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Multi-UAV Path Planning and Collision Avoidance Based on Particle Swarm Optimization (PSO)

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Date:2022/1/12

Outline

1. Background

A. Drone Package Delivery
B. Path Planning
C. Vehicle-to-Vehicle Communication

2. Motivation and Goals

3. Literature Review

4. Methodology

5. Initial Result

6. Conclusion and Future Work

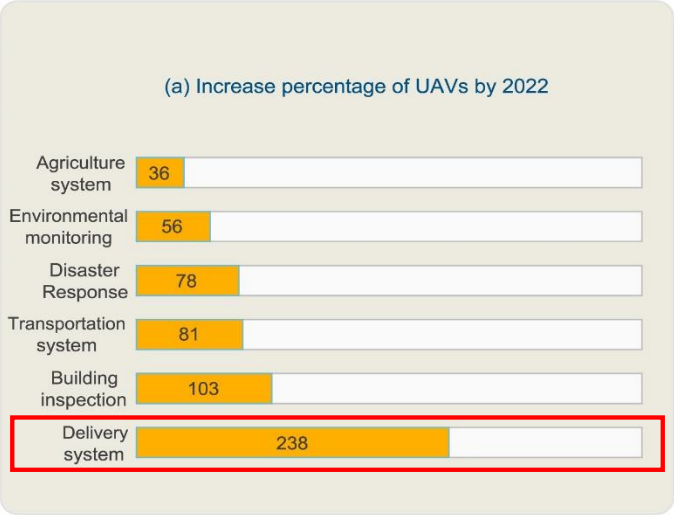
1. Background

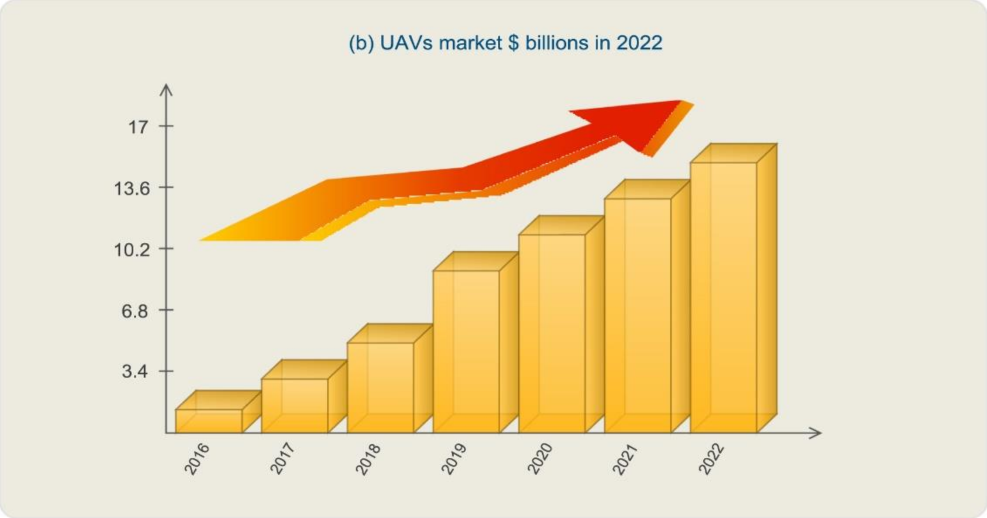
A. Drone Package Delivery
B. Path Planning
C. Vehicle-to-Vehicle Communication

1. Background

A. Drone Package Delivery

- In recent years, with the manufacturing technology of UAV rapidly developing, UAV has become a widespread product.
- UAVs are widely used in different fields these days, such as military applications, **package delivery**, etc.
- Drone package delivery requires a **unmanned aircraft system traffic management (UTM)** system to ensure that the package can be safely delivered to the destination.





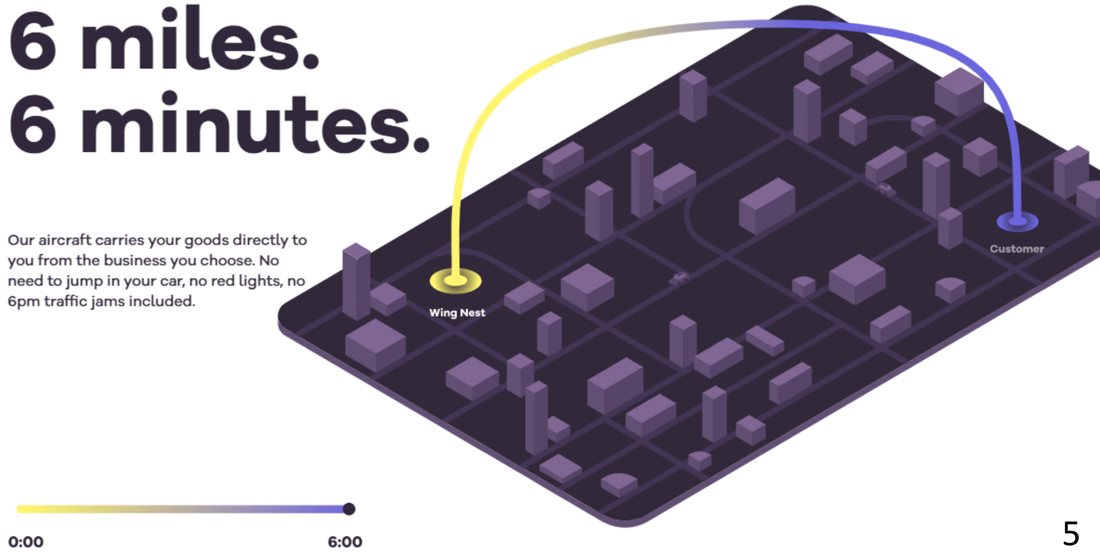
[1] Shubhani Aggarwal, Neeraj Kumar, Path planning techniques for unmanned aerial vehicles: A review, solutions, and challenges, Computer Communications, Volume 149, 2020.

1. Background

A. Drone Package Delivery

Wing

- Delivery drone
- UTM system plans a route designed to avoid obstacles and meet regulatory requirements
- Small packages that weigh approximately 1.2 kg or less



From: https://wing.com/

1. Background

A. Drone Package Delivery

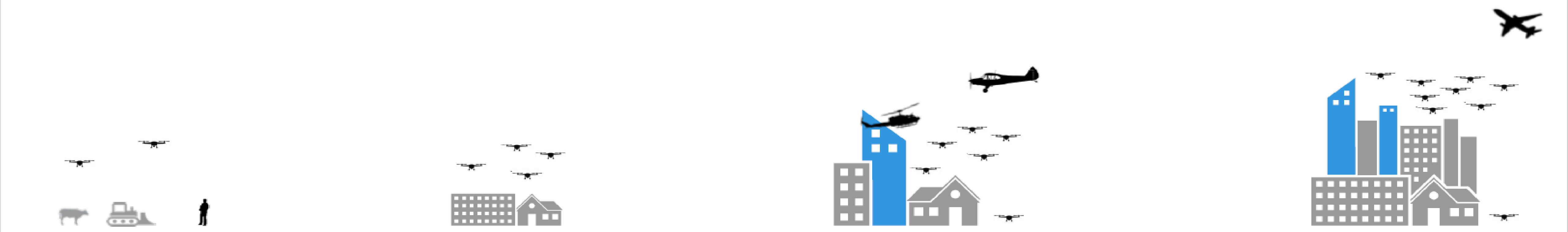
迅蚁
antwork

- Delivery drone, UTM system, distribution stations in the city
- Packages that weigh approximately 5 kg or less
- Maximum range 20km

From: https://www.antwork.link/index.html

1. Background

A. Drone Package Delivery



TCL1 (Remote)
- Visual Line of Sight
- Notice of Operation
- Position-Sharing (Optional)

TCL 2 (Rural)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment

TCL 3 (Suburban)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment
- Conflict Alert
- Detect and Avoid (DAA)
- Vehicle-to-Vehicle (V2V)

TCL 4 (Urban)
- Beyond Visual Line of Sight
- Intent Sharing
- Strategic De-confliction
- Geographic Containment
- Detect and Avoid (DAA)
- Vehicle-to-Vehicle (V2V)
- Obstacle Avoidance
- Dynamic Re-routing

