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Tracking Algorithm Using Leader Follower Approach for Multi Robots

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Abstract

This paper deals with a new type control formation for multi robot system (MRS). The formation can be either of leader-follower or follower-follower type. Using Leader Follower Approach (LFA), one robot acts as a leader whose motion defines the path for the entire group. All follower robots will use the defined path to attain a certain goal or to achieve a defined task. Follower robots should position themselves in accordance with the position and orientation of the leader. The leader moves along an assigned trajectory and the followers maintains the desired distance and orientation with respect to the leader robot. For each robot, a coordinate transformation is first derived to determine the error in the system. Based on this transformation, a tracking algorithm is designed with an observer to minimize the error. The algorithm is proposed and designed in such a way that the system kinematic equations derived for facilitating the development of a tracking controller would lead the desired formation parameters to zero. Simulation results illustrate the soundness of this algorithm.

Keywords: Multi Robot Coordination; Leader Follower Approach (LFA); Obstacle Avoidance; Mobile Robots; Wheeled mobile robots(WMR)

1. Introduction

Wheeled mobile robots (WMRs) are more efficient than legged robots and find its application in various industries [1]. Applications of WMRs exploit area such as stability, motion planning and control. Improved control systems with feedback techniques will enable the application of WMRs to autonomous mobile robot operation. Motion planning and control for WMR depends on the type of motion [2,3]. Different types of motion for coordinating multi robots have been adopted such as point-to-point motion (PP), path following (PF), trajectory tracking (TT) and purely reactive local motion (PR) [4,5]. In PF, the robot moves towards the destination point or goal starting from given fixed posture as shown in Fig. 1. In TT, the robot follows a path in the Cartesian space as shown in Fig. 2. In PR, the motion is a combination of both path following and trajectory tracking. Among all the approaches explained above, PR has been

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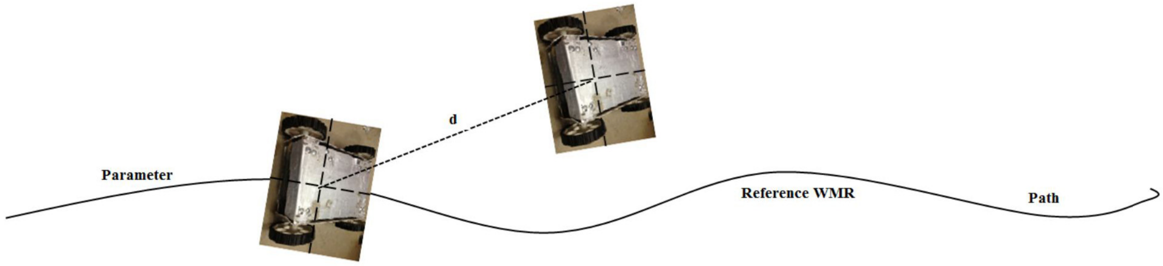

Fig. 1. Path following

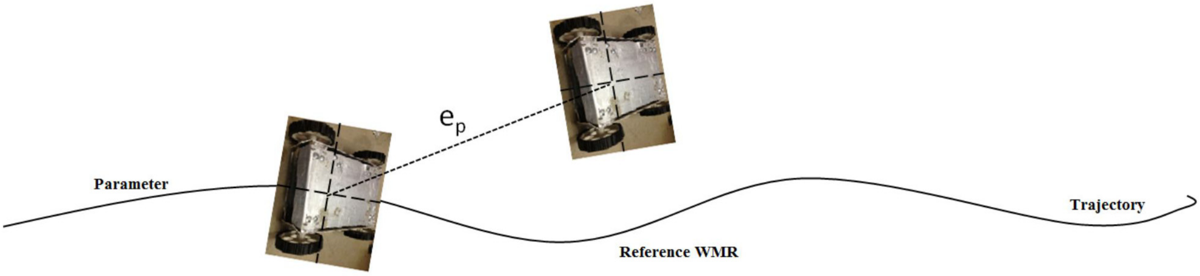

Fig. 2. Trajectory tracking

widely adopted because it is easy to incorporate. Further, in most of the studies found in literature, the leader robot plans its path and the follower robots follow it to attain the goal [6-9].

The objective of this research is to develop a tracking algorithm for formation control of multi robots using LFA. In this work, the robot team in consideration consists of one leader and three followers. All robots are equipped with sensors, but the leader alone has advanced navigation skills and sufficient computational power to execute an advanced strategy [10-12]. To show the validity of the proposed algorithm, a series of path tracking simulations and experiments were conducted for a prototype mobile robot in a virtual environment. The results demonstrate that the proposed algorithm provides a quick and smooth tracking performance with practical implementation.

