Multiple-Unmanned Air Vehicle Trajectory Optimization during Close-Approach Boundary based on Line-of-Sight Technique †

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Abstract: The rendezvous mission is one of the most useful and interesting in aerospace industry. Working together of multiple Unmanned Aerial Vehicles (UAV)s with limited space can cause the damage to UAVs. This research presents Unmanned Aerial Vehicle (UAV) rendezvous method that can approach UAV to another UAV with minimum displacement between them while they are moving. This rendezvous method is guided by Line-of-Sight (LOS) guidance law. The mission is guiding the UAV to join the route of another UAV to the end of mission with minimum displacement and without collision between them. Aerial Information and Robotics Simulation or AirSim which is working on Unreal Engine 4 software is presented. The positioning of UAVs is provided by Global Positioning System (GPS) sensor on both UAVs.

Keywords: Rendezvous; Multi-UAV; UAV; Line-of-Sight; AirSim; GPS;

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1. Introduction

Nowadays, the application of multiple UAVs is used in many fields. The autonomous UAV has been used for indoor search and rescue for a while [1]. To complete the mission automatically in limited space such as indoor is very difficult. Multiple UAVs is used for forest fire detection and tracking mission [2]. The simulation can help training and studying behavior of UAV more closely and easily in real-time with virtual environment that is realistic and accurate without danger and risk. This research chose AirSim to be the simulation for all experiments. [7] used UAV to spot poachers at night and report back before they hurt others animal by using AirSim. AirSim can provide GPS sensor which is important for this method. Guidance systems are important when considering the performance of aerial, surface, and underwater vehicles, regardless of the motion control scenario involved. The LOS guidance method is used in many fields of work, especially to guide underactuated marine vessels and vehicles, operating on or below the surface of the sea, in path-following tasks [8]. This paper used LOS guidance system with UAV rendezvous method.

This research proposed UAV rendezvous method to complete the mission of guiding main UAV into path of target UAV and maintain minimum displacement without any collision between UAVs. This paper compost of 5 sections. The information of AirSim and LOS guidance law is presented in section 2. Section 3 describes about new UAV rendezvous method based on LOS guidance including the simulation procedure of this method is described. Section 4 describes the result of simulation. The conclusion of this paper is presented in section 5.

2. Related Work

2.1. AirSim

Nowadays, the simulation modeling is used to solve real-world problem for avoiding the dangerous situation and decreasing the cost of the experiment. AirSim itself can supports common robotic platforms as well, such as Robot Operating System (ROS) [3]. However, this research used the default software-simulated flight controller provided by AirSim. The APIs are exposed through the RPC, and are accessible via a variety of languages, including C++, Python, C# and Java. AirSim can provide realistic sensor such as Barometer, Gyroscope, Accelerometer, Magnetometer, and GPS [5]. Because API controller of AirSim uses NED coordinate system, the GPS data will be converted to NED coordinate system. Geodetic coordinate such as latitude, longitude, and elevation can be converted to NED coordinate system related to AirSim by transform Geodetic coordinate to Acronym for Earth-Fixed (ECEF) coordinate [6]. Then convert ECEF coordinate to NED coordinate related to AirSim world [4].

2.2. Line-of-Sight Guidance Law

Conceptually, this guidance law steers the ground velocity vector towards an aim point, which is the moving UAV target in this work, chosen to be a specified look-ahead distance along the desired path in front of the UAV. The LOS guidance law is design ed from the azimuth angle of a UAV velocity, which is defined as the angle between the north and collector planes, to converge to the azimuth angle of the LOS, connecting between the main UAV position and the location of target UAV based on the geometry shown in Figure D2. Therefore, from knowing the position of main UAV and position of target UAV, the LOS angle which is the command angle of main UAV can be written as follow:

$$\Psi_{LOS} = \tan^{-1}\left(\frac{x_t - x_q}{y_t - y_q}\right) \tag{1}$$

$$\Psi_{cmd} = \Psi_{LOS} \tag{2}$$

$$v_x = v_s \sin \Psi_{cmd} \tag{3}$$

$$v_y = v_s \cos \Psi_{cmd} \tag{4}$$

3. Method

This research addresses new UAV rendezvous method which guided the main UAV to chase another moving UAV based on LOS guidance system, try to avoid the collision, and remain the minimum displacement between UAVs at the same time. The mission of this research is the same kind of problem. This UAV rendezvous method can not only send the main UAV to the path of target UAV but also can avoided the collision and maintain the minimum displacement between them at the same time. From those data, the displacement between UAVs (d_{TF}) can be computed as shown in Equation (5).

