A Vision-based Coordination Control for a UAV-UGV Tethered System

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I. Introduction and Related Work

In the last decades a considerable interest has been paid in investigating the pros and cons of adopting tethered mobile robotic platforms. Tethers have been proposed for both data communication and power supply, especially in applications where a radio communication link cannot be used or when a longer autonomy is needed. Typically, tethered single robots have been presented in the literature, however, recently more interesting solutions appeared, proposing multiple heterogeneous platforms connected through a tether [1], [2].

In a system of an Unmanned Ground Vehicle (UGV) cooperating with an Unmanned Aerial Vehicle (UAV) another relevant aspect to take into consideration is the control approach. A centralized control scheme for a target-chaser formation, involving a UAV and a UGV has been presented in [3], and several solutions have been proposed to address the problem of tracking a ground vehicle from an aerial platform, even for autonomous departure and landing [4], [5].

II. Proposed solution

This work presents a multi-robot system composed of an aerial vehicle connected through a tether to a ground mobile platform. We report a coordination strategy of the two vehicles, thus obtaining a formation control. A *delegated approach* is proposed, where the ground vehicle relies on the aerial vehicle, which is globally localized within the environment, and keeps following it. We do not explicitly deal with the physical constraint imposed by the tether, but the ground vehicle is forced to readily follow the aerial vehicle.

A. Ground Vehicle Navigation Control

From the control perspective, we assume that the UAV position projected to the ground is the target position, whereas the UGV dynamically chases such a target position. It is the opposite approach compared to the works available in the literature.

The position of the aerial vehicle is assumed to be known through GPS or indoor localization systems. The relative pose, i.e. position and attitude, of the ground vehicle is derived from the position of the aerial platform through computer vision algorithms for detection of a board of Aruco markers. The ground vehicle localization is based solely on the information coming from the Aruco detection. The control algorithm uses the output of the Aruco detection to drive the UGV exactly below the UAV. To this end, the detected pose of the vehicle is transformed from the camera reference frame to the ground vehicle frame. In this manner, the detected UGV position is seen as the aerial vehicle position in the ground vehicle frame (Figure 1). Finally, the vertical projection on the ground of the aerial vehicle position is used as a goal for the computation of the velocity control commands as follows [6]:

$$v = k_\rho \rho \tag{1}$$

$$\omega = k_\alpha \alpha + k_\beta \beta \tag{2}$$

where v and ω are the linear and angular velocities of the ground vehicle respectively, whereas ρ is the distance to the goal (intended as the vertical projection of the UAV on the ground), β and α are the direction angles of the vector to goal, with respect to the UGV frame, and the UAV frame respectively. The control parameters k_ρ, k_α and k_β have been experimentally tuned.

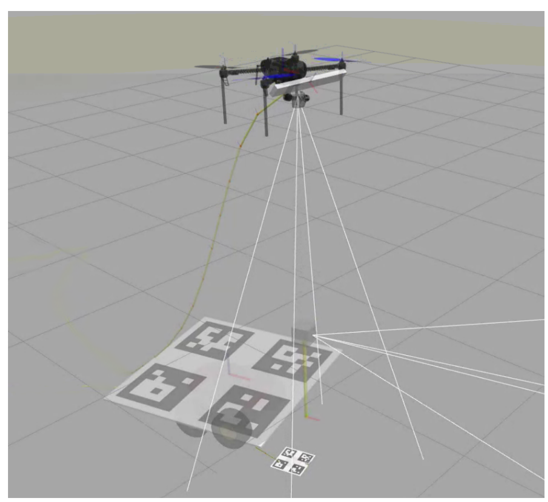
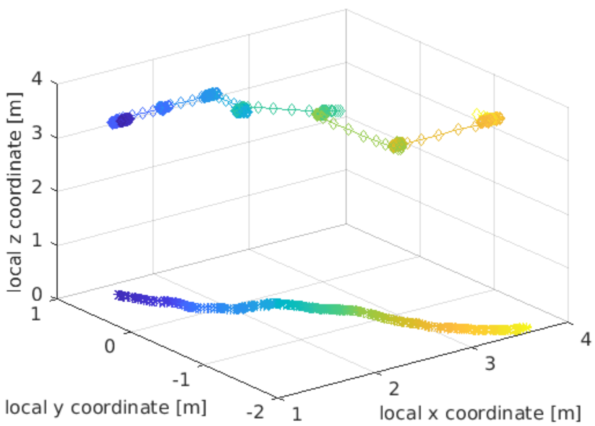


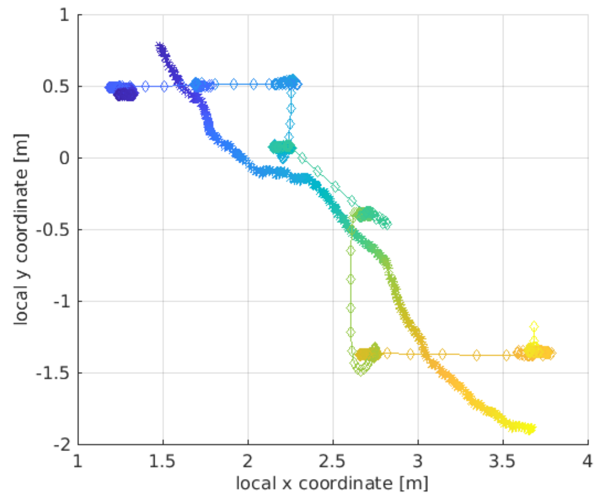
Fig. 1: Reference frames considered in the control: static frame, UAV frame and UGV frame.

III. Simulation setup

The open source 3D simulator Gazebo has been used to perform preliminary testing sessions of the control algorithm. The open source ROS (Robot Operating System) framework



(a) 3D view.



(b) Top view.

Fig. 2: Trajectories obtained from the simulated control.

has been chosen as the communication middleware, whereas a Software In the Loop (SIL) tool allowed us to develop a control algorithm that can be easily ported from simulation to real hardware. The multi-robot system consists of a Pioneer 3AT skid steer platform and a 3DR Iris drone, a commercial quadcopter based on the Pixhawk autopilot. The starting/landing platform, on which the Aruco markers are printed, was fixed above the UGV. The IRIS quadcopter is equipped with a downward-facing camera in order to detect the marker. During the simulation as set of randomly generated waypoints in 2D space at fixed altitude are provided to the drone.

IV. Results

The simulation results proved the effectiveness of the proposed control algorithm. The UGV was able to reach and stay within a 30 cm circle around the vertical of the drone as it travels between consecutive waypoints. A slight overshoot in the position control is experienced by the UGV as the distance to the vertical projection of the UAV increases. This implies the need to improve the control parameters to obtain a better leader-follower behaviour.

Figure 2 shows both the UAV and UGV trajectory from a simulation session. Figure 2a shows the 3D representation of the trajectory of the UAV and the path of the underlying UGV, resulting from the proposed control algorithm. The sequence of colors represents the temporal evolution of the two trajectories (i.e., the same color indicates the same instant of time for both vehicles).

V. Conclusion

The control algorithm presented in this work provides a simple yet effective solution to the problem of coordinating a UAV-UGV tethered system. This is a first step towards making this multi-robot system capable of autonomously navigating in hostile environments, also in GPS denied areas. As future development, we plan to introduce a control strategy limiting the relative speed between the vehicles, due to the tether constraint.

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