This paper is organized as follows. In Section 2, the kinematics of a mobile robot and the formation model based on the leader-following approach is introduced. Section 3 addresses the control algorithm, controller design part and obstacle avoidance. Simulation and experimental results are presented in Section 4. Section 5 gives conclusions of this paper.

2. Mathematical Modelling

2.1. Robot-Robot Referenced MRS

Let us consider a robotic team consisting of one leader and three followers. Assume that the pose vectors of all the robots are given in the global reference frame. Here, R_L represents the leader robot and R_F represents the follower robot [13-15]. LFA model for multi robots is shown in Fig. 3. Two critical parameters: k and θ determine the geometric shape of WMR. The proposed control scheme for LFA is shown in Fig. 4. The overall architecture is shown in (a) and the subroutines for path flow, task flow, are presented in (b) and (c) respectively.

The controller checks for two strategies, when the strategy is related to an obstacle, the controller updates speed and position and based on this updated information a new trajectory is defined. When the strategy is environment such as pothole, bump, wall and ditch, it updates angle and similarly computes another new trajectory. The controller carries this information through Wi-Fi and executes the algorithm. The values of (X, Y, Z) and θ are updated in the table at each instance. The following are the notations used in this paper,

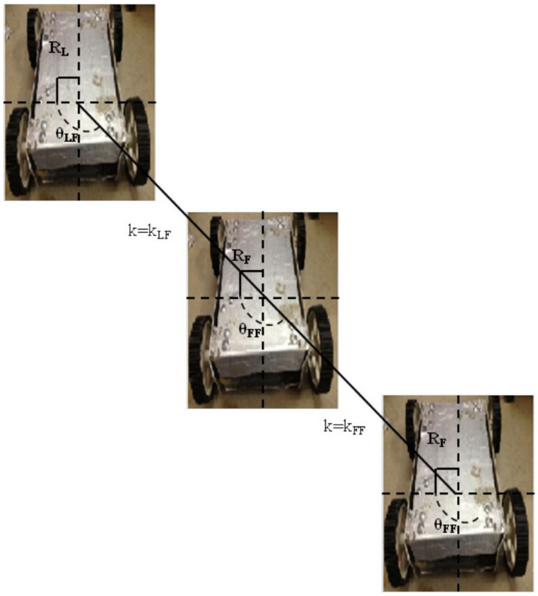

Fig. 3. LFA model for multi robots

- k and k^d represent the relative and desired linear separation respectively,
- ϕ and ϕ^d represent the relative and desired angular separation respectively,
- (X_L, Y_L) represents the position of the leader,
- (X_F, Y_F) represents the position of the follower,
- (X_R, Y_R) represents the position of the reference robot, which can be either the leader or the follower,
- θ_L and θ_F represent orientation of leader and follower respectively,
- v_F and ω_F represent translational and rotational wheel velocities of follower respectively,
- V_L and ω_L represent translational and rotational wheel velocities of leader respectively,
- $(\dot{x}_e, \dot{y}_e)$ represents the error vector.

The motion for WMR is given by

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} cos\theta & 0 \\ sin\theta & 0 \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} v \\ w \end{bmatrix} \tag{1}$$

Now velocity equation of leader and follower in ground frame is given by

$$\dot{x}_L = \dot{v}_L cos\theta_L \tag{2}$$

$$\dot{y}_L = \dot{v}_L sin\theta_L \tag{3}$$

$$\dot{\theta}_L = \omega_L \tag{4}$$

$$\dot{x}_F = \dot{v}_F cos\theta_F \tag{5}$$

$$\dot{y}_F = \dot{v}_F sin\theta_F \tag{6}$$

$$\dot{\theta}_F = \omega_F \tag{7}$$

In order maintain a desired linear separation k^d and desired linear separation ϕ^d, it is necessary to assume that the reference robot exist.

