Leader follower formations of multi quadrotors group

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I. Introduction

Formations of multi-UAVs has attracted the attention of the robotics and artificial intelligence communities in the late decades. There are numerous advantages of flying in group over using single robot in mission execution, however a kind of coordination has to be achieved during the fly. Different solutions may be considered for that purpose and respecting a spatial geometric shape while maneuvering the environment is one of them. This work focuses on the development of a leader/follower scheme for achieving a virtual rigid body.

Several formation controller schemes already exist, each of which rely on one or more assumptions about the nature of the single robot and the properties of the group controller. Most of them implement centralized policies relying on GPS or optical motion tracking methods. In decentralized scenarios the robots have to rely on local sensing, preferably on-board computation power, and should perform local communications in between the group. The merit of deploying group of autonomous MRS in unconstrained environment (e.g., indoor and outdoor centralized-denied locations), costs the price of designing much more complicated controller schemes.

There are many approaches adopted to come over the challenges facing the MRS specially in their deployment in realistic scenarios. In the leader–follower formation control approach, a robot, i.e., the leader, moves along a predefined set of waypoints or with human steering, while the other robots, i.e., the followers, are supposed to maintain a desired distance and orientation to the leader [1], [2]. While many papers proposed a centralized controller, our contribution is to solve the problem in a more distributed way.

The leader trajectory is designed with respect to differential flatness which allows for the use of highly efficient trajectory planning algorithms as in [3], [4]. Each follower is equipped with its own trajectory planner. The leader and followers do not share information about the trajectory.

The goal is to have a distributed control protocol, based on local information, that tries to ensure the convergence of the tracking errors in finite time. Many challenges should be tackled like the lack of common reference frame, or having global communication channel.

The concept of Virtual Rigid Body is related to the idea of a virtual structure, which has been used extensively in the multi-agent formation control literature [5]. These works use a pre-defined virtual formation structure, combined with local control to maintain that structure throughout a mission.

II. Problem Statement

The goal of the formation controller is to construct a Virtual Rigid Body (VRB) in order to establish the desired formation, a virtual structure between several robots. This was achieved in a leader and follower fashion. The follower's robot controller has to keep a predefined separation distance and angle from the leader. Unlike other VRB methods which rely on the group barycenter to steer the formation [6], in our approach each robot is planning its own low level motion controllers, which corresponds to a distributed formation control. The velocities of the UAVs in the formation have to be similar in order to achieve a fixed geometric configuration, otherwise it will not be possible to track the positions of the UAVs with a fixed shape.

We consider a group of N drones labeled by $1, ..., N$ flying in a 3D environment.

F_i is the local frame of robot i; $i \in 1, 2, ..., N$.

F_v is the local reference frame of virtual rigid body in the space, where local positions of the robots are specific by a set of potentially time varying vectors. $i \in 1, 2, ..., N$.

A. Approach description

Kinematic relation in 3D space can be formulated as

$$\overrightarrow{V_B} = \overrightarrow{V_A} + \overrightarrow{\Omega} \wedge \overrightarrow{oD_1} \tag{1}$$

D_i is the Drone where *i* represent the number of the drone.

$$V_o = [U, V, W]^T \tag{2}$$

Where U is the linear velocity in x, V is the lateral velocity in y, W is the vertical velocity in z.

$$\overrightarrow{\Omega} = [0, 0, r]^T \tag{3}$$

where r is the angular velocity around Z, yaw velocity. In Earth reference, the yaw angle of all the drones should align to be equivalent to the yaw angle of the VRB as follows: $\theta_1 = \theta_2 = \theta_3 = \theta$

$$\overrightarrow{V_B} = \overrightarrow{V_A} + \overrightarrow{\Omega} \wedge \overrightarrow{oD_1} \tag{4}$$

The velocity of each drone in the formation can be attained according to the following equation,

$$\begin{aligned} \overrightarrow{V_{D1}} &= \overrightarrow{V_o} + \overrightarrow{\Omega} \wedge \overrightarrow{oD_1} \\ \overrightarrow{V_{D2}} &= \overrightarrow{V_o} + \overrightarrow{\Omega} \wedge \overrightarrow{oD_2} \\ &\vdots \end{aligned} \tag{5}$$

Within the VRB reference frame, the robots are trying to maintain distances in 3 axis. This is formulated as: $\overrightarrow{oD_1} = [e_{x1}, e_{y1}, e_{z1}]^T$, $\overrightarrow{oD_2} = [e_{x2}, e_{y2}, e_{z2}]^T$, ..., $\overrightarrow{oD_n} = [e_{xn}, e_{yn}, e_{zn}]^T$

Each follower is equipped with its local controller to compensate for the tracking error toward the leader robot. For controlling the vertical velocity a phase lead controller is designed. A PID controller is designed for the horizontal velocity and the angular velocity around Z-axis direction as well.

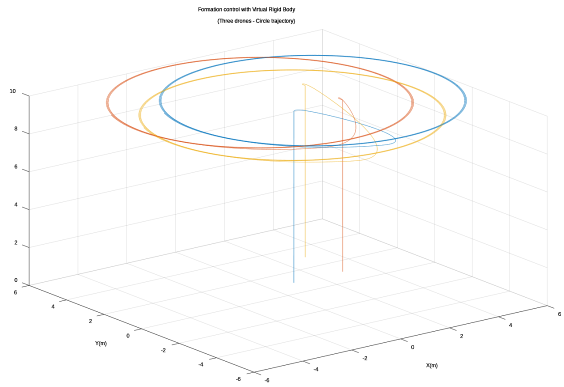

Figure 1. Circle formation control of 3 drones. Leader is in blue.

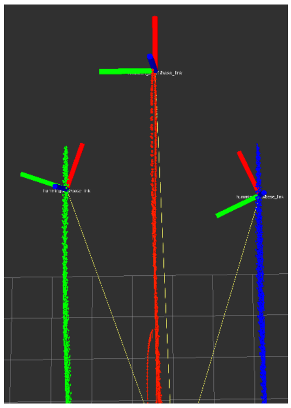

Figure 2. Formation of a triangle in a linear path. Trajectory of Leader is in Red, the 2 followers are in green and blue.

III. Simulation Design and Results

We are now going to present the simulation results both for the matlab-simulink simulator and for the GAZEBO 3D-simulator.The model of one robot is described with full dynamic model of quad-rotor UAV in a simulink model. Then the formation is represented. ROS is chosen to be the development framework for both the simulation and real experiments. Simulation with full dynamic robot model using both Simulink and Gazebo are used to validate our approach.

Results obtained from the simulink formation controller design is shown in 1. These results show the transition from initial configuration to the desired circular configuration successfully.

Results obtained from the Gazebo quadrotor model and controller through the implemented ROS package is shown in 2. Each quadcopter is represented by the three major axes coming out from the center of mass. Only a position controller is currently developed in this simulator which works fine on non changing velocity trajectories.

IV. Conclusion and Future work

This paper presented a controller for a Leader/Follower formation of multi unmanned aerial vehicles. In future work, we will experiment and validate these results in our laboratory. In order to achieve the experiments, a hardware setup is being designed relying mostly on open source software and hardware. Enhancing the controller in Gazebo model to work on varying velocities trajectories.

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