A FRAMEWORK FOR EVALUATING UAVS PATH PLANNING IN LOW-ALTITUDE ENVIRONMENTS

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ABSTRACT

The development of disruptive technologies has changed the way the airspace operates. In fact, the improvements regarding safety and efficiency achieved highlight the opportunity for enhancing existing products, such as the Unmanned Aircraft Vehicles (UAVs). Although UAVs can be used in several applications, challenges faced by the research community rely on how these robots can operate autonomously and collaboratively. In this paper, we present a framework for enabling the test of different strategies regarding path planning in low-altitude environments. Finally, interfaces for measuring the quality of the solutions provided by local behaviours embedded in UAVs are proposed.

Keywords: Unmanned Aircraft Vehicles (UAV), Path Planning, Efficiency.

1. INTRODUCTION

Nowadays, air transportation is essential for society and it is increasing gradually (Marquart, 2003). The annual number of flights annually is large, which leads to a high revenue. Conversely, aviation is composed by a variety of safety-critical systems. This systems demand a special effort from developers, companies, final users and authorities in order to guarantee a minimum safety level, i.e., to reduce the probability of incidents and accidents. Indeed, safety is a key metric in aviation and procedures have been produced and redesigned in order to attend several safety requirements. Thus, efficiency is another key metric regarding the airspace operation, which can be associated to the profitability of air traffic (FINAVIA, 2015). As these two metric may oppose each other in many situations (e.g., a higher safety level may lead to huge separation between the aircraft, which reduces the number of aircraft operating simultaneously from a global perspective), a challenge in air space optimisation is to balance them. The best scenario regarding this optimization process is to find highly efficient solutions that respect all safety requirements, which is not possible in some situations. Instead, the solutions provided must be contained in a set of solutions considered appropriate.

In the past few years, there has been a growth in Unmanned Aircraft Vehicles (UAV) numbers (Guerin, 2015). This increase was perceived in segregated airspaces, i.e., the UAVs are not common to operate along with traditional commercial aircraft. In this sense, in the following years, there is an understanding that the number of UAVs in low altitudes (e.g., urban environments) tends to rise considerably. Furthermore, there are some organisations investing in the development of such technology, such as The Boeing Company and NASA.

Moreover, there are many areas in which UAS can be applied to and are still under development. Examples of these areas are:

- Mapping ([redacted]);
- Irrigation (Shi,2018);
- Delivery Monitoring System ([redacted]);
- Delivery Services ([redacted]);
- Firefighting (Yu, 2018);

One important challenge in this context is the path planning. This challenge consists in defining efficient and safe routes that a set of UAVs must follow. Indeed, there are many works that focus on path planning. For instance, there are works focused on digital terrain model reconstruction (Yang, 2018), critical situations (Silva Arantes, 2017), search and rescue ([redacted]), and obstacle avoidance ([redacted]).

In this context, the main goal of this research is to propose a framework for evaluating UAVs path planning in low-altitude environments. This framework aims to offer the possibility of building scenarios as well as solutions regarding path-planning and the its quality (e.g., efficiency).

This paper is organized as follows: Firstly, Section II presents the related works. Secondly, Section III presents the main contribution of this research, i.e., the framework for evaluating the quality of paths of UAvs. Then, Sections IV and V presents, respectively, the experiments conducted and the discussion. Finally, Sections VI presents the conclusion of this research.

2. RELATED WORKS

The authors in (MahmoudZadeg, 2018) propose a hierarchical dynamic mission planning framework for AUV with focus on task-assign process in restricted time in uncertain undersea environments. The authors describe the Biogeography-Based Optimization (BBO) algorithm and how it can be applied to local path planning considering, for instance, the path constraints. The results showed that the proposed strategy is able to provide efficient solutions in real-time challenges. However, this paper is focussed on the UAV reality, i.e., although the concept of path planning is similar, the routes as well as the way the routes are built are different.

In (Yu et al., 2018), the authors present a centralized algorithm framework for dealing with multi-robot path planning problems. The framework aims to offer possibilities regarding path planning problem in 2-D continuous environments with high effectiveness level by means of a discretization of the continuous problem. The authors present a detailed description of their contributions as well as possible future directions. However, the authors focus in a wide range of robots. Furthermore, the framework in focussed in solving problems. In addition to this research, our proposal focus on evaluating solutions proposed for specific problems involving small UAVs.