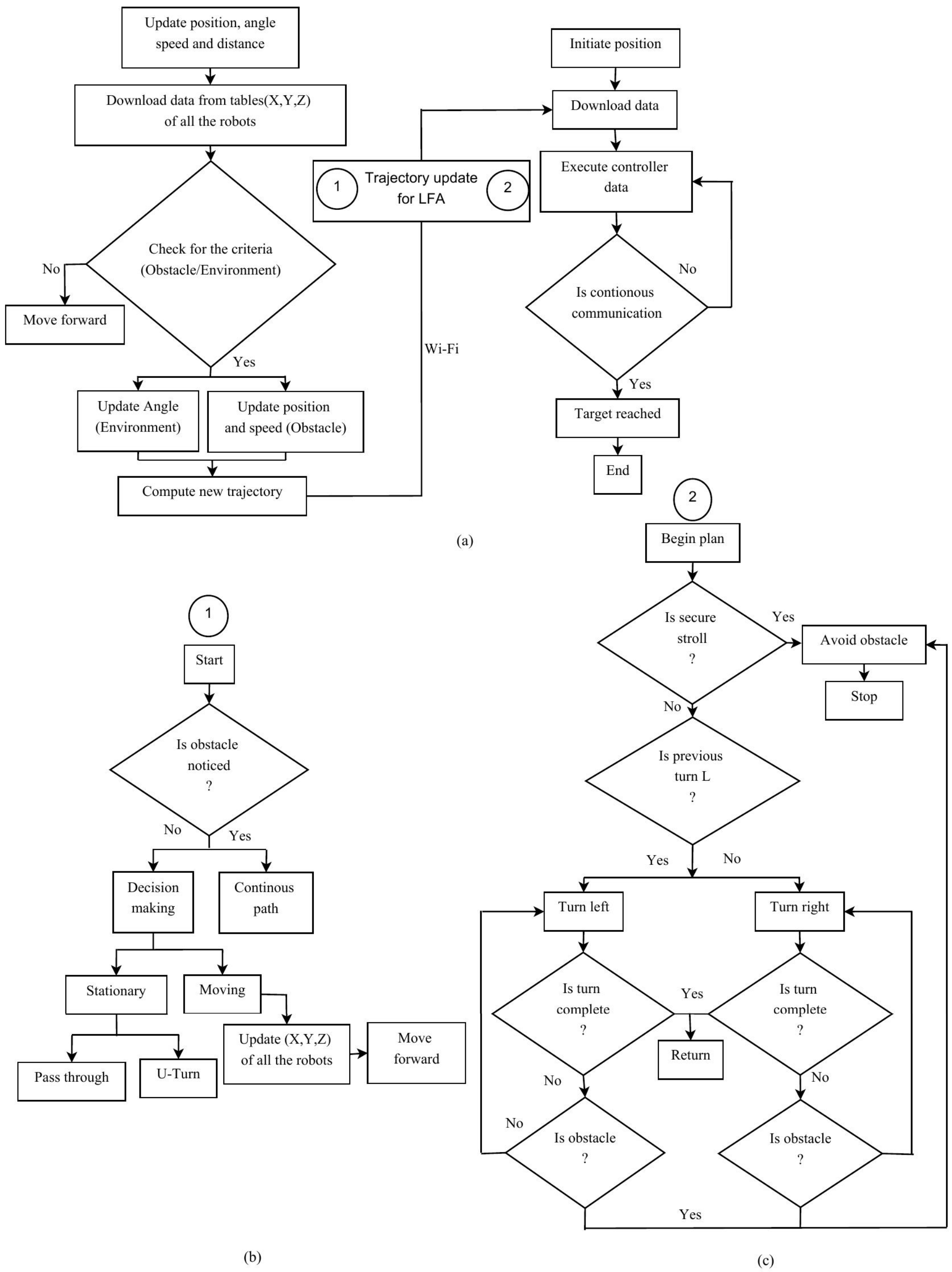

Fig. 4. Proposed control scheme: (a) Overall control architecture; (b) Path flow; (c) Task flow