$$d_{TF} = \sqrt{(x_T - x_F)^2 + (y_T - y_F)^2 + (z_T - z_F)^2} \tag{5}$$

where $(x_T,\ y_T,\ z_T)$ is the position of main UAV, $(x_F,\ y_F,\ z_F)$ is the position of target UAV. Those position is getting from GPS sensor on each UAV which is already converted into NED coordinate system as describe in section 2.1. The condition of main UAV's speed is made related to the radius of 4 barriers $(R_1,\ R_2,\ R_3\ ,\ R_4)$ as describe in Algorithm 1. The method is reducing the summation speed of main UAV (v_s) when main UAV is close to the target UAV. When main UAV is in the closest barriers (R_1) of target UAV, the summation velocity of main UAV from LOS guidance will be 0 meter per second that means there will no velocity command from LOS guidance at that time. Can say that the closest barrier (R_1), zone 1, is the dangerous zone which is the zone that main UAV should not cross to it. Thus, the next barrier (R_2) after the closest barrier, zone 2, is the zone for starting to maintain the same speed as target UAV speed (v_T). In the case that main UAV is at between $R_2$and R_3, zone 3, the target UAV is far away from main UAV so the summation speed of main UAV will be more than the speed of target UAV with specific speed. The speed will be increased with specific speed in case of main UAV is at between R_3 and R_4, zone 3. If main UAV is very far away which is out of all barrier, main UAV will be moving with the maximum speed of main UAV (v_{max}).