In (Wu et al., 2018), the authors propose a solar-powered UAV path planning framework with focus on complexity and other constrains of urban environments. Indeed, these environments present many challenges from the operational perspective, and the inclusion of solar-powered systems makes it even harder. In order to accomplish this, the authors propose a strategy for obstacle avoidance. After that, the process of planning is executed. In summary, the authors employ the Restrained Interfered Fluid Dynamical System (RIFDS) and the Whale Optimization Algorithm (WOA). Finally, specific metrics are employed to solve the accurate modelling problem of solar energy in urban environments. The experiments presented showed the proposed approach achieves good solutions for the problem faced. In addition to this contribution, our proposal aims in offering a platform for measuring the quality of the solutions proposed and considers extensions of this metrics by means of database manipulations.

In (Alam, 2008), the authors introduce the Air Traffic Operations and Management Simulator (ATOMS). This aims to model and to simulate free-flight concepts with a focus on end-to-end airspace operations and air navigation procedures for conventional air traffic. Indeed, the focus of this contribution is related to the shared airspace. It also adopts a multiagent-based modeling paradigm for modular design and easy integration of various air traffic subsystems. Finally, advanced air traffic management (ATM) concepts are considered in this research, including Airborne Separation Assurance (ASA), cockpit display of traffic information (CDTI) and weather avoidance. The results showed appropriate scenarios can be achieved for free flight. However, this research does not consider small UAVs in low altitude scenarios.

The authors present a distributed air traffic flow management model aiming to address the four-dimensional trajectory planning in (Alam, 2017). This approach, which considers the European Functional Airspace Blocks (FAB), is a concept adopted in European airspace for allowing cooperation. Indeed, improves the air traffic flow regarding efficiency and. Safety. Moreover, this distributed approach of flow management enables the information sharing between airspace blocks in strategic planning. This minimizes the interaction between trajectories, i.e., possible unsafe states. This method is implemented and tested with a real air traffic data (European airspace) and interaction-free 4D trajectories are produced in short computational time. The results showed that this strategy reduces the interactions effectively. In addition to this outstanding contribution, we propose a method for evaluate the fitness (quality) of path planning strategies in low altitude environments.

3. FRAMEWORK

This research is focused on low altitude environments, in which the aircraft are conducted to different objective points. The UAVs considered herein are quadcopters. Note that these UAVs may have an objective point in any region, as well as may have a start point in any region. Furthermore, this can become complex and difficult as specific factors appear, such as increase in the traffics numbers. This makes the path planning more complex and finding a near-optimal solution may not be simple.

In this framework JSON scripts are employed for describing the airspace (i.e., the UAVs and the objective points).The aircraft's state is represented its position. In this first approach, we consider a constant speed of

20kts (or 37,04 km/h, or approximately 10m/s), which is reasonable for small UAVs. Finally, the position of the aircraft is a tuple (x,y) that represents a point in the Cartesian plane, i.e., the framework considers a 2D scenario in order to simplify the representation and focus on the path planning process itself. The simulations are driven by ticks, which represents a duration of 5 seconds in the real world for approximation purposes. For instance, considering that 1 knot (kt) is equivalent to 1 nautical mile (nm)/ hour (h) and that 1kt is equivalent to 0.000278nm/ second (s), if the aircraft is performing a speed of 20kt (or, approximately, 10m/s), in 6 second (1 tick or 1 loop execution) it flies 60m. Finally, the minimum separation adopted is 60m, according to (DECEA, 2016).

The operation of the UAVs is conducted into a squared region. The area of each square is exactly 3600m² as the minimum separation between the UAVs is 60m. Moreover, the UAVs are able to move to any direction, one square per simulation tick.

In order to accomplish what is expected from the UAVs, a function implemented performs the following process: given a position indicated into the JSON as objective point, the UAV flies in the direction of it by selecting the square that reduces the distance between the UAV and the objective point. The approach sequencing finishes when all aircrafts are delivered to this point.

The outputs of the simulations consists into a pandas Data Frame (Pandas, 2018), which can be faced as a dataset that describes the movements conducted. It is worth noting that the metrics are extracted from this data and different metrics (e.g., complexity metrics) can be derived from this data. One example is the minimum distance between UAVs throughout the time. Basically, the efficiency if expressed in terms of the numbers of tick the simulation took to be finished, i.e., it presents the solution quality. It may be short or long, depending on the situation presented.