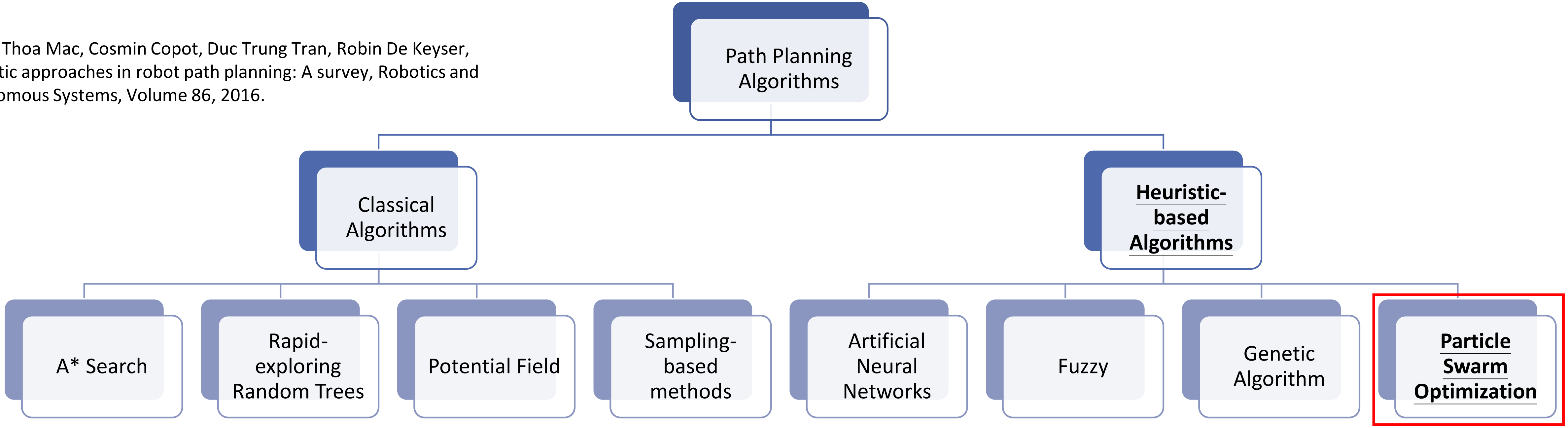
From: https://www.nasa.gov/utm

1. Background

B. Path Planning

- Path planning is one of the most important problems to be explored in UAVs for finding an optimal path between source and destination.
- The aim of path planning techniques is not only to find an **optimal** and **shortest** path but also to provide the **collision-free** environment to the UAVs.

[1] Thi Thoa Mac, Cosmin Copot, Duc Trung Tran, Robin De Keyser, Heuristic approaches in robot path planning: A survey, Robotics and Autonomous Systems, Volume 86, 2016.



1. Background

C. Vehicle-to-Vehicle Communication

In order to achieve collision avoidance, UAVs must have the ability to sense other UAVs.

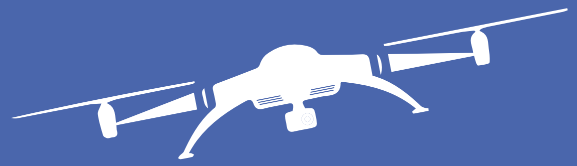
— Cooperative sensors:

- Traffic Alert and Collision Avoidance System (TCAS)
- Automatic Dependent Surveillance – Broadcast (ADS-B)
- ***Wireless Sensor Network (Wi-Fi, Zigbee, Bluetooth, etc.)***

— Non-cooperative sensors:

- Laser/Light Detection and Ranging (LIDAR)
- Sound Navigation and Ranging (SONAR)
- Camera

1. Background



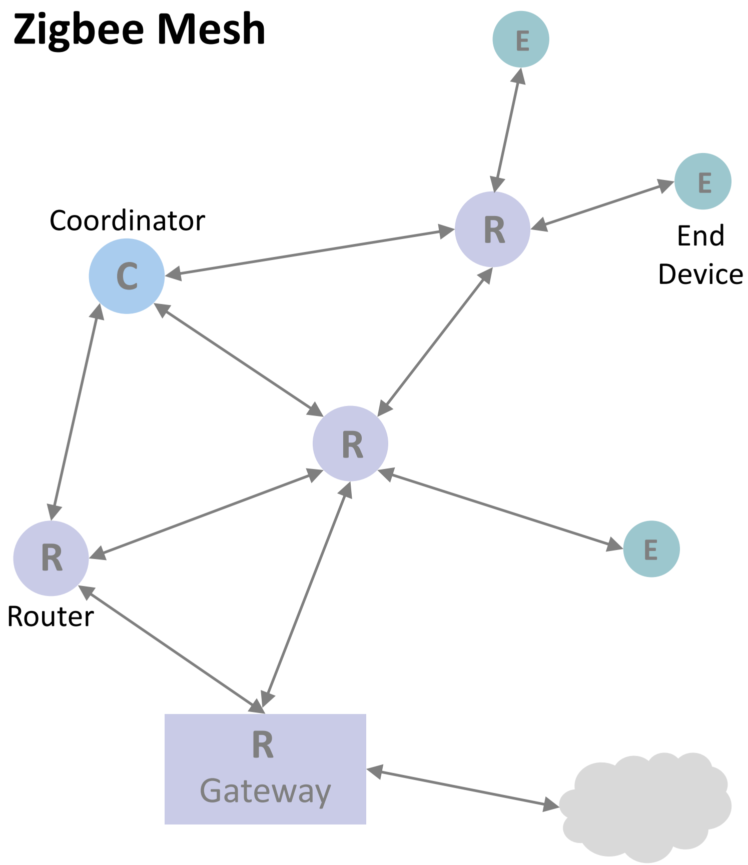
C. Vehicle-to-Vehicle Communication

	Zigbee	Wi-Fi	Bluetooth
Range(meter)	10 to 100	100	10
Topology	Mesh, star, and cluster tree	Star and point-to-point	Piconet
Data Rate	250kb/s	54Mb/s	3Mb/s
Cost	Low	High	High
Power Consumption	Very low	High	Medium
Battery Life	Months to years	Hours	Days
Network Nodes	65000	32	8
Benefits	Low power and low cost, reliability, scalability	Speed, flexibility	Convenience

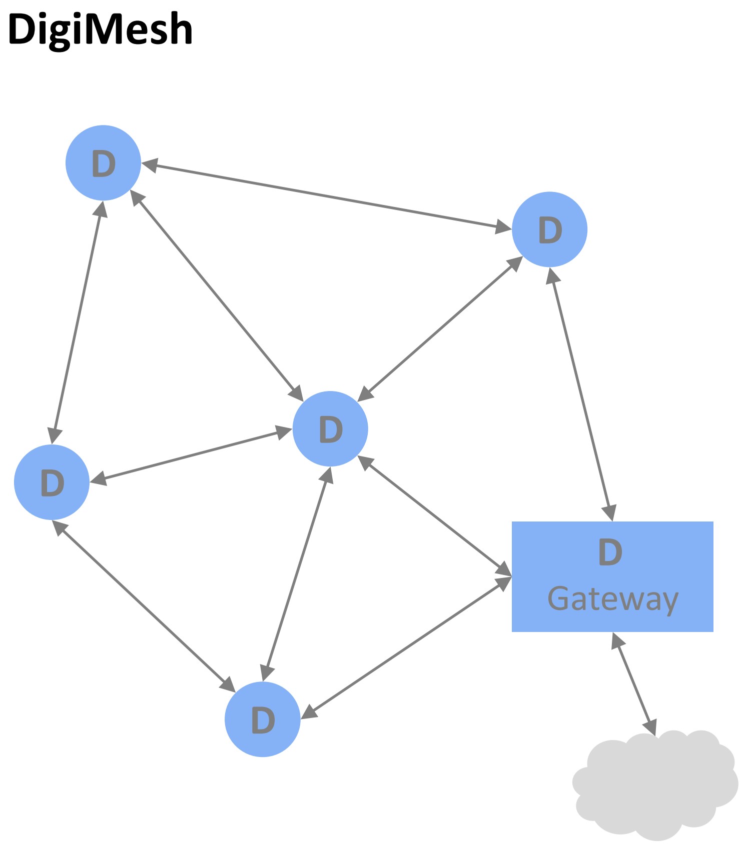
[1] Haider Mshali, Tayeb Lemlouma, Maria Moloney, Damien Magoni,
A survey on health monitoring systems for health smart homes,
International Journal of Industrial Ergonomics, Volume 66, 2018.

