both for civil and the military domain. In this context, Detect and Avoid (DAA) system plays important role in integrating, in safe manner, this new technology into the conventional aviation world. The absence of a pilot on board the aircraft has raised the question of how these aircraft would detect and avoid hazards, and, particularly, how it would avoid collision. Many efforts have been made to study these aspects and to develop suitable technological solutions, considering several constraints that SAA/DAA system for UAS must comply with. The challenges and considerations of DAA systems for UAS integration are multifaceted:

1) **Situational Awareness:** Drones lack the direct visual and sensory perception of human pilots, making it critical to develop systems that can replicate this situational awareness. This involves providing the drone with sensors, such as cameras, radars, and lidars, to accurately perceive its surroundings and potential obstacles.
2) **Collision Avoidance:** Ensuring that UAS can autonomously detect and avoid other aircraft, both manned and unmanned, is a core challenge. This requires sophisticated algorithms that can process sensor data in real-time to identify potential collision risks and calculate evasive actions.
3) **Regulatory Compliance:** DAA systems must adhere to aviation regulations and standards to ensure safe operations in shared airspace. These systems need to be thoroughly tested and certified to meet safety requirements, similar to those imposed on manned aircraft.
4) **Communication:** Effective communication between UAS and manned aircraft, as well as Air Traffic Control (ATC), is essential for coordinated operations and

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[1] Airspace where different types of aircraft, including manned and unmanned, operate without strict physical or procedural separation, requiring advanced technologies for safe integration and coordination.

airspace management. DAA systems need to facilitate reliable communication to exchange information about positions, intentions, and potential conflicts.

5) **Technological Constraints:** Drones often operate in diverse environments with varying weather conditions, altitudes, and terrain. Developing DAA solutions that work effectively under these conditions can be challenging, requiring robust technology that performs consistently.
6) **Integration with Air Traffic Management (ATM):** The seamless integration of UAS operations into the existing Air Traffic Management system is crucial. DAA systems must interact with ATM systems to ensure overall airspace safety and efficient traffic flow.
7) **Human-Machine Interaction:** If human intervention is required, the design of user interfaces and control systems for DAA needs to be intuitive and user-friendly, enabling operators to make informed decisions in real-time.
8) **Cost and Scalability:** Developing and implementing DAA solutions can be costly. Finding a balance between cost-effective technology and comprehensive safety features is a consideration, especially as drone operations scale up.

In essence, the challenges revolve around creating robust and reliable DAA systems that replicate human pilot decision-making and situational awareness, while also adhering to regulations and seamlessly integrating into existing aviation infrastructure. Addressing these challenges is crucial to the successful and safe integration of drones into non-segregated airspace domains.

The main functions of the SAA/DAA system are: (i) the sense function, aimed to perform detection and tracking of the surrounding objects, (ii) and the avoid function, aimed to provide early identification of possible conflicts (i.e., loss of separation and collision threats) to be able to determine suitable maneuvers to be performed by the UAS to resolve the identified conflicts.

Within the ADS, the needs for safe integration of UAS has been identified as a common need for both Sweden and Brazil. The project in development studies the SAA/DAA operational and technical aspects, including the interoperability of using technologies already in place for manned aviation (e.g., ACAS/TCAS, ADS-B and Air – To – Air – Radar (ATAR)). Guided by the following main question: What operational and technical aspects, whether based on existing technological solutions or to be developed, can be used for SAA/DAA implementation?

In order to discuss the methods guideline, we need to list the expected research questions to be followed up in the scope of this work:

- **SIMUA-RQ01:** Technological solutions that can be developed or adapted to allow the RPIC ("Remote Pilot in Command") to comply with ICAO Annex 2 [2] ("avoidance of collisions")?
- **SIMUA-RQ02:** What concepts and technological solutions should be developed or adapted to allow a more automated traffic management for drones in the UTM airspace domain?
- **SIMUA-RQ03:** Is there the feasibility of using technologies already in place for manned aviation?
- **SIMUA-RQ04:** What concepts and technological solutions should be developed or adapted to allow the unmanned aircraft to perform "detect and avoid" functions?