4. CASE STUDY

In this section, the case studies are presented. The main objective is to show the applicability of the proposed approach. In the following experiments, the red stars represent the final and intermediate objective points that the UAVs must reach. These aircraft and their position (i.e., the position of the square the UAV is located in) are also illustrated. It is worth noting that the distances and positions consider Meters (m) as measure unit. Firstly, we present a simple case study, in which two UAVs are presented. Secondly, a more complex case study is presented, which considers two UAVs with crossing paths. Finally, a complex scenario is presented, which considers 20 UAVs flying simultaneously. In each case study, (i) the script for building the scenario faced, (ii) the frames that illustrate the simulation process and (iii) the minimum distance of all UAVs presented on that scenario are described.

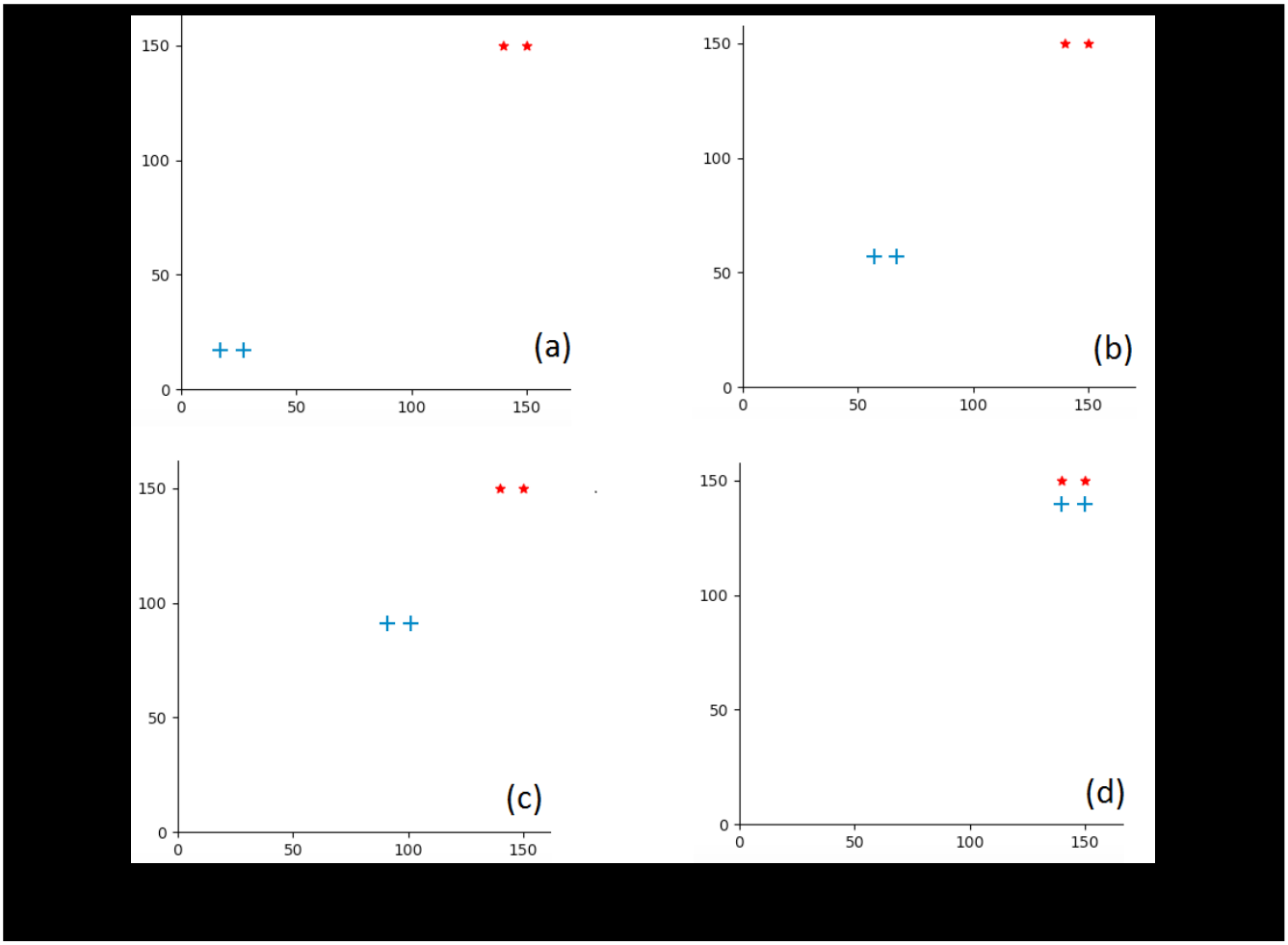
4.1. Case Study I

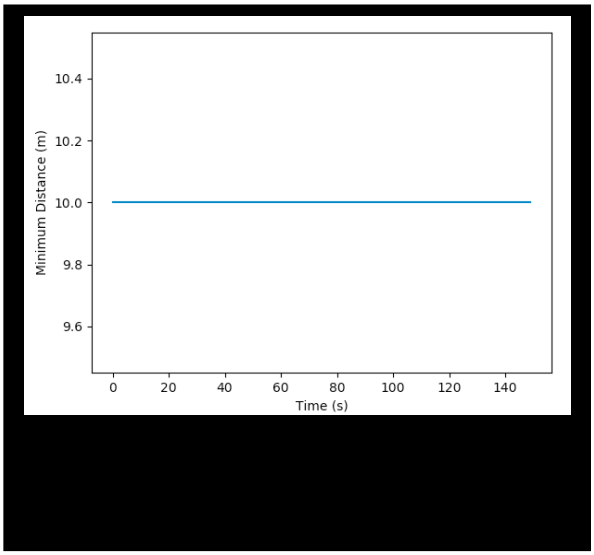
In this case study, a simpler scenario is faced. This scenario considers two UAVs with two different objective points. Figure 1 shows the script used for building this

```
{
    "aircraft_list":
    [
        {
            "x":0,
            "y":0,
            "obj_list":[[140,150]],
            "id":1
        },

        {
            "x":10,
            "y":0,
            "obj_list":[[150,150]],
            "id":2
        }
    ]


}
```





scenario (considering a direct flight).

The first UAV is within the square which is set at the position (0,0), whereas its only objective point is set at the square (140,150). The second UAV is set at the position (10,0), whereas its objective point is set at (150,150). It is worth noting that the x position of the second UAV is greater than the x position of the first UAV, and so is the difference of the objective points.