1. Background

C. Vehicle-to-Vehicle Communication



	Zigbee Mesh	DigiMesh
Node types	Coordinators, Routers, End Devices	One homogeneous node type
Range	less than 2 miles (3.2 km) for each hop	up to 40+ miles (64km) for each hop
Frame payload & throughput	Up to 80 bytes	Up to 256 bytes
Advantage	End devices are less expensive because of reduced functionality.	It **is more flexibility to expand the network**, and simplifies network setup and reliability.



From: https://www.digi.com/blog/post/what-are-the-differences-between-digimesh-and-zigb

2. Motivation and Goals

2. Motivation and Goals

- Motivation:
  - ➢ The demand for drone package delivery is increasing, so an operating system is needed to allow drones to deliver safely and efficiently.
  - ➢ When multiple UAVs are operating, effective methods are needed to plan paths and collision avoidance between each other.

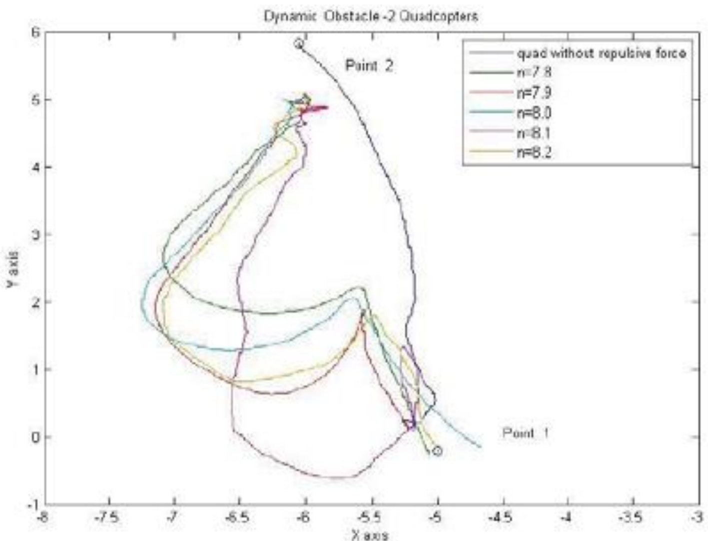
- Goals:
  - ➢ To implement UAV swarm system.
  - ➢ To generate the overall shortest and optimal path for the multi-UAV system.
  - ➢ To ensure that there is collision-free between UAVs.
  - ➢ To dynamically plan paths when UAVs encounter a collision risk during flight

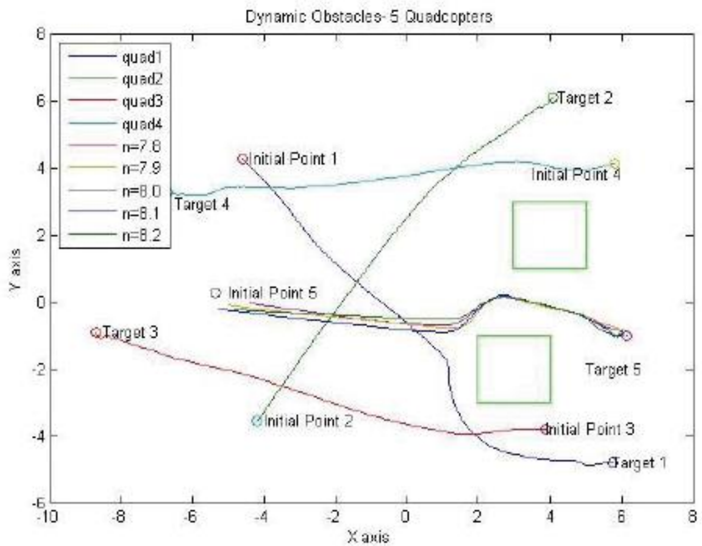
3. Literature Review

3. Literature Review

1	A. Budiyanto, A. Cahyadi, T. B. Adji, O. Wahyunggoro, **UAV obstacle avoidance using potential field under dynamic environment.** ICCEREC, 2015.

- In this paper, the **potential field** principle is applied to several UAVs for optimal path planning.
- The **attractive potential function** was used to attract the UAV to the desired position while the **repulsive potential function** was implemented to repel the collision when the UAV approached the obstacles in certain distance.
- The results of this research controlled **thrust** by applying attractive and repulsive forces.
- **Shortage:** The potential field is hard to calculate in the real world, and the optimal path cannot be guaranteed. In addition, it may lead to a deadlock.

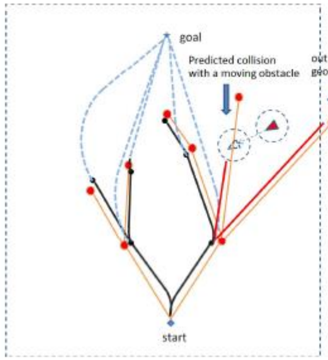


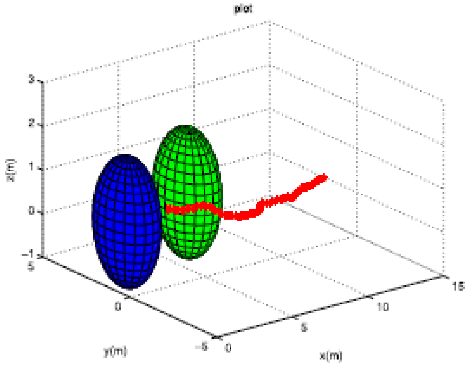


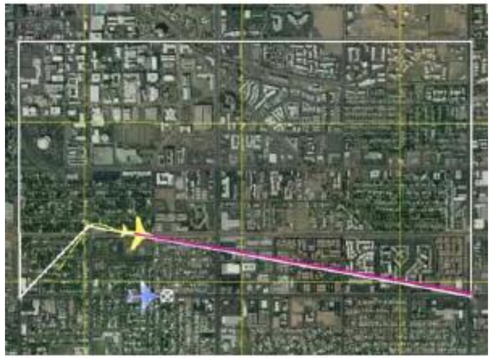
3. Literature Review

2	L. Yucong, S. Srikanth, **Sampling-Based Path Planning for UAV Collision Avoidance**. IEEE Transactions on Intelligent Transportation Systems. 2017 ; Vol. 18, No. 11.

- The authors develop and demonstrate a method based on the **closed-loop rapidly-exploring random tree(RRT)** algorithm and three variations of it.
- The experiments showed that the algorithms were able to guide a UAV to **avoid moving obstacles of different numbers, speeds, and headings**.
- The experiments also proved that the planners were able to work across different UAV platforms.
- **Shortage:** The calculation of RRT is time-consuming. And the sampling-based methods are probabilistically complete, in other words, they cannot determine if no solution exists.