III. DISCUSSION AND RESULTS

This item presented the preliminary results of research is going investigated. A brief review of concepts and technological solutions that can be developed or adapted to enable unmanned aircraft to perform DAA functions.

A. *SIMUA-RQ01: ICAO Annex 2*

ICAO Annex 2, **[1]**, outlines the rules and regulations for the avoidance of collisions in the airspace. It provides guidance on the responsibilities of pilots and air traffic controllers in avoiding collisions, and sets out the standards for equipment and procedures to be used in order to maintain safe separation between aircraft. In particular, Annex 2 specifies the procedures and requirements for maintaining visual and instrument flight rules, as well as the requirements for air traffic services and communication procedures. It also provides guidance on airspace classification, minimum altitudes, and separation standards for different types of aircraft and operations. Overall, Annex 2 is a critical document for the safe and efficient operation of aircraft in the airspace, and is an important reference for pilots, air traffic controllers, and other aviation professionals.

In order to comply with the International Civil Aviation Organization's (ICAO) Annex 2 requirement for avoidance of collisions, remote pilots in command (RPICs) of unmanned aerial systems (UASs) need to have access to reliable and effective technological solutions. This section will explore some of the technological solutions that can be developed or adapted for RPICs to ensure the safe operation of UASs.

The technological solutions for RPICs to comply with ICAO Annex 2 can be broadly categorized into two types: detect-and-avoid (DAA) systems and sense-and-avoid (SAA) systems. DAA systems are designed to detect potential collisions and provide alerts or take corrective action to avoid them. SAA systems, on the other hand, use sensors to detect obstacles and other aircraft in the environment, and allow the UAS to maneuver around them.

There are several methodologies that can be used to develop or adapt these solutions. These include the use of radar, lidar, cameras, acoustic sensors, and machine learning algorithms to analyze sensor data and make decisions about how to avoid potential collisions. Additionally, communication technologies such as Automatic Dependent Surveillance-Broadcast (ADS-B), **[2]**, and cooperative and non-cooperative technologies can be used to enable communication between UASs and other aircraft.

The technological solutions for RPICs to comply with ICAO Annex 2 can be applied in a variety of scenarios, including deliveries, search and rescue, and surveillance. In delivery scenarios, UASs equipped with DAA and SAA

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[2] International Civil Aviation Organization (ICAO) Annex 2, titled "Rules of the Air,"provides essential regulations and procedures for the safe and orderly conduct of aircraft operations in international airspace. It outlines fundamental principles for flight, navigation, and communication, serving as a globally recognized standard to ensure harmonized aviation practices and enhance aviation safety.

systems can ensure that packages are delivered safely and efficiently without endangering people or property. In search and rescue scenarios, UASs can be used to locate people in need of assistance and provide critical supplies without putting human rescuers in harm's way. In surveillance scenarios, UASs can be used to monitor critical infrastructure and provide situational awareness without risking the safety of personnel.

Overall, the technological solutions for RPICs to comply with ICAO Annex 2 are critical for the safe and effective operation of UASs. By using a combination of DAA and SAA systems, as well as communication technologies, UASs can detect and avoid potential collisions, ensuring safe and efficient operation in a variety of scenarios.

In general, the considered main scenario of this project is the city of Florianopolis, Brazil. Thus, this analysis can be extended in the following approaches:

- **Delivery Drones:** Delivery drones, **[3]**, **[4]**, have the potential to revolutionize the delivery of goods in urban and suburban areas of Florianópolis. Equipped with DAA and SAA systems, drones can detect and avoid collisions with other aerial vehicles and objects in their path, ensuring fast and safe deliveries in hard-to-reach areas by land vehicles. The delivery of food and medicine can be especially important in areas with limited infrastructure or during emergencies.
- **Monitoring and Public Safety Drones:** Monitoring and public safety drones have multiple applications in Florianópolis, including monitoring traffic on public roads, surveillance of public events, detection of forest fires, and response to medical emergencies. With thermal imaging equipment and motion detection sensors, drones can detect suspicious activity or in hard-to-reach areas, providing vital information to public safety teams.
- **Drones Applied in Healthcare with Transport of Medicines and Organs** Drones applied in healthcare have the potential to save lives in Florianópolis. Equipped with cooling systems and temperature monitoring, drones can transport medicines and organs quickly and safely, reducing wait times and increasing the chances of successful transplants. Drones can also be used for emergency deliveries of medical equipment in remote areas of the city.
- **Maritime Surveillance Drones** The city of Florianópolis has a large coastal area, and maritime surveillance drones can be used to monitor the coast, detect suspicious activity, and perform search and rescue operations. Drones can be equipped with high-resolution cameras, radar, and motion detection sensors to detect ships in distress or people in need of help. They can also be used to detect pollution and monitor marine life in the area.
- **Offshore Platform Drones** Offshore platform drones can be used to inspect equipment and structures on oil platforms in Florianópolis, avoiding the exposure of workers to potential risks. With gas detection sensors, drones can also be used to detect leaks or other safety issues. In addition, drones can be used to transport spare parts and other equipment between platforms, saving time and money for oil and gas companies.

B. SIMUA-RQ02: Concepts and Technological Solutions for Automated Traffic Management in UTM Air Domain

The UTM (Unmanned Traffic Management) airspace domain, **[5]**, is a framework for managing the airspace in which unmanned aerial systems (UAS), commonly known as drones, operate. It includes the airspace up to 400 feet above the ground, which is where most drone operations take place, as well as higher altitudes for more advanced drone operations. UTM is designed to provide a safe and efficient system for integrating drones into the airspace alongside manned aviation, while also ensuring compliance with regulations and minimizing the risk of collisions. The UTM airspace domain is managed by a network of UTM service providers, which provide services such as flight planning, airspace authorization, and traffic management.

As the number of drones in the airspace continues to increase, the need for an efficient and safe traffic management system becomes critical. Unmanned Traffic Management (UTM), as discussed previously, is a framework that integrates drones into the airspace with manned aviation and provides the necessary infrastructure for managing drone operations. In order to achieve a more automated traffic management system for drones in the UTM airspace domain, certain concepts and technological solutions must be developed or adapted.

There are several methodologies that can be used to develop or adapt technological solutions for automated traffic management in the UTM airspace domain, including:

1) **Machine Learning and Artificial Intelligence**: Machine learning and artificial intelligence (AI) can be used to develop predictive models that can anticipate the behavior of drones and other aircraft in the airspace. These models can be used to generate alerts and warnings to pilots, allowing them to take the necessary action to avoid collisions. Machine learning can also be used to develop algorithms for automated traffic management, such as route planning and collision avoidance. For example, in **[6]** it demonstrates that the trajectory of a flight forms the basis for many decisions in the National Airspace System (NAS). These trajectories are generated by different modelers, using different inputs, within automation systems across several domains. Future evolution towards the Info-Centric NAS provides an opportunity to consolidate these modelers into a trajectory service. While some different modeling needs must still be supported, avoidable differences are removed, allowing a common basis for decision making across domains. Further, consolidation of a trajectory service through a microservices architecture enables more rapid evolution across all domains as new technologies mature and allows for external services when their use of private data improves performance. This paper presents a decomposition of the common trajectory services and outlines how the decomposition can be applied to meet present-day modeling needs and facilitate the transition from the present to the future vision.
   The Fig. 2 shows an integrated information environment provides the means of exchange for simulations to use real operational data.
   The simulations produce data and use the integrated