The simulation, presented in Figure 2, shows that both UAVs are able to achieve their objective points successfully, without any crash. Finally, the distance between these aircraft, illustrated in Figure 3, is constant (10m). Finally, the duration of the solution proposed is 906 seconds.

4.2. Case Study II

In this case study, a more complex scenario is faced. This scenario considers two UAVs with two opposite objective points, i.e., the path of these UAVs may cross depending on the solution proposed Figure 4 shows the script used for building this scenario (considering a direct flight).

The first UAV is set at the position (0,100), whereas its only objective point is set at (90,10). The second UAV is set at the position (0,0), whereas its objective point is set at (90,90). In this case, the objective points are set at opposite positions.

The simulation, presented in Figure 5, shows that both UAVs are unable to achieve their objective points once there is a collision, i.e., the solution proposed (direct flight) conducted these aircraft to the same position

```
{
    "aircraft_list":
    [
        {
            "x":0,
            "y":100,
            "obj_list":[[90,10]],
            "id":1
        },

        {
            "x":0,
            "y":0,
            "obj_list":[[90,90]],
            "id":2
        }
    ]

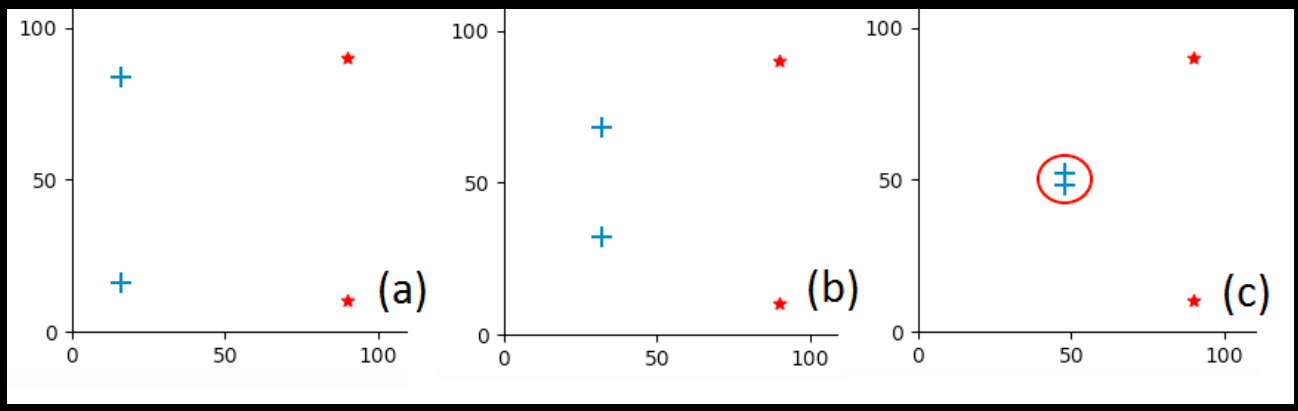

}
```

distance graph, as illustrated in Figure 9. The distance, in this case, decreases when the UAVs are close to each other (during the paths crossing) and increases when the UAVs fly in the direction of their objective points (Figure 10).

