Proposed System of Leader-Follower Formation Control of 4-wheeled Mobile Robot and Quadcopter by Using Image Processing of Hybrid Robot

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***Abstract*— Robot formation control has drawn significant attention for many years, and now it is well understood and mature in its field. First, this paper is concerned with planning the motion of mobile robots in Leader-Follower Formation, which means certain geometrical constraints are imposed on the relative positions and orientations of the robots throughout their travel. Second, it identifies the method of manipulating vision and image processing system from both UGV and UAV; analyzing path in real-time and projection objects on smart-digital-map based-on the computational algorithm embedded inside the UGV. System of Leader-Follower Formation use a control strategy for take-off, tracking, and landing of a quadcopter relative to ground mobile robot to be used for monitoring and guidance for mobile robot in unknown environment.**

I. INTRODUCTION

Networks of mobile robot and quadcopter for planetary exploration and terrestrial applications are currently under much investigation. A key element in the control of such networks is motion planning. The ability to maintain a specific formation of hybrid robots is of particular where data need to be collected simultaneously from different resources or inputs [1]. This paper investigates the kinematics of formations of mobile robot and quadcopter, that is, how a certain class of geometrical configurations of mobile robots can be maintained during motion. Given this reference trajectory each robot in the formation is able to compute its individual trajectory.

A particular approach is teaming mobile robots using the Leader-Follower (L-F) formation, where a mobile robot is labeled as the leader that follows desired trajectory, and one or many robots, labeled followers, that follow the path described by the leader [2]. In this paper, we analyze a L-F formation scheme where a quadcopter UAV follows a 4-wheeled mobile robot UGV.

Today, Unmanned Ground Vehicles have the ability to self-navigation, since they are based on data received from the onboard sensors, image processing and GPS. Unmanned Ground Vehicle (UGV) is able to detect static and moving obstacles and find the best and shortest path to get through a number of given points to the target.

For detecting and avoiding obstacles in their paths, robots should be able to monitor and adapt their surrounding by embedding system to analyze its view and environment. Distinctive cameras from both UGVVS (Unmanned Ground Vehicle Vision System), and UAVVS (Unmanned Aerial Vehicle Vision System) are used to detect obstacle.

II. QUADCOPTER

A **quadcopter** or quad-rotor is a multi-rotor helicopter that is departed and landed by four rotors. Quadcopter is a small Unmanned Aerial Vehicle (UAV) has significantly increased in recent decades. Quadcopter is one of the most successful vertical take-off and landing vehicle with autonomous flight control and stable hovering capabilities.

A. Quadcopter Modeling and Dynamics

The UAV considered here is a quad-rotor helicopter, where four rotors laid up symmetrically around its center as illustrated in Fig.1. The quadcopter dynamic model is obtained using Lagrange method [3]. The simplified quadcopter dynamics are:

$$x = \ sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi\ \frac{U_z}{M} \qquad \phi = \frac{U_\phi}{J_{xx}}$$

$$y = \ sin\psi \sin\theta\cos\phi - \cos\psi\sin\phi \ \frac{U_z}{M} \qquad \theta = \frac{U_\theta}{J_{yy}} \qquad (1)$$

$$z = -g + \ cos\theta\cos\phi \ \frac{U_z}{M} \qquad \psi = \frac{U_\psi}{J_{zz}}$$

where ϕ, θ, and ψ are the Euler angles which represent roll, pitch and yaw respectively. M is the quadcopter mass. J_{XX} , J_{YY} , and J_{ZZ} are the quadcopter moment of inertia according to x, y, and z axes respectively, where g is gravity. Forces and moments along quadcopter axes in Eq. (1) can be defined as [4]:

$$\begin{aligned} U_Z &= F_1 + F_2 + F_3 + F_4 \\ U\phi &= L(F_3 - F_4) \qquad (2) \\ U\theta &= L(F_1 - F_2) \\ U\psi &= K_z\,(F_1 + F_2 - F_3 - F_4) \end{aligned}$$

where F_1 , F_2 , F_3 and F_4 are the thrust generated by the four rotors, L is the distance between the motor and the quadcopter center. K_z is a constant relating the propellers thrust with the yawing moment.

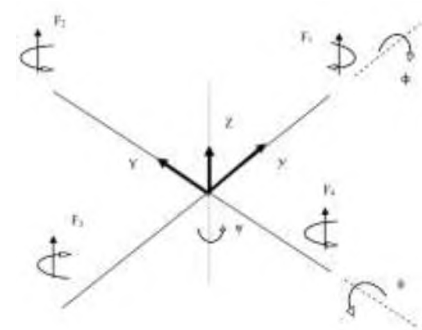

Fig 1: kinematic position of a quadcopter

III. Formation Control of UGV-UAV

There have been several approaches to maintaining formations of mobile robots including behavior-based methods, potential field methods, virtual structures, Leader-follower, and neural networks.