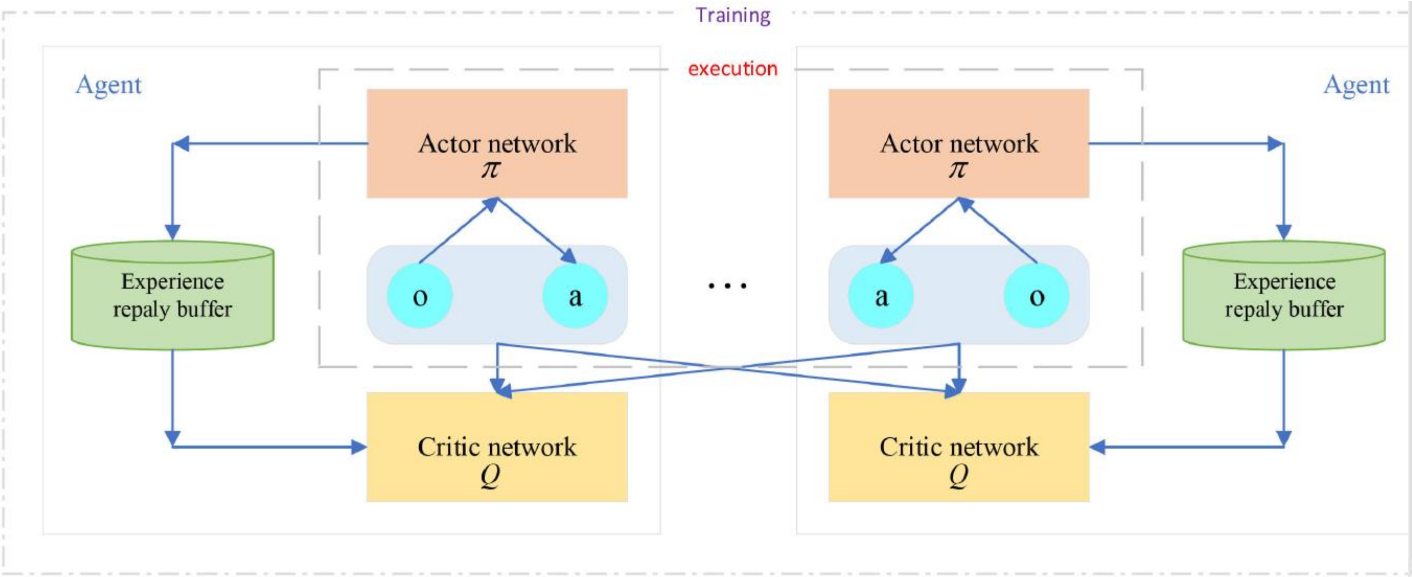


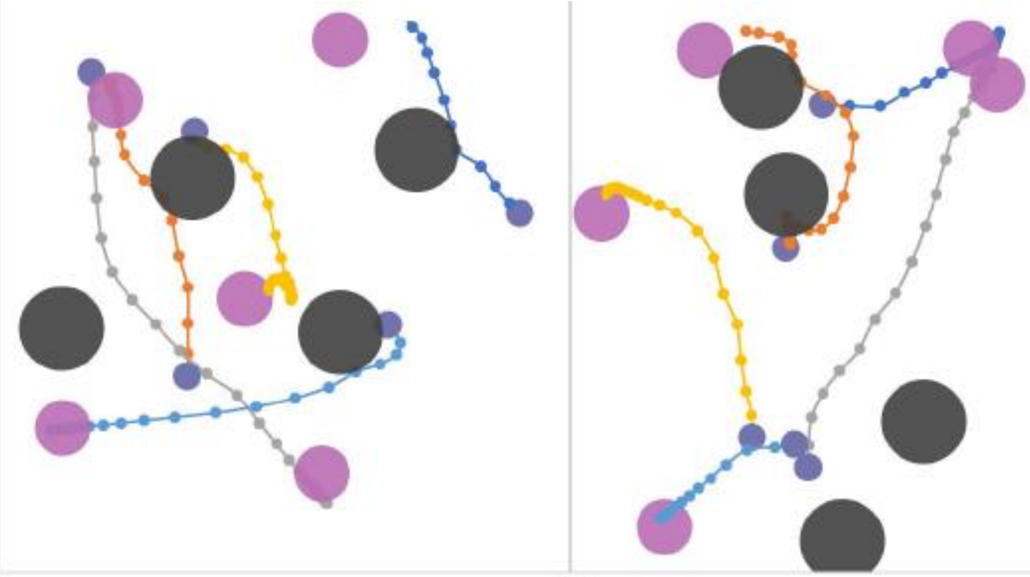


3. Literature Review

3	H. Qie, D. Shi, T. Shen, X. Xu, Y. Li, L. Wang, **Joint optimization of multi-UAV target assignment and path planning based on multi-agent reinforcement learning.** IEEE Access, vol. 7, 2019.

- This paper presents an innovative artificial intelligence method named simultaneous target assignment and path planning, which incorporates the most advanced **multi-agent reinforcement learning** algorithm to solve multi-UAV target assignment and path planning problems in dynamic environments.
- **Shortage:** It is still possible to hit a threat area.

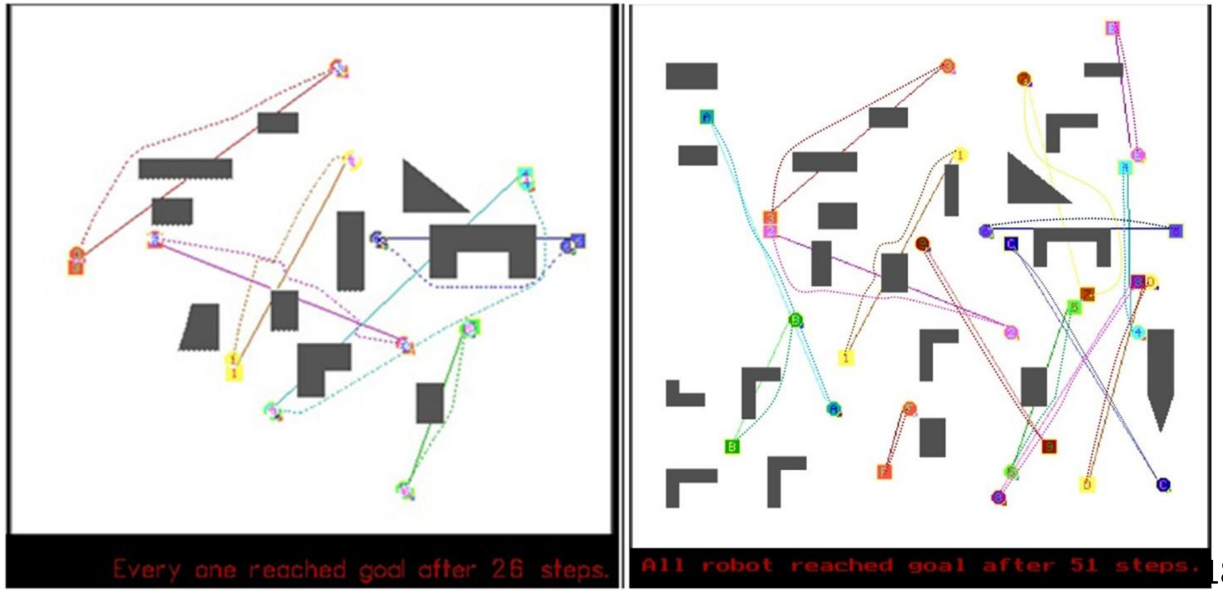




3. Literature Review

4	P.K. Das, P.K. Jena, **Multi-robot path planning using improved particle swarm optimization algorithm through novel evolutionary operators.** Applied Soft Computing, Volume 92, 2020.

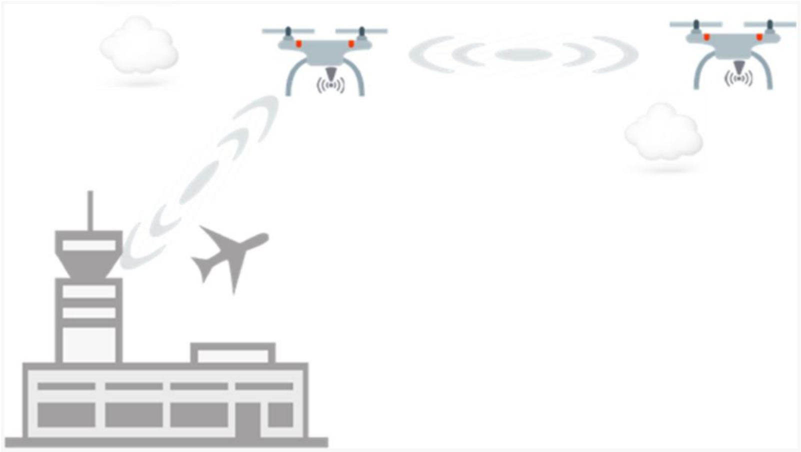
- A hybridization of **improved particle swarm optimization (IPSO) and evolutionary operators (EOPs)** algorithm has been proposed to enhance the exploration and exploitation capability for better convergence.
- A case study on multiple mobile robot path planning compute the optimal trajectory path from the predefine initial position to target position for each robot in the environment by avoiding the static and dynamic obstacles.