4.3. Case Study III

In this case study, a complex scenario is considered, in which 20 UAVs different objective points operates into the airspace It is worth noting that these UAVs as well as their objective points are set on a greater range.

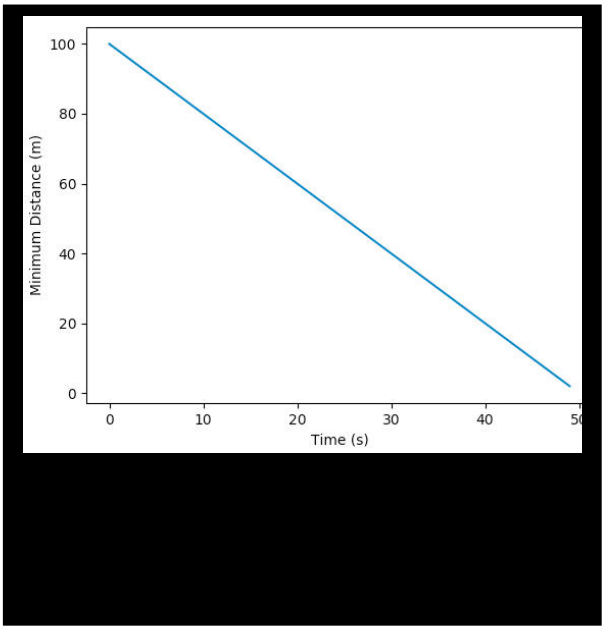
The simulation, presented in Figure 11, shows the UAVs are not able to be delivered to their objective points safely, i.e., there is a collision. This highlights that as the number of UAVs increases, the complexity regarding finding appropriate solutions is also



at the same time (306 seconds). Naturally, the distance between these aircraft decreases thought the UAVs operation, as illustrated in Figure 6.

In order to deliver these UAVs successfully, additional objective points may be included. For instance, the first UAV can be conducted to the point set at the position (40,20) before going to its final objective point, as illustrated in the script for building the scenario and solution presented in Figure 7.