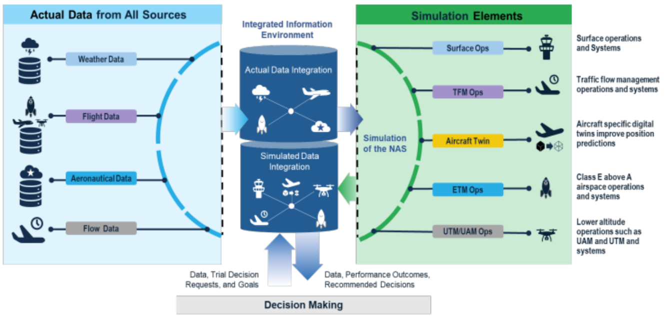

Fig. 2. Continuous Planning with Smart Systems

information environment as a means of exchange for ATS, operators, and xTM service suppliers to extract and utilize information needed to meet their performance goals. The left side of Fig. 2 shows actual operational data, such as weather, flight, flow, and aeronautical data that is collected from a wide range of sources. This data has varying levels of quality that are known and taken into consideration when modelling and making decisions based on the information derived from the data. The integrated information environment fuses the data from disparate sources to add context and transforms it into actionable information. The right side of the graphic shows several simulations and machine-learning sources at varying levels of abstraction ranging from TFM, ETM, and UTM operations, to detailed aircraft digital twins. The data obtained from these simulations are fused and put into context when sent to the integrated information environment and turned into actionable information for use by authorized NAS users. Parties interested in using data from the integrated information environment are able to send data, request trial decision evaluation, and submit performance goals. The integrated information environment, together with the associated simulation elements, can return data, predicted performance outcomes, and a range of recommended actions to achieve performance goals.

2) **Remote Identification and Tracking**: Remote identification and tracking (RID/T), **[7]**, is a key technology for UTM, as it enables the identification and tracking of drones in the airspace. RID/T systems can be used to establish a reliable and secure means of identifying drones and their operators, as well as tracking their movements in real-time. This information can be used by UTM systems to manage drone traffic and ensure safe operations.
3) **Communication and Data Exchange** Effective communication and data exchange is essential for automated traffic management in the UTM airspace domain. Technologies such as 5G and satellite communications can be used to provide reliable and secure communication links between drones, ground control stations, and other aircraft in the airspace. Standardized data exchange protocols can also be developed to ensure interoperability between different UTM systems. For example, in **[8]** is discussed that cellular networks are suitable only for terrestrial communication and have limitations in supporting aerial communications. These issues motivate the investigation of an appropriate communication technology for advanced UTM systems. Thus, this study presents a future perspective of 6G-enabled UTM ecosystems in a very dense and urban air-traffic scenario focusing on non-terrestrial features, including aerial and satellite communication - this scope is represented by Fig. 3.