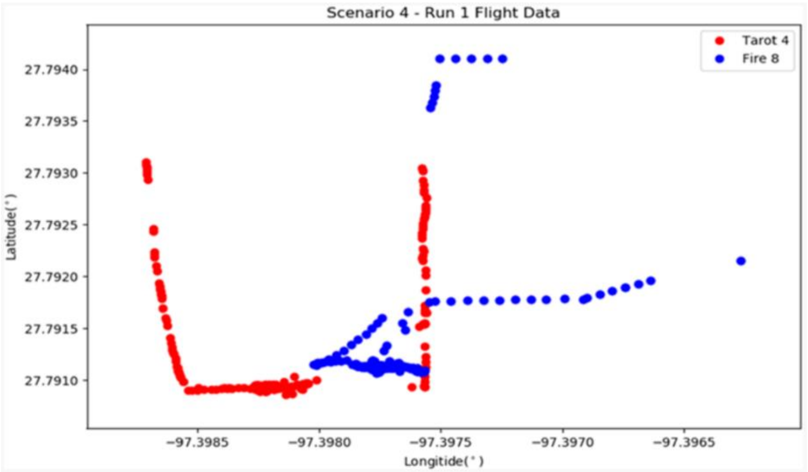


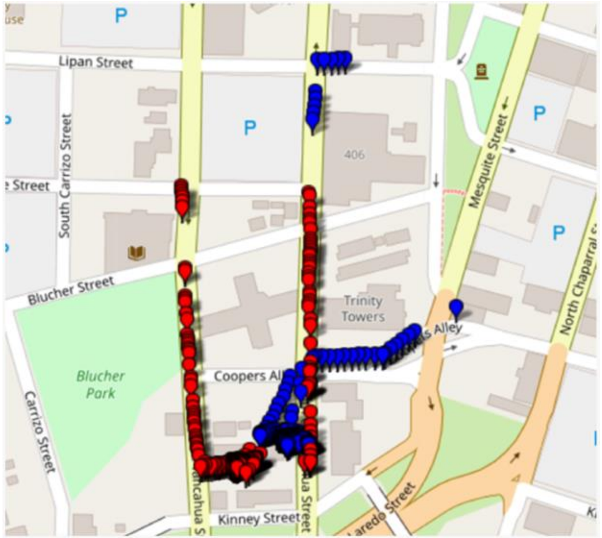
3. Literature Review

5	E. Murrell, Z. Walker, E. King, K. Namuduri, **Remote ID and Vehicle-to-Vehicle Communications for Unmanned Aircraft System Traffic Management.** Communication Technologies for Vehicles, vol 12574, 2020, Springer, Cham.

- This article presented the results of experiments, which were conducted to assess the functionality, capabilities, and limitations of DSRC-based Vehicle-to-Vehicle (V2V) communication system.
- There are two primary benefits of V2V communications: 1) **Collision Avoidance or Deconfliction** between UASs and 2) **Beyond Radio Line of Sight (BRLoS) communications** between any pair of UASs.
- **Shortage:** Only a DSRC radio is used, and it is not compared with other communication methods.