Velocity equation of reference robot with leader in ground frame is given by

$$\dot{x}_r = \dot{v}_L cos\theta_L + k^d sin\phi^d \tag{8}$$

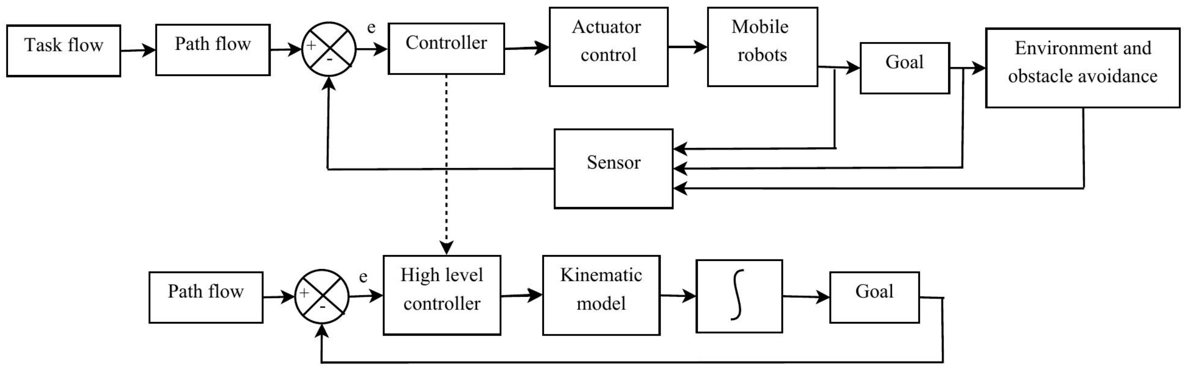

Fig. 5. High level tracking controller

$$\dot{y}_r = \dot{v}_L sin\theta_L - k^d cos\phi^d \tag{9}$$

$$\dot{\theta}_L = \dot{\theta}_r = \omega_L \tag{10}$$

Velocity equation of reference robot with follower in ground frame is given by

$$\dot{x}_r = \dot{v}_F cos\theta_F + k^d sin\phi^d \tag{11}$$

$$\dot{y}_r = \dot{v}_F sin\theta_F - k^d cos\phi^d \tag{12}$$

$$\dot{\theta}_F = \dot{\theta}_r = \omega_F \tag{13}$$

3. Controller Design

3.1. Tracking Control

The objective of the controller design is to find the values of translational and rotational wheel velocities such that separation and orientation errors are zero. Fig.5 represents the block diagram of the tracking controller. The task of this controller is to reduce the separation and orientation errors to zero, i.e. all the robots should move in accordance to the velocity V_F and ω_F computed by the controller. At every instant the follower pose is computed using the leader pose, which in turn allows another follower to move in accordance with this follower robot. A feedback loop is created to compare the followers actual pose and the current pose to reduce the error. The tracking controller compares the error coordinates and the leader robot pose, and uses this to compute the velocity of the follower robot.

Now tracking error is given by

$$\begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\theta}_e \end{bmatrix} = \begin{bmatrix} \dot{x}_r - \dot{x}_F \\ \dot{y}_r - \dot{y}_F \\ \dot{\theta}_r - \dot{\theta}_F \end{bmatrix} \tag{14}$$

The follower robot tracks the leader robot at all times, and at the instant when the formation parameter k^d (linear separation) and β (angular separation) converge to zero, the formation control equations are derived. Using the model equations, the tracking error of the entire system is obtained. To find the control law, this equation is linearized using the feedback linearization technique by giving suitable values to the velocity error coordinates. Thus the controller based Leader-Follower robot control velocity is:

$$\dot{x}_e = \dot{x}_r - \dot{x}_{F1} = \dot{v}_L cos\theta_L - \dot{v}_{F1} \;\; cos\theta_{F1} + k^d sin\phi^d \tag{15}$$

$$\dot{y}_e = \dot{y}_d - \dot{y}_{F1} = \dot{v}_L sin\theta_L - \dot{v}_{F1} sin\theta_{F1} + k^d cos\phi^d \tag{16}$$

$$\dot{\theta}_e = \dot{\theta}_d - \dot{\theta}_{F1} = \omega_L - \omega_{F1} \tag{17}$$

Similarly, the controller based Follower-Follower robot control velocity is

$$\dot{x}_e = \dot{x}_r - \dot{x}_{F2} = \dot{v}_{F1} cos\theta_{F1} - \dot{v}_{F2} cos\theta_{F2} + k^d sin\phi^d \tag{18}$$

$$\dot{y}_e = \dot{y}_d - \dot{y}_{F2} = \dot{v}_{F1} sin\theta_{F1} - \dot{v}_{F2} sin\theta_{F2} + k^d cos\phi^d \tag{19}$$

$$\dot{\theta}_e = \dot{\theta}_d - \dot{\theta}_{F2} = \omega_{F1} - \omega_{F2} \tag{20}$$

The velocity equations of reference robot with respect to leader is given as

$$\dot{x}_r = \dot{v}_L cos\theta_L + k^d sin(\phi^d + \theta_L)\dot{\theta}_L \tag{21}$$

$$\dot{Y}_r = \dot{v}_L sin\theta_L - k^d cos(\phi^d + \theta_L)\dot{\theta}_L \tag{22}$$

$$\dot{\theta}_r = \dot{\theta}_L = \omega_L \tag{23}$$

The velocity equations of reference robot with respect to follower is given as

$$\dot{x}_F = \dot{v}_F cos\theta_F + \omega_F h sin\theta_F \tag{24}$$

$$\dot{Y}_F = \dot{v}_F sin\theta_F + \omega_F h cos\theta_F \tag{25}$$

$$\dot{\theta}_F = \omega_F \tag{26}$$

Tracking algorithm is defined as

$$\begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} \cos\theta_F & \sin\theta_F & 0 \\ -sin\theta_F & \cos\theta_F & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} (x_r - x_F) \\ (y_r - y_F) \\ (\theta_r - \theta_F) \end{bmatrix} \tag{27}$$