4. Simulation Result

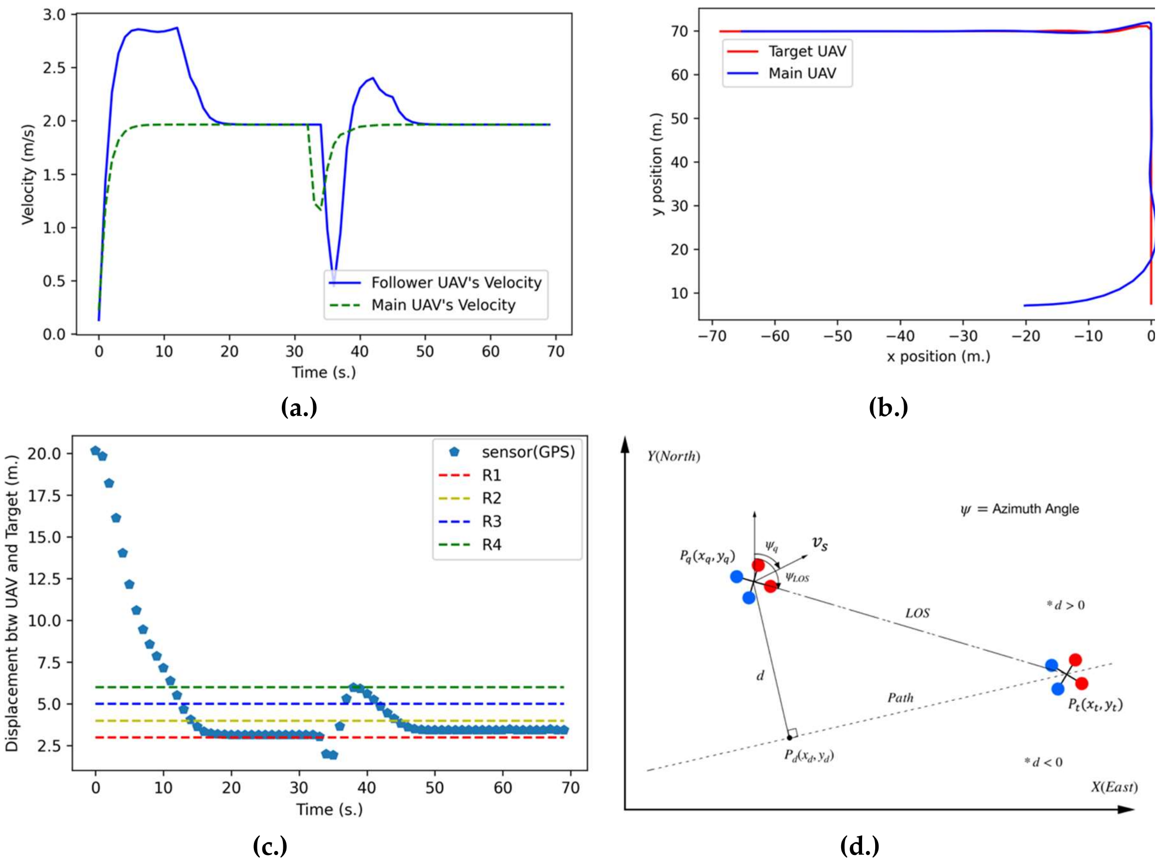

Figure 2. (a), (b) and (c) Describes the result of the experiment. (d) is structure of LOS system.

The mission of both experiments is to send main UAV into the path of target UAV and approach it to stay close to the target UAV as much as possible without any collision between UAVs. Then, main UAV will continue follow target UAV and maintain minimum displacement between UAVs. Target UAV will be moved by API control of AirSim along the waypoint. Main UAV will be used this UAV rendezvous method to complete the mission. Let assume the GPS sensor of both experiments is working with 1 Hz device. This case of experiment is 90-degree path of target UAV. In this experiment, target UAV is moving along the path which has 90-degree turning to see if this method can work with critical turning angle or not. Target UAV started at position (0, 0) at altitude 7 meters. Target is moving with velocity $v_T = 2$ meter per second. Target UAV is moving along WP1 (0, 0) to WP2 (0, 70) and turn 90-degree to WP3 (-70, 70) at the same altitude at 7 meters. The initial state of main UAV consider as main UAV start at position (-20, 0) at altitude 7 meters. The maximum speed of main UAV (v_{max}) is equal to 3 meter per second. The parameter of this UAV rendezvous method is consider following:

$$R_1 = 3, R_2 = 4, R_3 = 5, R_4 = 6$$

Let consider, the specific velocity command of main UAV (v_s) in zone 3 is 2.25 meter per second and the specific velocity command of main UAV (v_s) in zone 4 is 2.5 meter per second. Figure 2 shows the result of this experiment. Figure C2 shown the displacement between UAVs during the mission. Main UAV is moving closer to target UAV until it reach to the minimum displacement (R_1) in 17 seconds when main UAV is at position (-0.1772, 35.2805) at altitude 6.885 meters and target UAV is at position (0, 38.6122) at altitude 6.7740 meters. At time 34 seconds, the displacement of UAVs is less than R_1 because target UAV was turning 90-degree at this time which made target UAV decrease velocity as shown in Figure A2 and Figure C2. However, even target UAV was decrease speed to turn a critical angle of corner, this method still can prevent the collision between UAVs. Figure A2 shows the result of velocity of UAVs during the mission.

3. Conclusion

This paper present UAV rendezvous method based on LOS guidance system. The mission for this method is to guide main UAV into the path of target UAV and maintain on the path with minimum displacement and without any collision between UAVs. This research addresses a experiments which is 90-degree turning path of target UAV. In 90-degree path of target UAV, main UAV can reach to minimum displacement in 17 seconds. Main UAV can maintain displacement between UAV until target UAV decrease speed to turn 90-degree at time 34 seconds that makes the displacement between UAV less than the minimum displacement for 2 seconds and then come back to the minimum displace. However, even the displacement between UAVs is less than minim value, there is no collision between UAVs.

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