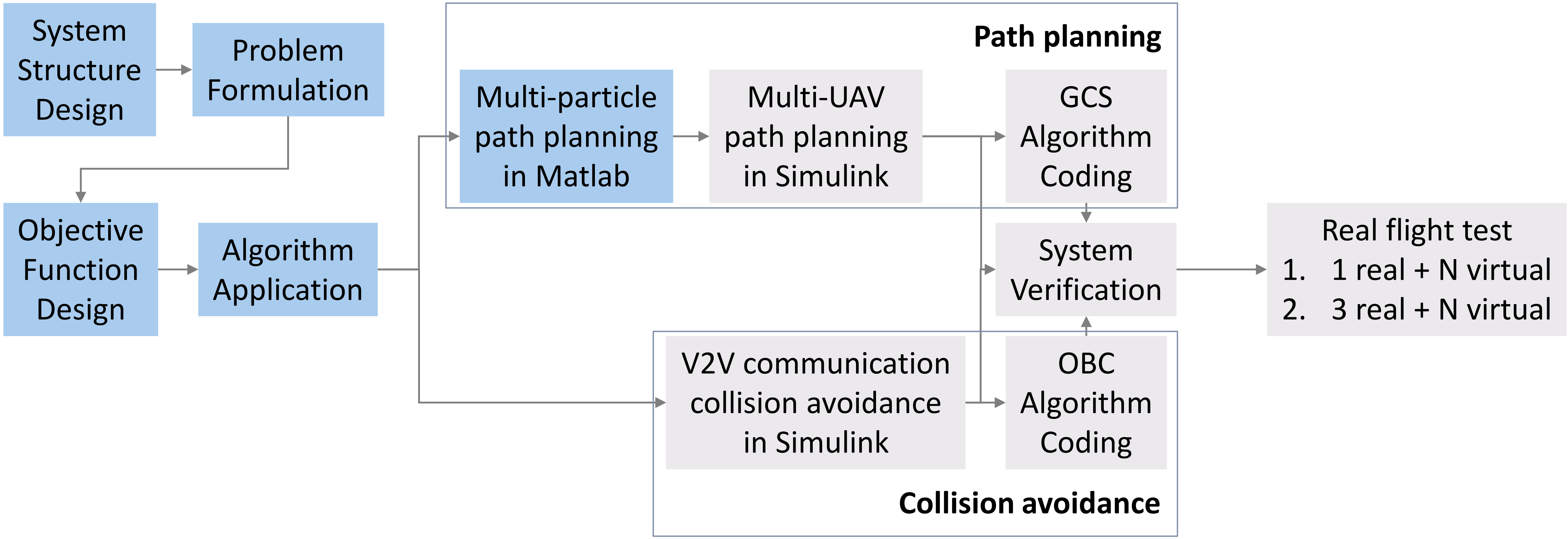




4. Methodology

4. Methodology

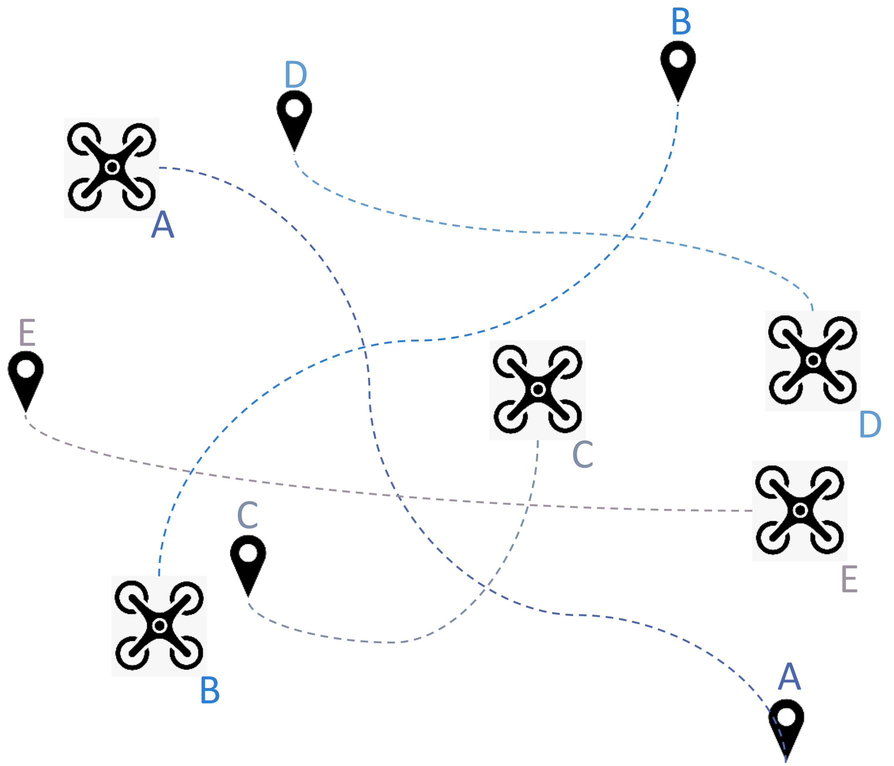
Research Process Overview



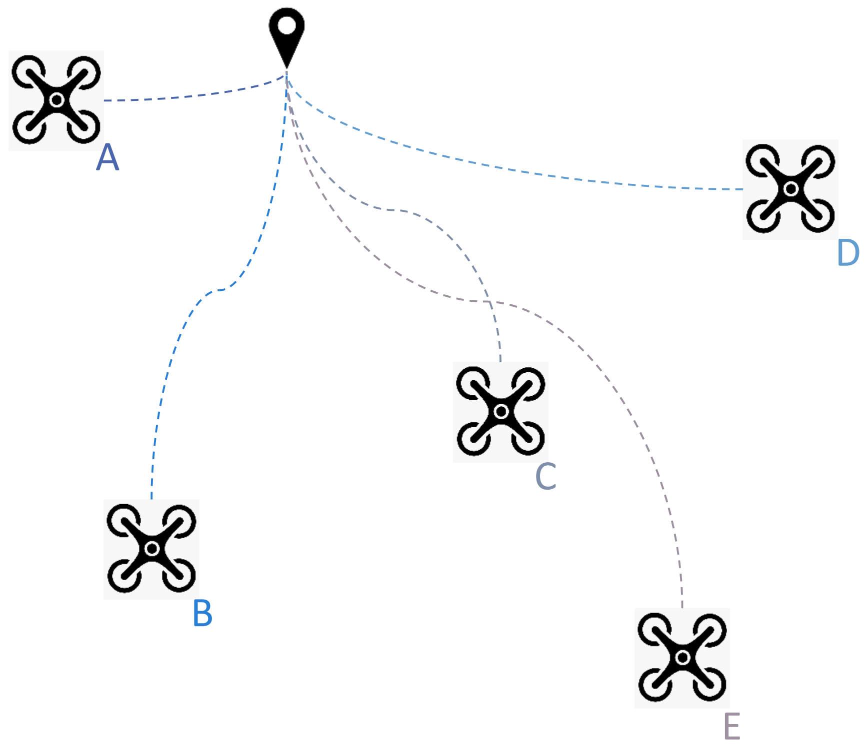
4. Methodology

Scenario Setting

Scenario 1 : Assigned Target

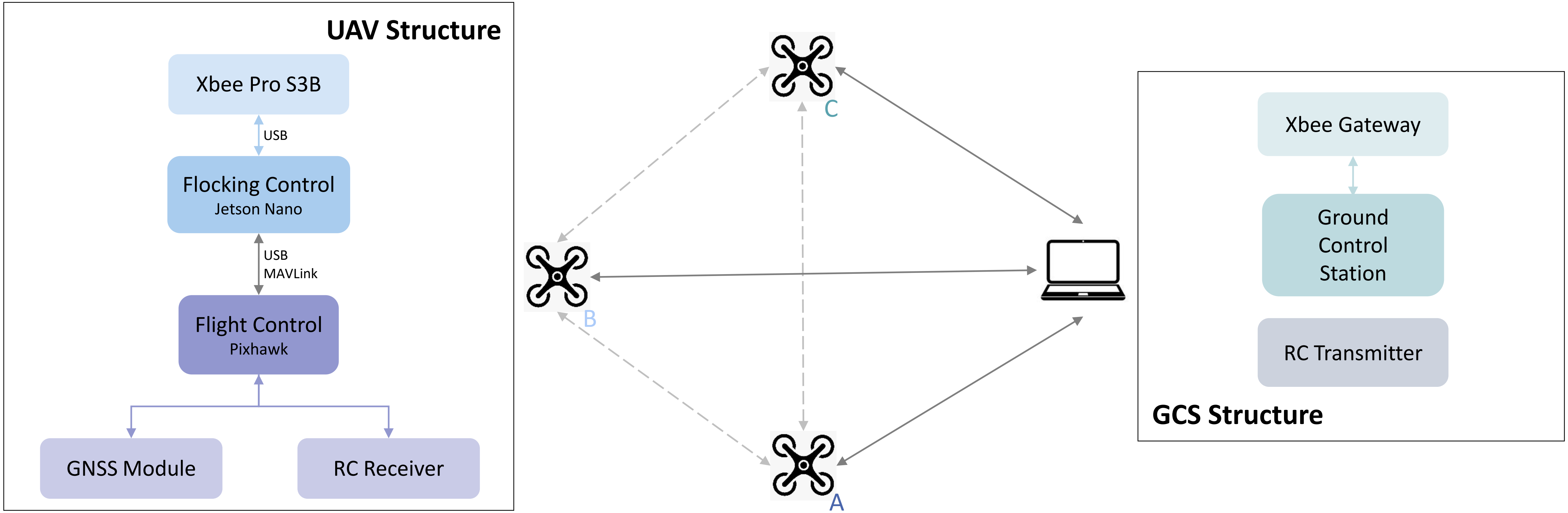


Scenario 2 : Single Target, Sequentially Arrived



4. Methodology

System Structure



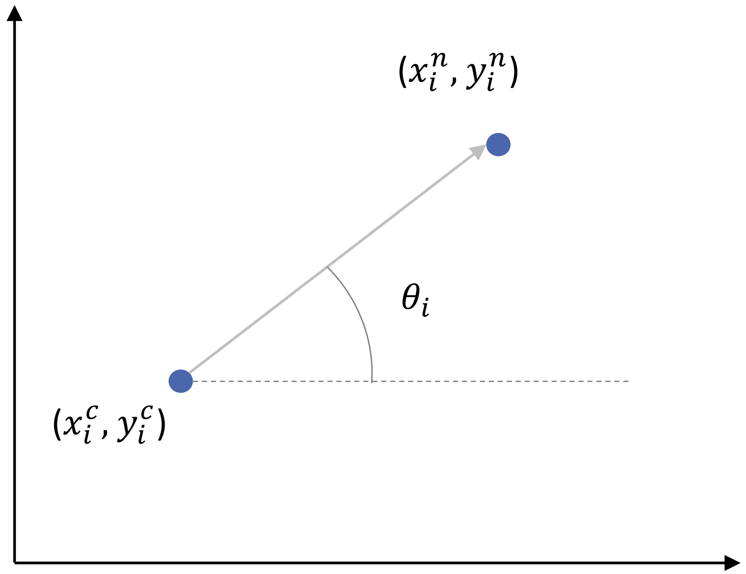
4. Methodology

Problem Formulation

- Due to:
  - The drone has the problem of **downwash**.
  - It consumes more energy to climb and descend.
- In this research, the path planning and collision avoidance are all carried out on the **2D plane**.

4. Methodology

Problem Formulation



- current position (x_i^c, y_i^c)
- goal position (x_i^g, y_i^g)
- current velocity v_i^c
- next position (x_i^n, y_i^n) move in time $(t + \Delta t)$

$$x_i^n = x_i^c + v_i^c cos\theta_i \Delta t$$
$$y_i^n = y_i^c + v_i^c sin\theta_i \Delta t$$

[1] H. Qie, D. Shi, T. Shen, X. Xu, Y. Li and L. Wang, Joint Optimization of Multi-UAV Target Assignment and Path Planning Based on Multi-Agent Reinforcement Learning, IEEE Access, 2019.

4. Methodology

Objective Function

- 1st objective function : determine the trajectory of path length for m UAVs

$$F_1 = \sum_{i=1}^{m} \left\{ \sqrt{\left(\left(x_i^c - x_i^n\right)^2 + \left(y_i^c - y_i^n\right)^2 \right)} + \sqrt{\left(\left(x_i^n - x_i^g\right)^2 + \left(y_i^n - y_i^g\right)^2 \right)} \right\}$$

- 2nd objective function : avoid collision between teammates

$$f_{j,k} = \begin{cases} 10^5, & collision \\ 0, & collision - free \end{cases}$$

$$if\ dist(j,k) < 2r\ , collision$$

$$(j = 1,2,\dots,m, \quad k = 1,2,\dots,n\ , \quad j \neq k,$$
$$r = safety\ separation(based\ on\ the\ velocity\ of\ UAVs))$$

$$F_2 = \sum_{j=1}^{n} \sum_{k=1}^{n} f_{j,k}$$

[1] H. Qie, D. Shi, T. Shen, X. Xu, Y. Li and L. Wang, Joint Optimization of Multi-UAV Target Assignment and Path Planning Based on Multi-Agent Reinforcement Learning, IEEE Access, 2019.
[2] Z. Shao, F. Yan, Z Zhou, X. Zhu, Path Planning for Multi-UAV Formation Rendezvous Based on Distributed Cooperative Particle Swarm Optimization, Applied Sciences, 2019.