Our approach is able to support an arbitrary geometrical configuration of robots. As we will see, this shape will be slightly altered when the formation is turning [5]. As the geometrical distances between robots vary slightly with time, our approach can be classified as *flexible* rather than *rigid* [6]. The system describes a formation of 2-robots as a tuple $F = (r, G)$ where r is a set of variables describing the relative position of the robot (quadcopter) with respect to the reference robot (ground mobile), and G is a formation graph describing the control strategy used by each robot. Thus, F is a dynamical system evolving in continuous-time on the interval $T=[t_o,t_N]\subset R+$. Thus, the control problem of formations of robots can be formulated as a hybrid system whose continuous dynamics change in a controlled fashion.

The position of quadcopter (follower) with respect to mobile robot (leader) is shown in Fig.2.

A. *Kinematics of mobile robot (Leader)*

The mobile robot is assumed to be moved in a flat plane where the motion P can be described in XYZ. The direction θ_L determines the rotation of mobile robot in counter clockwise with respect to x-axis. Where X, Y and Z axis represents global coordinate system; and E_x , E_y and E_z represents local one.

The kinematics of the mobile robot (leader) is given by:

$$x_l = V_L cos\theta_L \quad y_l = V_L sin\theta_L \quad z_l = 0 \quad \theta_l = \omega_l \qquad (3)$$

where x_L, y_L and z_L represent the coordinates of the center of the axis of the actuated wheels on the XYZ and θ_L is the angle formed by the longitudinal axis of the robot and the X axis. V_L represents the linear velocity, ω_L represents the angular velocity.

B. Kinematics of quadcopter (Follower)

The kinematics of the quadcopter (follower) can be obtained by using L-F kinematic model [7]. In such a model, the XY plane speeds on the body frame, V_{FX} and V_{FY} are also considered, together [8] with the angular speed in the leader inertial frame, $\boldsymbol{\theta_f = \omega_F}$. Moreover, the height Z_F is be achieved via proposed controller where the kinematic model takes the form

$$\begin{aligned} \boldsymbol{x_F} &= \boldsymbol{V_{FX}cos\theta_F - V_{FY}sin\theta_F} \\ \boldsymbol{y_F} &= \boldsymbol{V_{FX}sin\theta_F + V_{FY}cos\theta_F} \\ \boldsymbol{\theta_f} &= \boldsymbol{\omega_F} \qquad (4) \end{aligned}$$

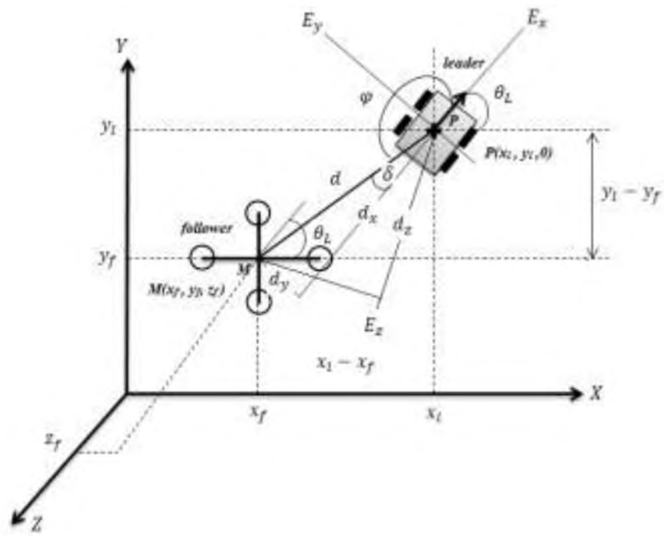

Fig 2: Representation of quadcopter (follower) with respect to Mobile Robot (leader)

C. Leader-Follower kinematic error model

UGV is the leader, and the UAV is the follower. The objective of the formation controller is to generate the commands for the UAV controller based on the UGV position and the desired height. Relative distances from the follower to the leader are considered on the leader body frame to describe the desired formation [9], as it is shown in Fig.2. The projected distances between vehicles, with respect to $E_xE_yE_z$ system (leader body frame), are given by

$$\begin{aligned} \boldsymbol{l_x} &= \boldsymbol{-\ x_l - x_f\ \ cos\theta_L -\ \ y_l - y_f\ \ sin\theta_L} \\ \boldsymbol{l_y} &= \boldsymbol{\ x_l - x_f\ \ sin\theta_L -\ \ y_l - y_f\ \ cos\theta_L} \qquad (5) \end{aligned}$$

where l_x and l_y are the projected distances between the robots to the X and Y axis of the leader, respectively.