On simplification, the equation for Leader-Follower is given by

$$\dot{x}_e = -v_{F1} + v_L cos(\theta_L - \theta_{F1}) + k^d \omega_L sin(\phi^d + \theta_L - \theta_{F1}) + \omega_{F1} y_e \tag{28}$$

$$\dot{y}_e = -v_L sin(\theta_L - \theta_{F1}) + k^d \omega_L cos(\phi^d + \theta_L - \theta_{F1}) - \omega_{F1} x_e - b\omega_{F1} \tag{29}$$

similarly, the equation for Follower-Follower is given by

$$\dot{x}_e = -v_{F2} + v_{F1} cos(\theta_{F1} - \theta_{F2}) + k^d \omega_{F1} sin(\phi^d + \theta_{F1} - \theta_{F2}) + \omega_{F2} y_e \tag{30}$$

$$\dot{y}_e = -v_{F1} sin(\theta_{F1} - \theta_{F2}) + k^d \omega_{F1} cos(\phi^d + \theta_{F1} - \theta_{F2}) - \omega_{F2} x_e - b\omega_{F2} \tag{31}$$

3.2. Obstacle Avoidance

Another essential challenge is to tackle problems which arise due to obstacles and environment disturbance, thus allowing proper movement of robots, even though they are perturbed by critical situations. The follower robots not only perform obstacle avoidance but also update information about other robots. When the strategy is related to an obstacle, the controller updates the speed and position of all the robots. Based on this updated information, a new trajectory is defined. The algorithm checks for both stationary and moving obstacles. Based on the type of obstacle, the robot will make a decision in each instant of time.

For stationary obstacle, the robot will either proceed through with left and right turn or make a U-turn whereas for moving obstacles, of all the robots are updated. When the strategy is environment such as pothole, bump, wall and ditch, it updates angle and similarly computes another new trajectory. For pothole, if the range of the sensor output is