4. Methodology

Objective Function

- 3rd objective function : express the smoothness of the path

$$F_3 = \frac{\cos^{-1}[\left(x_i^c - x_i^g\right)\cdot\left(x_i^n - x_i^g\right) + \left(y_i^c - y_i^g\right)\cdot\left(y_i^n - y_i^g\right)]}{\sqrt{\left(x_i^c - x_i^g\right)^2 + \left(y_i^c - y_i^g\right)^2} \times \sqrt{\left(x_i^n - x_i^g\right)^2 + \left(y_i^n - y_i^g\right)^2}}$$

- overall objective function

$$F = \lambda_1 F_1 + \lambda_2 F_2 + \lambda_3 F_3$$
$$\lambda_1 = 1, \qquad \lambda_2 = 1, \qquad \lambda_3 = 0.5$$

4. Methodology

Particle Swarm Optimization (PSO) Algorithm

Let N be the size of the population. Each particle is characterized by its position and velocity.

$$v_i^d(t+1) = v_i^d(t) + c_1 \cdot \emptyset_1 \cdot \left(pbest_i^d(t) - x_i^d(t)\right) + c_2 \cdot \emptyset_2 \cdot \left(gbest_i^d(t) - x_i^d(t)\right)$$

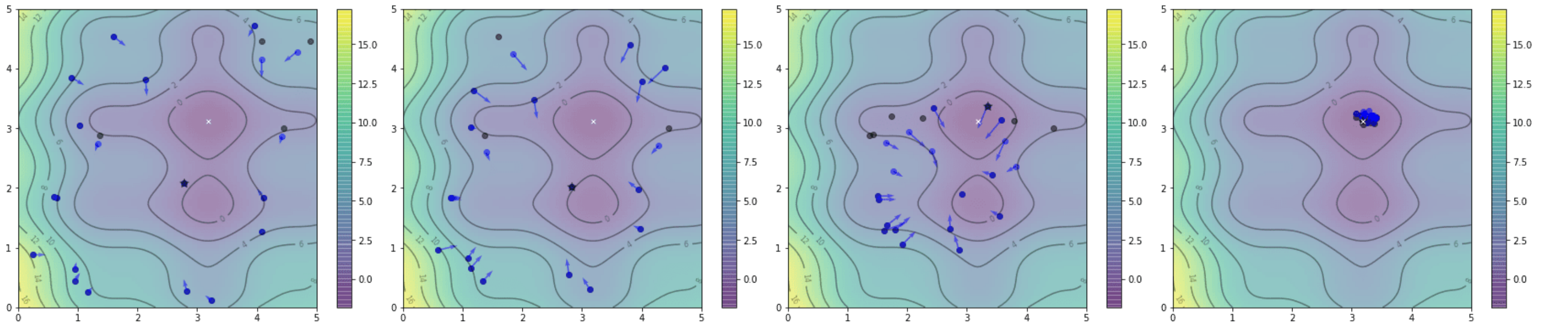
$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$$

The personal best position:

$$pbest_i(t+1) = \begin{cases} pbest_i(t), if \;\; O_{bj}\left(x_i(t+1)\right) > O_{bj}\left(pbest_i(t)\right) \\ x_i(t+1), if \;\; O_{bj}\left(x_i(t+1)\right) < O_{bj}\left(pbest_i(t)\right) \end{cases}$$

The global best position:

$$gbest(t) = \min\{\, O_{bj}(pbest_1(t)),\, O_{bj}(pbest_2(t)), \dots \dots\, O_{bj}(pbest_N(t))\}$$

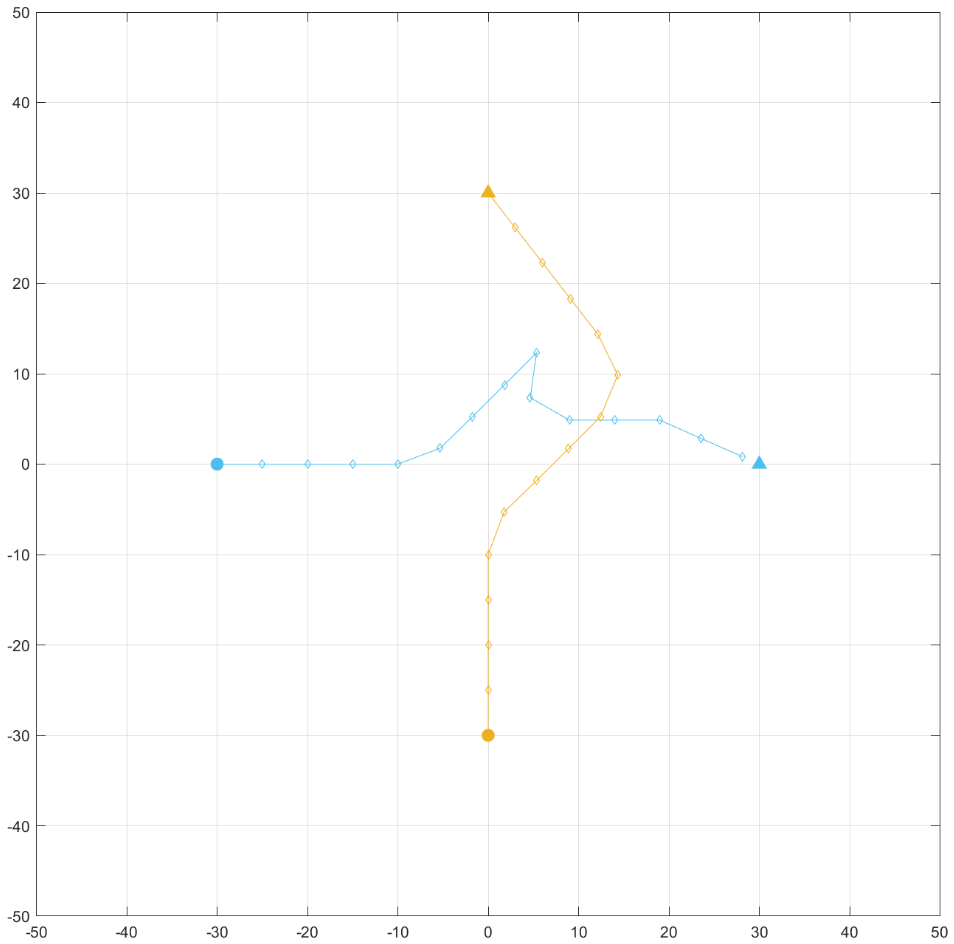


[1] J. Kennedy and R. Eberhart, “Particle swarm optimization”, Proceedings of ICNN ‘95 - International Conference on Neural Networks, 1995, vol.4.