a) UAV Take-off and tracking model

During take-off, the formation controller sends the commands to the UAV local controller [10] to stabilize the UAV position at the desired height Z_d as shown in Fig.4. During tracking, the UAV controller should maintain the UAV at the desired height Z_d as follows:

$$\boldsymbol{\lim_{t\to\infty} e_h = Z_f - Z_l = Z_d} \qquad (6)$$

b) UAV landing model

During landing model, the commands which sent to the UAV should satisfy the following conditions:

$$\lim_{t\to\infty} e_{x_{la}} = x_l - x_f = 0$$
$$\lim_{t\to\infty} e_{y_{la}} = y_l - y_f = 0$$
$$\lim_{t\to\infty} e_{z_{la}} = z_l - z_f = 0 \quad (7)$$

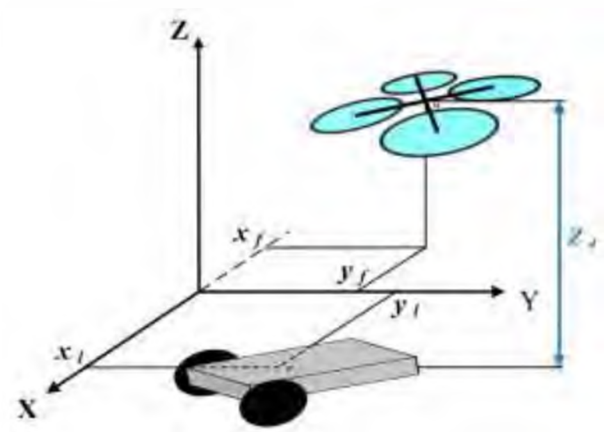

Fig 4: Position of UAV and UGV diagram

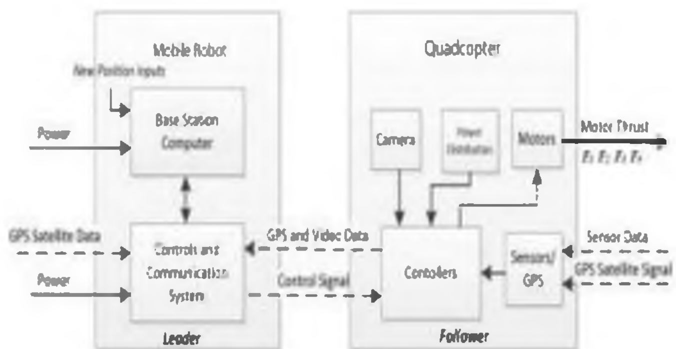

Fig 5: General scheme of communication and image system block diagram

IV. Position and Image Processing System of UGV-UAV

A new method to obtain accuracy is a combination of work standard GPS, UGVVS (Unmanned Ground Vehicle Vision System), and UAVVS (Unmanned Aerial Vehicle Vision System) as shown in Fig.5. The GPS system provides the exact locations of the binding data on digital map, UGVVS, and UAVVS are used to ensure the continuity of location determination process [11].

A. *Unmanned Ground Vehicle Vision System (UGVVS)*

UGVVS use image processing system to extract elements or objects by processing each image in the video sequence. UGVVS projects each found object with a vertex on a digital-map. Each found object has the following properties:

1) ID: a unique number assigned to the new object detection.
2) Position of new object (x_i , y_i, θ_i).
3) Label the dimension of new object (l_i , w_i, h_i).

4) Life Time - the number of frames of a video sequence in which the object was present since the first detection.

5) Object type (human, car, tree, building, …).

B. *Unmanned Aerial Vehicle Vision System (UAVVS)*

UAVVS use image-down-view processing system to extract elements or objects by processing each image in the video sequence [12]. UAVVS projects each object found with a vertex on the same digital-map to compare and analyze the the projection of new objects from both UAV and UGV. Each found object has the following properties:

1) ID: a unique number assigned to the new object detection.

2) Position of new object (x_r , y_r, θ_r).

3) Label the dimension of new object (l_r , w_r, h_r).

4) Life Time - the number of frames of a video sequence in which the object was present since the first detection.

5) Object type (human, car, tree, building, …).

V. CONCLUSIONS

This paper presented a strategy for the generation of formation trajectories for UGV and UAV. Autonomous take-off, tracking and landing of a UAV controlled by UGV is discussed in this paper. A leader–follower approach was adopted, which allow the UAV to track the UGV in the leader-follower formation manner. The proposed algorithms controlled by UGV (leader) are capable of allowing the UAV (follower) to take-off, track and land on.

The proposed system is able to take into consideration the occurrence of obstacles along the path of travel. The successful generation and simulation of two different kinds of static obstacles from UGV and UAV are projected on smart-digital-map. Future work will be tested with obstacles avoidance and the application of the proposed controller experimentally.

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