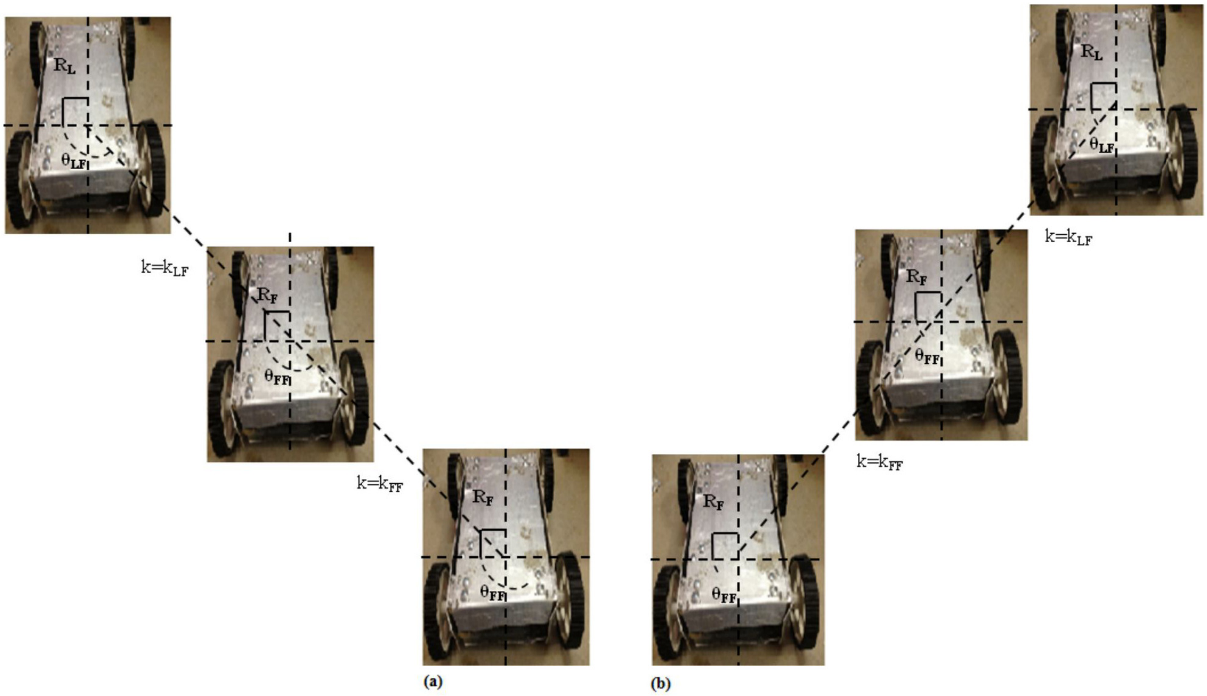

Fig. 6. (a) Orientation 1; (b) Orientation 2

greater than width depth of the pothole, the robots either overcome it or make a U-turn. For bump, if the range of the sensor output is greater than width height of the bump, the robot either climbs or make a U-turn For wall identity, if the sensor range is greater compared to swing radius, the robot might take right, left or U-turn. The desired angular orientation ϕ^d is derived for two orientations: one is right orientation and other is left orientation.
For left orientation as shown in Fig. 6(a),desired angular separation ϕ^d is given by

$$\phi^d = \begin{cases} \pi + \phi; \ \phi < \frac{\pi}{2} \\ \frac{3\pi}{2} - \phi; \ \phi > \frac{\pi}{2} \end{cases} \tag{32}$$

For right orientation as shown in Fig. 6(b), desired angular separation ϕ^d is given by

$$\phi^d = \begin{cases} \frac{\pi}{2} + \phi; \ \phi < \frac{\pi}{2} \\ \pi - \phi; \ \phi > \frac{\pi}{2} \end{cases} \tag{33}$$

4. Results and Discussion

In this section, four simulations are performed to demonstrate the validity of the suggested approach. The first test presented in Fig. 7 measures the distance error for multi robots. Due to the presence of obstacles, there is a variation in output. The spikes clearly indicate that there exists an obstacle while moving towards the goal in an unknown environment. In path 1 and 2, there are many spikes during the initial stages. As the robots move forward towards the goal, the spikes settle. The height and width of the spikes directly reflect the time taken to overcome an obstacle.

Test two records the separation error for multi robots as shown in Fig. 8. From the simulation, both cases show that one robot is followed by another in a steady manner. While flocking in an environment, in case the leader gets stuck due to an obstacle, immediately the remaining robots follow the path traced by the next leader. The number of spikes is directly proportional to the number of times the leader robot requests for a change in orientation. In path 1, the leader robot gets stuck at many instances and because of this time taken to reach the goal is more.