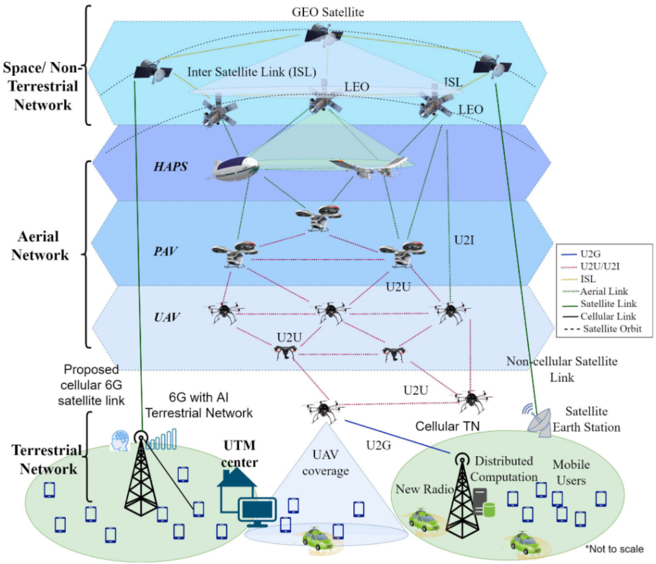

Fig. 3. 6G Communication Support for UTM Ecosystem

In addition, it relates the several urban airspace segmentation and discuss a strategic management framework for dynamic airspace traffic management and conflict-free UAV operations. The UTM enhances the adaptive use of the airspace by shaping the airspace with the overall aim of maximizing the capability and efficiency of the network
4) **Sensor Fusion**: Sensor fusion is the process of combining data from multiple sensors to provide a more accurate and comprehensive picture of the airspace. For UTM, sensor fusion can be used to integrate data from multiple sources, such as radar, lidar, and cameras, to provide a real-time view of the airspace. This information can be used by UTM systems to manage drone traffic and ensure safe operations. In LiDAR approaches, for example, **[9]** presents a Detect and Avoid system for the autonomous navigation of Unmanned Aerial Vehicles (UAVs) in Urban Air Mobility (UAM) applications. The current implementation is designed for the operation of multirotor UAVs in UAM corridors. During the operations, unauthorized flying objects may penetrate the corridor airspace posing a risk to the aircraft. In this article, the feasibility of using a solid-state LiDAR (Light Detecting and Ranging) sensor for detecting and positioning these objects was evaluated. The **[10]** approach is to have UTM integrations coupled with onboard machine vision which is tied to automated collision avoidance systems. Future BVLOS regulations in urban situations may require robust embedded software that is capable of detecting air collision hazards in realtime at near and far ranges as uncooperative small aircraft and other unpredictable small objects with fast-

changing and unscheduled trajectories pose significant hazards to UAS (Fig. 4). This work presents the concept and initial prototyping of a Digital Twin to evaluate the capability of UAS mounted LiDAR to detect small-object air collision risks.

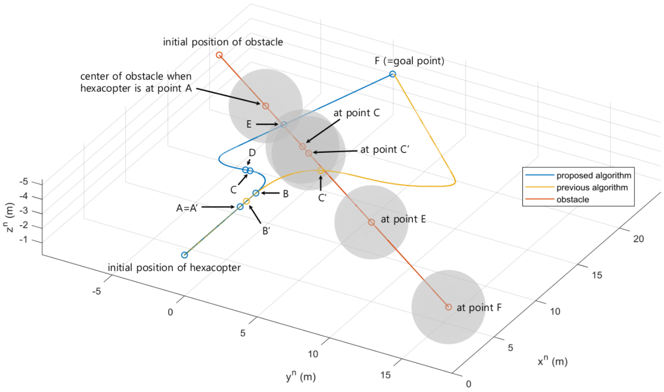

Fig. 4. Trajectories of the hexacopter and the obstacle

C. SIMUA-RQ03: Feasibility of Using Technologies Already in Place for Manned Aviation

As the use of unmanned aerial systems (UAS), or drones, becomes more widespread, the need for effective and safe integration of drones into the airspace is increasingly important. One potential approach is to adapt existing technologies and concepts that are already in use for manned aviation, and apply them to UAS operations. This report explores the feasibility of using technologies already in place for manned aviation, including the Daidalus approach developed by NASA.

The Daidalus approach, **[11]**, **[12]**, is a safety assurance framework developed by NASA that can be adapted for UAS operations. It uses a set of algorithms to detect potential conflicts and hazards in the airspace, and provides automated alerts and guidance to the pilot to avoid them. The Daidalus approach can be used for both manned and unmanned aviation, and has been tested in a variety of scenarios, including UAS operations.