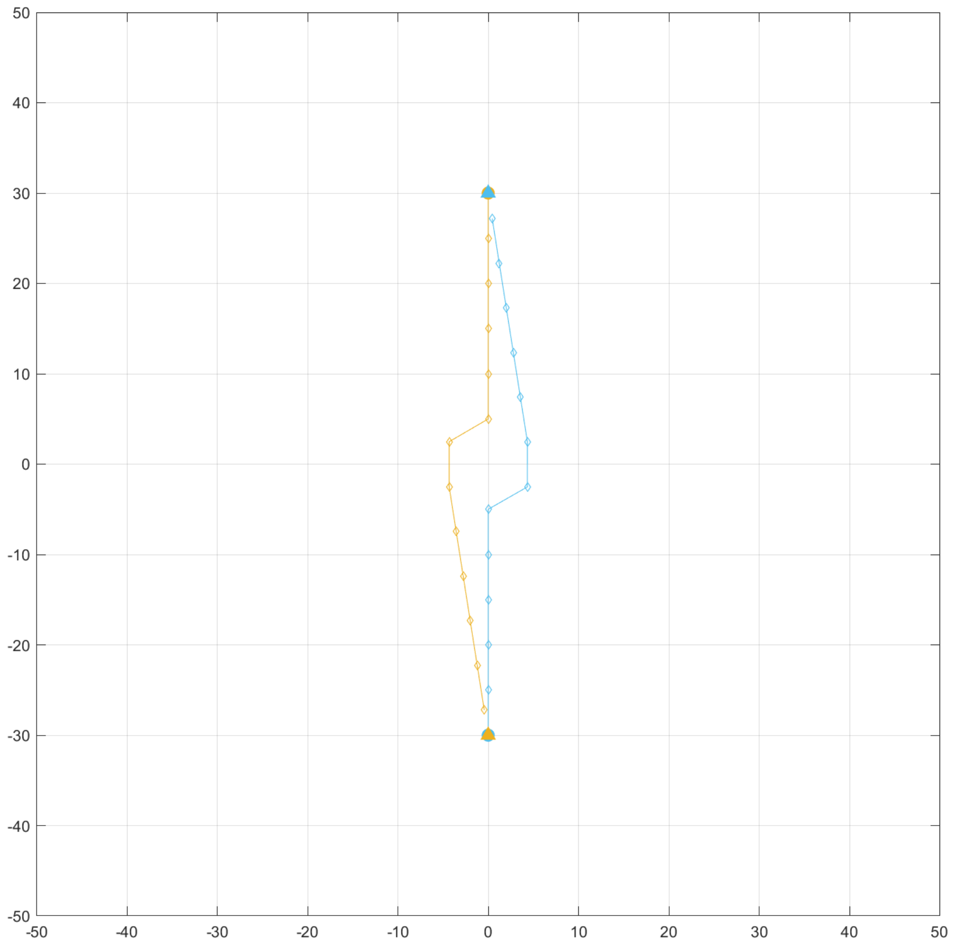
5. Initial Result

5. Initial Result

2 UAVs without any obstacles (perpendicular)

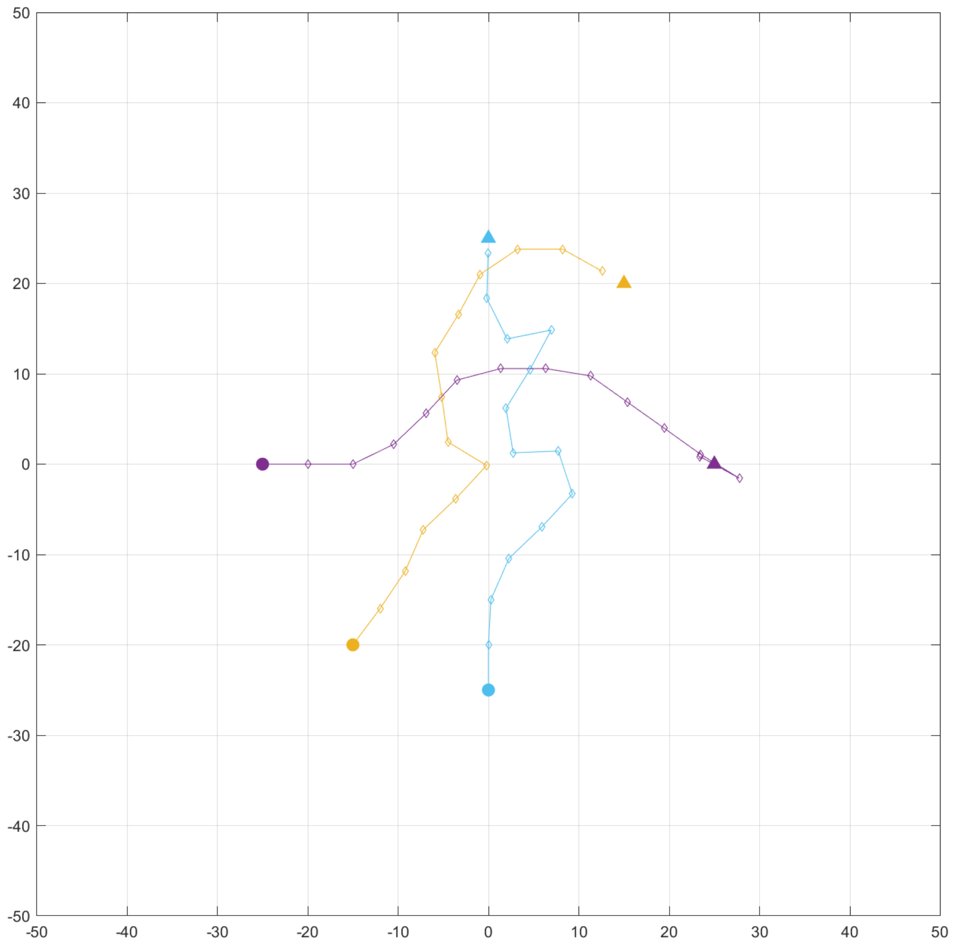


2 UAVs without any obstacles (head-on)

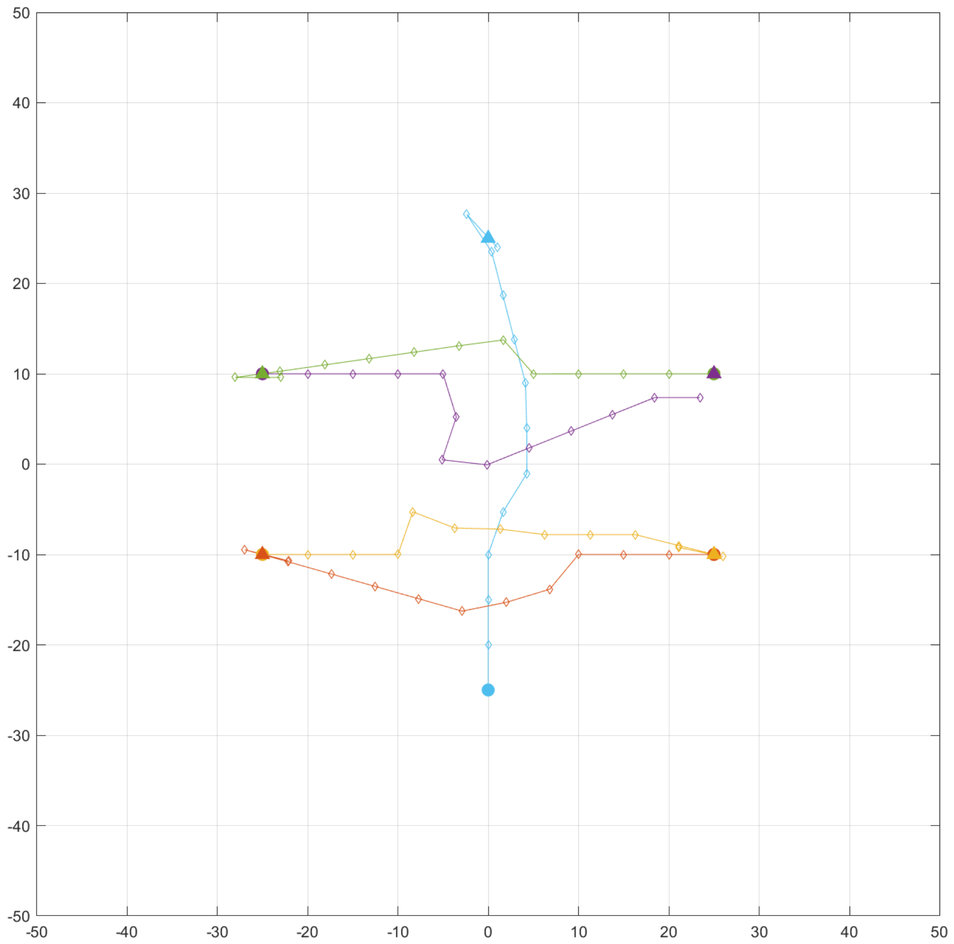


5. Initial Result

3 UAVs without any obstacles



5 UAVs without any obstacles



6. Conclusion and Future Work

6. Conclusion and Future Work

- Conclusion:
  - With PSO algorithm and the designed objective function, path planning and collision avoidance between each other of multiple UAVs can be achieved.
  - Through V2V communication and GCS information sharing, dynamic path planning can be achieved and the optimal path can be generated.
- Future Work:
  - Consider kinematic constraints and simulate scenarios in Simulink.
  - Code the algorithm in GCS and OBC, and validate the system.
  - Conduct real flight test.

Q&A

Thank you for your attention!