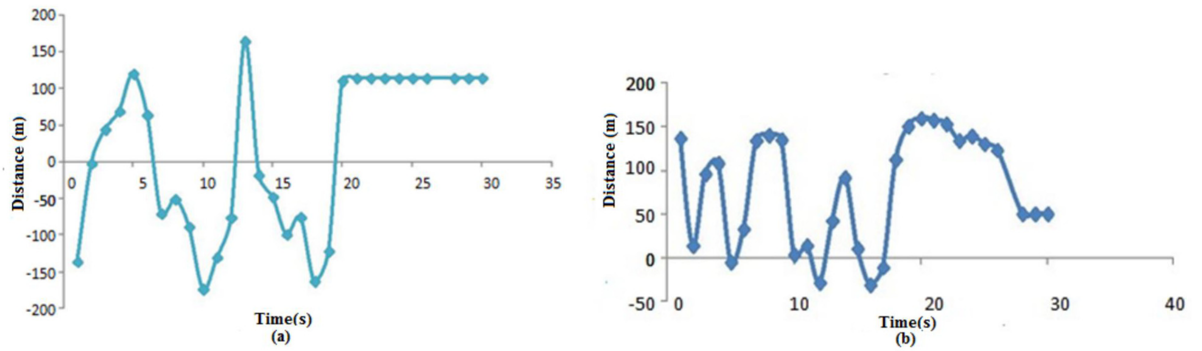

Fig. 7. Distance error for: (a) path 1; (b) path 2

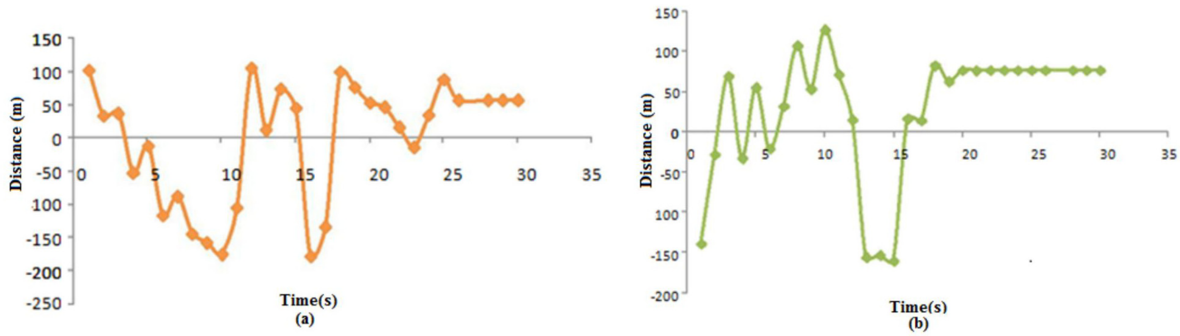

Fig. 8. Orientation error for: (a) path 1; (b) path 2

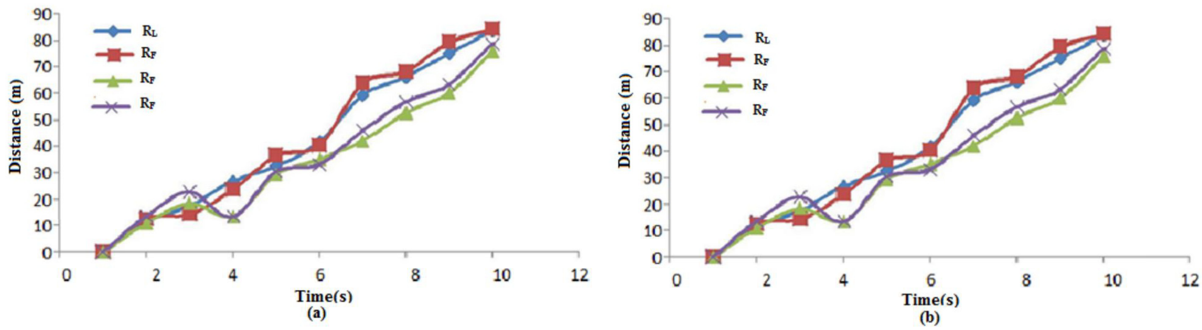

Fig. 9. Path flow for multi robots (a) path 1; (b) path 2

The path flow is demonstrated in Fig. 9. As separation and distance error is minimized as shown above, the path traced by the robots is trained optimally. Further, all the robots in the overall closed loop system are bounded. The obstacle faced by one robot is not mandatorily faced by another robot. In iteration 1, robot 2 and 4 face many obstacles. The tracking controller is simulated in LabVIEW software and shown in Fig. 10. Fig. 11 records the tracking controller output for four parameters.

The initial conditions for $(X_L, Y_L), (X_F, Y_F)$ are (0,0). Assuming $k^d = 1.2m$ and $\phi = \frac{\pi}{3}$, the values of the observer are calculated. The values are 4, 6,-11.9, and 9. Based on this the output is recorded and from the Fig. (a) and (b), the separation error and distance error are zero. The overall distance and separation error is minimized. During running time, the robot faces a number of obstacles but does not tackle all the obstacles. In each instance the number