In this case, as illustrated in Figure 8, shows that both UAVs are able to achieve their objective points once the collision is avoided. Indeed, there is a change into the



```
{
    "aircraft_list":
    [
        {
            "x":0,
            "y":100,
            "obj_list":[[40,20],[90,10]],
            "id":1
        },

        {
            "x":0,
            "y":0,
            "obj_list":[[90,90]],
            "id":2
        }
    ]

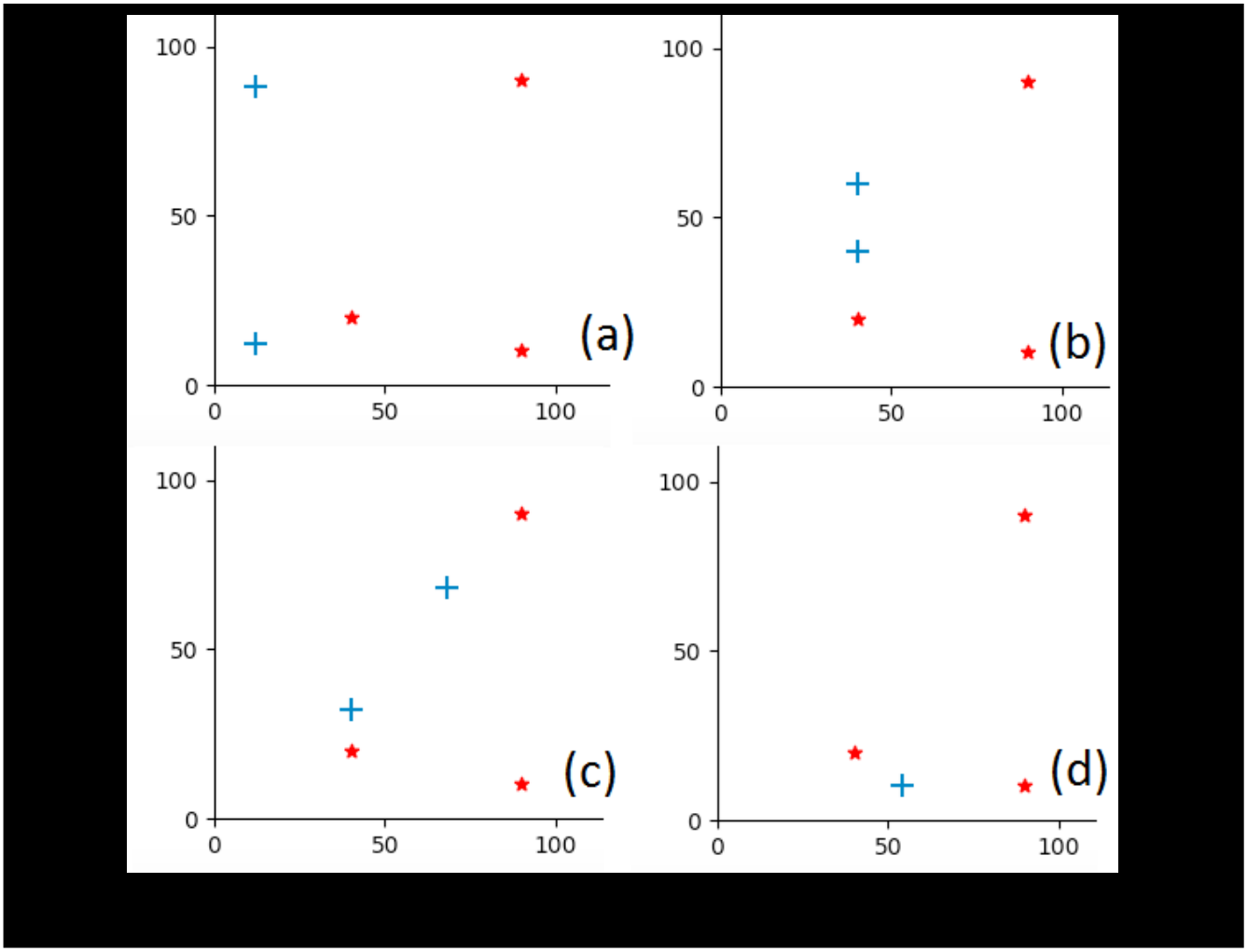

}

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increased. Note that the minimum distance of two UAVs varies considerably throughout the simulation (Figure 12).

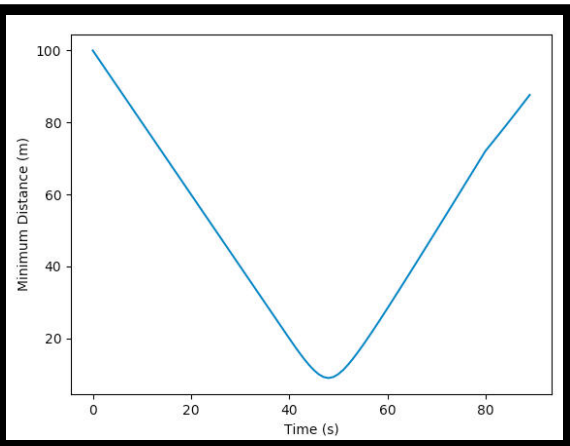
Conversely, a similar scenario, with 20 UAVs, is considered. In this case, though, the UAVs are able to be delivered safely, as illustrated in Figure 13. The minimum distance varies substantially throughout the time (i.e., according to the UAVs delivery), as presented in Figure 14. Finally, this solution presented 1116 seconds of duration.

Conversely, a similar scenario, with 20 UAVs, is taken into account. In this case, though, the UAVs are able to be delivered safely, as illustrated in Figure 13. The minimum distance varies substantially throughout the time (i.e., according to the UAVs delivery), as presented in Figure 14. Finally, this solution presented 1116 seconds of duration.



5. DISCUSSION

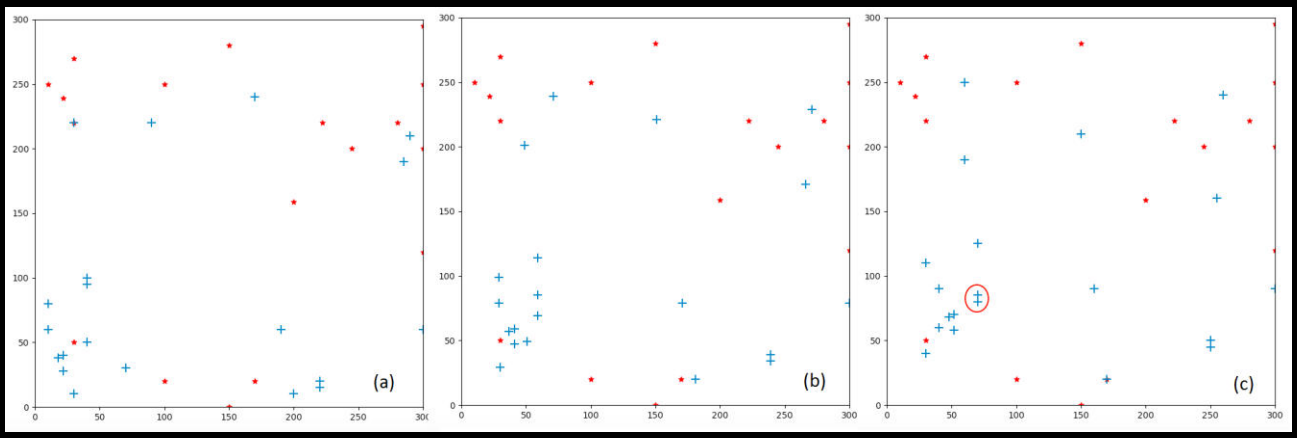