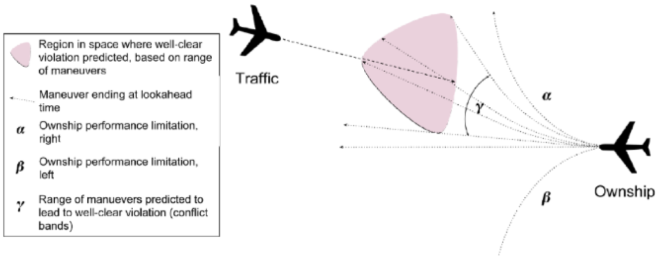

Fig. 5. DAIDALUS alert and guidance design principles

This method (Fig. 5) can be used for UAS traffic management in a similar way as for manned aviation. It can provide an automated system for detecting and avoiding collisions in the airspace, using a combination of sensors and algorithms. The approach can also be integrated with existing manned aviation traffic management systems, such as the Automatic Dependent Surveillance-Broadcast (ADS-B) system, to provide a more comprehensive view of the airspace. The feasibility of using technologies already in place for manned aviation for UAS operations depends on the specific technology and the characteristics of the UAS operations. The Daidalus approach developed by NASA is one example of a technology that can be adapted for UAS traffic management, and has been tested in a variety of scenarios. By conducting literature reviews, case studies, and experimental studies, it is possible to identify and evaluate other technologies and concepts that can be adapted for UAS operations.

D. SIMUA-RQ04: Concepts and Technological Solutions Applied to the Detect and Avoid Functions

The integration of unmanned aircraft into the airspace presents a host of intricate challenges. Ensuring collision avoidance and overall safety is paramount, necessitating the development of autonomous systems capable of preventing potential collisions. Unmanned aircraft lack the innate situational awareness of human pilots, making it imperative to replicate this awareness through advanced sensor technologies. These systems must also possess the ability to make rapid decisions in real-time, requiring the implementation of sophisticated algorithms.

Integrating unmanned aircraft into the existing Air Traffic Management (ATM) system is a complex task. This involves establishing effective communication protocols to ensure coordination with air traffic controllers and other aircraft. Moreover, regulatory compliance is a crucial consideration, demanding the development of technology that adheres to stringent aviation regulations and gains the necessary approvals.

The interaction between humans and machines plays a pivotal role. Designing intuitive user interfaces that allow operators to control unmanned aircraft effectively, especially in intricate scenarios, is challenging. Reliable communication and data links are essential for the seamless exchange of information between unmanned aircraft and ground control.

The environment in which unmanned aircraft operate is dynamic and often shared with various types of aircraft. This necessitates adaptable systems that can account for different operating characteristics and behaviors. Additionally, addressing public concerns related to privacy, noise, and safety is vital for building public trust and acceptance of unmanned aircraft operations.

In summary, the successful integration of unmanned aircraft into the airspace is contingent on addressing multifaceted challenges across safety, technology, regulation, communication, and public perception. Detect-and-avoid (DAA) technologies and other advanced solutions are pivotal for ensuring the harmonious coexistence of unmanned and manned aircraft in the shared airspace.

We have already made a walkthrough the existing DAA technologies, but other can be added, such as **[13]**, in which an improved fruit fly optimization algorithm (named ORPFOA) is proposed to solve the path planning problem in both initial task sequences and new task sequences after tasks change, in which the optimal reference point and a distance cost matrix are used to reach both faster solving and higher optimizing precision for the optimal flight path.

In **[14]**, a flyable path planning for multi-UAV systems is presented by using a Genetic Algorithm (GA) in a known environment at a constant altitude. A feasible path is firstly calculated by GAs, and then this path is smoothed by using Bezier curves. Experimental results indicate that the proposed approach produces effective and feasible paths for each UAV in a multi-UAV system. System is implemented in Java with a GUI for presenting results. The paper also draws future works that can be done on this topic.

Finally, **[15]** presents an efficient and feasible algorithm for the path planning problem of the multiple unmanned aerial vehicles (multi-UAVs) formation in a known and realistic environment. The artificial potential field method updated by the additional control force is used for establishing two models for the single UAV, which are the particle dynamic model and the path planning optimization model. The additional control force can be calculated by using the optimal control method.

IV. FINAL REMARKS

For next steps, it is necessary to study the feasibility of the highlighted approaches along with the designed models. And, to embed the methods and validate the main Detect and Avoid functions in potential risk scenarios. As an alternative, to addapt those methods for different use cases and manage multiple sensors to make a real-time safe decision.

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