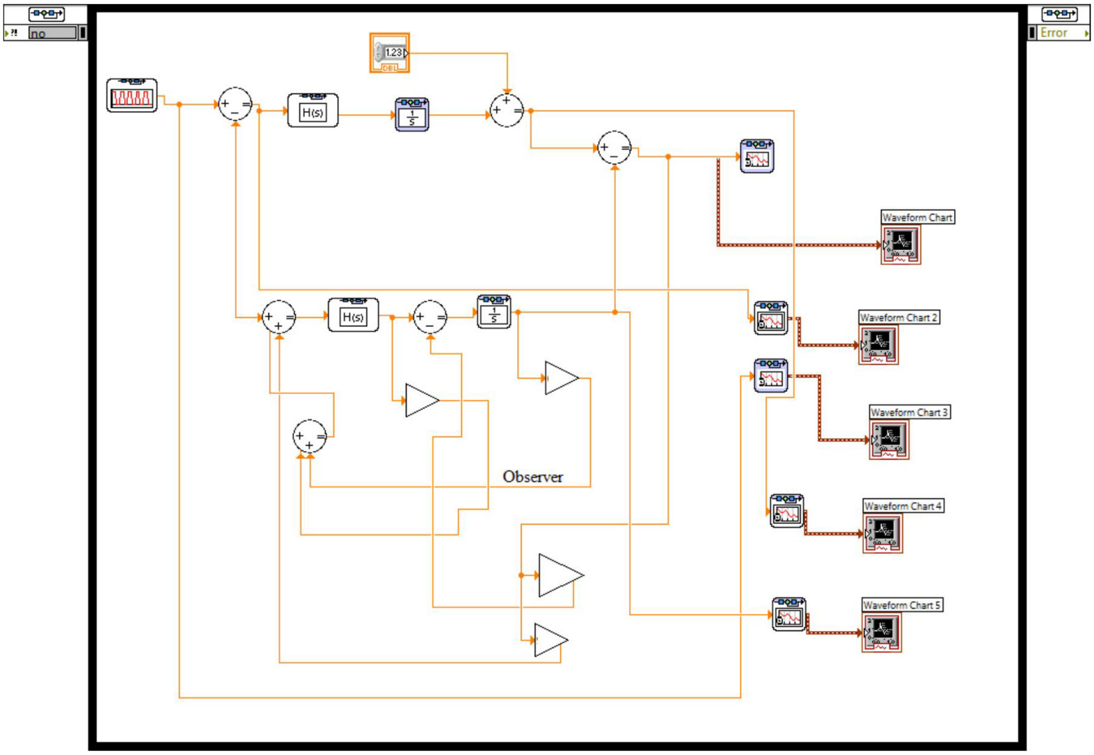

Fig. 10. LabVIEW model for tracking algorithm

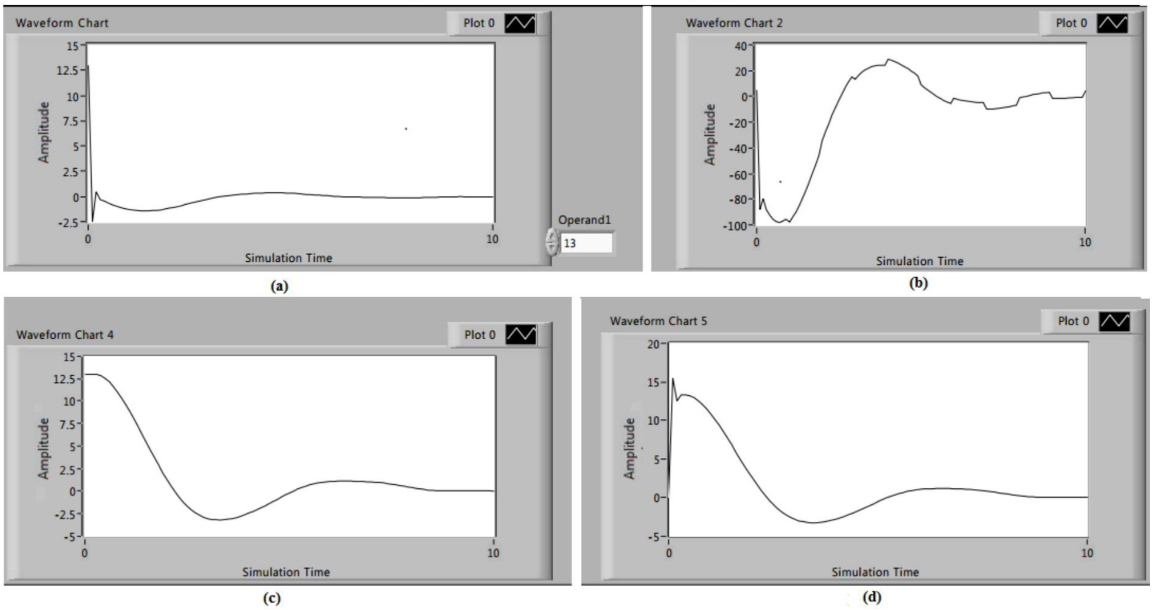

Fig. 11. (a) Distance error; (b) Orientation error ; (c) Leader velocity ; (d) Follower velocity

of stationary and moving obstacles present in the trajectory is recorded. As the robot reaches the goal, the velocity of the leader and follower are zero.

5. Conclusions

In this paper, a new formation approach for multi robots has been proposed. This approach has the capability to address the combined problem of the formation planning and navigation through obstacle avoidance. The formation parameters i.e., orientation angle and separation distance, can be varied depending on the requirement. A tracking controller with observer has been designed for this purpose. The effectiveness of this proposed design is validated via simulation experiments. A unique feature of the proposed formation control approach is the incorporation of the role switching methodology and their behaviours to actively avoid obstacles in its path. In this work, a detailed study about LFA has been presented. Finally the stability of the system has not been analyzed and would be the subject of further investigation and study. Analytical results and simulation experiments show that the tracking algorithm proposed in this paper is more intuitive and effective. Currently one robot has been procured and further two mobile have been fabricated. Future research lines include the experimental validation of LFA and extension of the results described in this work towards the unknown environment.

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