The first case study presented a simple scenario, which considered a uniform distance between the UAVs. It can be faced as an approach to use the proposed approach in evaluating a direct flight in a small area. Indeed, although its duration is not small in comparison to the other case studies (906 seconds), the airspace is free of other flights and the probability of facing paths crossing is reduced.



simple situation, a proper approach is suitable.

The alternative solution proposed, though, is able to overcome this challenge. Note that this experiment is short with duration of 306 seconds, i.e., even in small areas, challenging situations may show up. Finally, by handling the dataset, new constraints can be inputted, such as minimum acceptable separation of UAVs. In this case, the solution proposed may not be appropriate and alternative objective points may be needed.

Finally, a broader area is presented in the case study III. The main goal is to



It is worth noting that the proposed approach returns the movements of the UAVs as a time series within a pandas data frame. Indeed, different strategies of measuring the quality of the solution can be considered based on different computations using the dataset. Finally, note that the solution proposed (direct flight for both UAVs) is an optimal solution, i.e., including new objective points (that do not rely on the path already designed) conducts the solution not to be optimal.

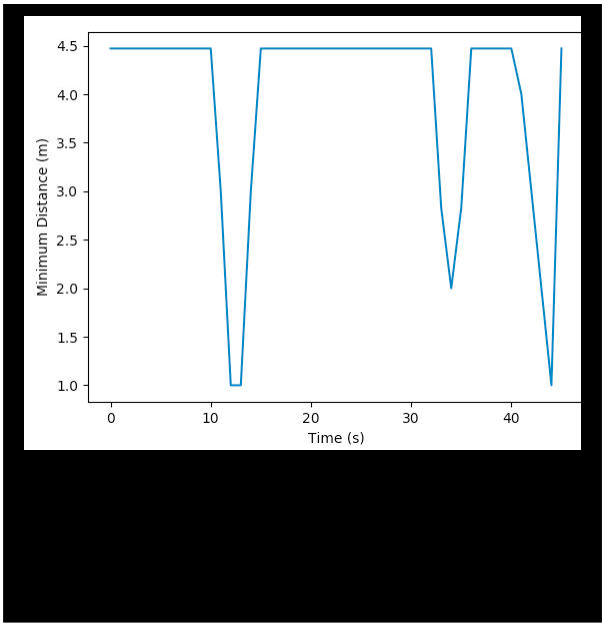
Furthermore, the case study II stands out as a challenge. The UAVs are set with opposite positions and a collision is identified. In this case, the data frame indicates the state of both aircraft as "crashed". This highlights the need for a careful path planning in order to maintain the airspace safe. Even in this

presented how complex a path planning strategy can be when considering a more realistic scenario. Indeed, 20 UAVs are considered, but in a real-world scenario hundreds of UAVs may be taken into account. Thus, the first solution represents a collision due to the difficulty faced in the planning using the direct flight approach. In order to solve this delivery problem,

Conversely, the second scenario presented shows that direct flights may be applied successfully. Indeed, this scenario allows the UAVs to be safely delivered by employing a direct flight strategy. Albeit large, the area faced herein is composed of UAVs with considerably short paths, which conducts the simulation to be finished quickly (1116 seconds).

Finally, the minimum distance of the UAVs varies throughout the operation and shows that when most of the UAVs are

delivered, the distance rises. Thus, handling the data frame returned, new constraints can



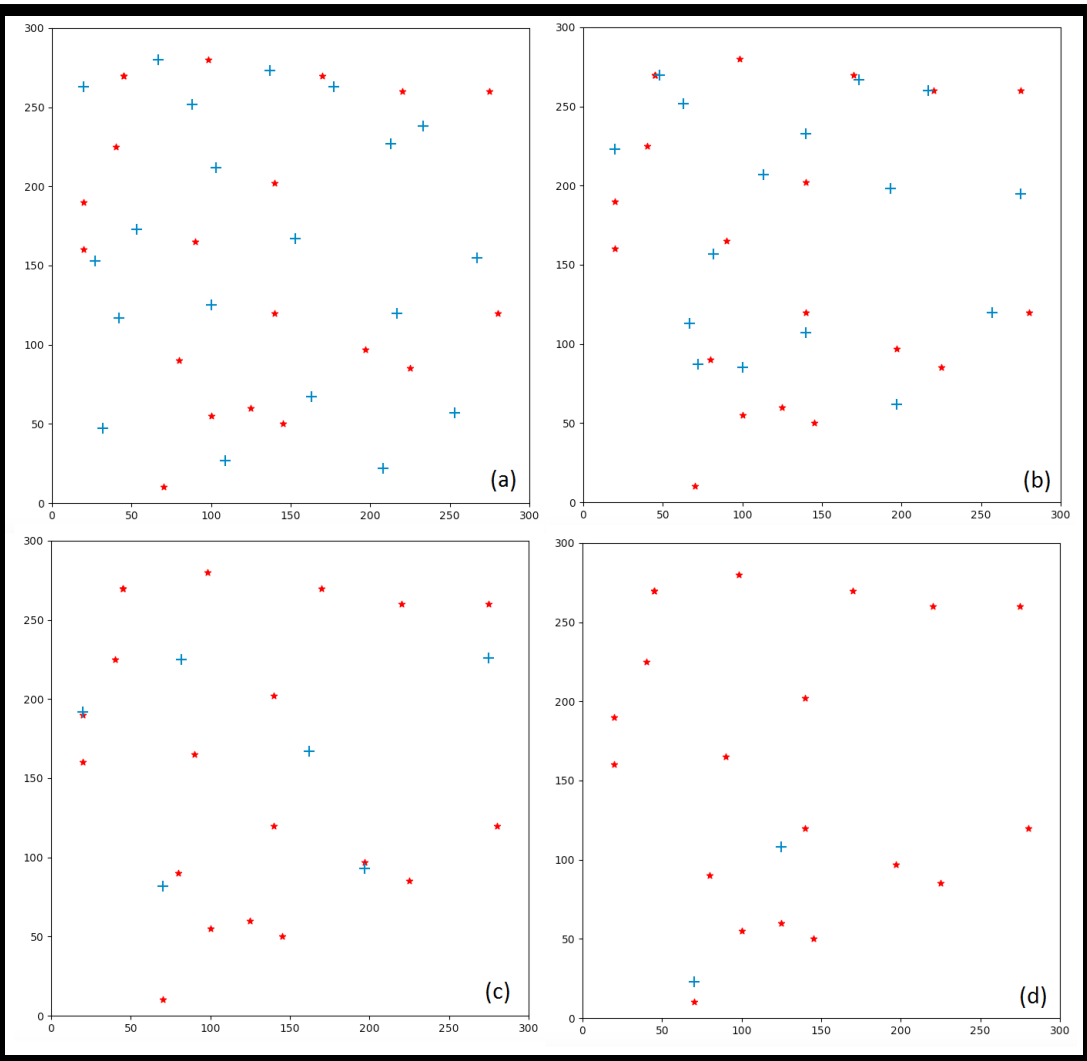
be inputted, e.g., minimum separation accepted and restricted areas.

6. CONCLUSION

In conclusion, this research presented a framework for enabling the test of different strategies regarding path planning in low-altitude environments. Different case studies were presented, which highlighted the applicability of the proposed strategy. As future directions, the authors aim to enhance the framework by considering advanced UAVs representations.

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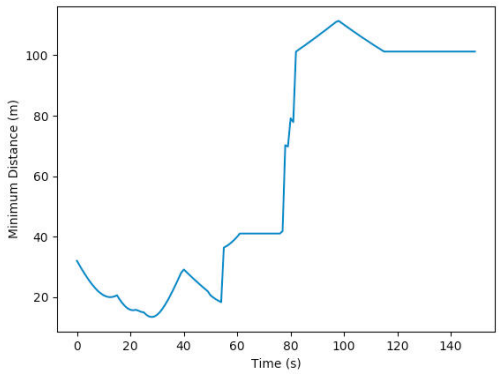


Figure 12. Distance between these aircraft throughout the simulation (scenario II, case study III).