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Design of Robots Formation Controllers Using Evolutionary Fuzzy Systems

Chi-Chung Chen* and Han-Wen Chang
Department of Electrical Engineering, National Chiayi University, Chiayi City, Taiwan

ABSTRACT

Based on the leader-follower approach, this paper proposes a new design scheme of fuzzy controllers for robots formation using evolutionay algorithms. In the proposed scheme, the inputs to the fuzzy controller are the relative position errors of the follower robot on the coordinate system varying with respect to the heading of the leader. The outputs of the designed fuzzy controller are the two orthogonal velocities. The headind speed of the leader is then directly combined with the output of the fuzzy controller to generate the control inputs for the follower robot. This scheme simplifies the design of the controllers for the robots formation. Based on the proposed scheme, the fuzzy controller to be designed is optimized by using a modified particle swarm optimization to minimize the relative accumlated position errors for robots formation. The learned fuzzy controllers can be adopted for the changes of different formation shapes without additional learning. Using the proposed design scheme, the simulation and exeriement of the formation control of the educational e-puck robots are demonstrated.

Keywords: formation control, fuzzy systems, evolutionary algorithms

I. INTRODUCTION

Formation control of multiple mobile robots and vehicles has been studied extensively over the last decade for both theoretic research and practical applications. Several methods have been reported to solve the formation control problem of multiple robots [1]. Virtual structure approach [2], behavioral approach [3], and leader follower approach [4-8] are the three main methods, each of which has several advantages and weaknesses that can be found in [1]. In the leader-follower approach, one of the robots is designated as the leader with the rest robots being followers, and the robots formation is achieved by all followers through positioning themselves relative to the leader and maintaining at desired relative positions with respect to the leader. In this approach, the motion of the leader and the desired relative positions of the followers with respect to the leader are specified to prescribe a formation.

In recent years, fuzzy logic systems are often adopted to control mobile robots because they are capable of making inferences and could be robust to uncertainty [5-12], some of which used fuzzy controllers for robots formation. A leader-follower approach with separate fuzzy formation position control and internal collision avoidance was proposed in [5]. Based on the leader-follower approach, a fuzzy controller consisting of three fuzzy inference systems was proposed and manually designed for formation control [6]. The inputs to these three fuzzy systems are the leader velocity and the relative position errors based on the coordinate according to the heading direction of the leader. Based on the work in [6], this paper proposes a new design scheme of fuzzy formation control. In the same conditions of available information as in [6], the proposed scheme simplifies the design of the fuzzy controllers for the robots formation. Furthermore, the fuzzy controller is designed (optimized) by using a modified particle swarm optimization [13] to reduce the time-consuming manual effort. Without additional learning, the designed fuzzy controllers are to conform to the change of formation shape.

II. FUZZY FORMATION CONTROL

The objective of the fuzzy formation controllers are for the follower robots initially being in arbitrary positions and heading angles to move toward the desired set of positions relative to the leader while the leader can traverse in arbitrary path. In this section, we propose a new design scheme of robot formation controllers using zero-order Takagi-Sugeno-Kang (TSK)-type fuzzy systems.

A. Scheme of Formation Control

Assuming that the state information of the leader (position, velocity, and the heading angle) is available to each follower, a new scheme of feedback control loop to control the movement of the follower is proposed and described in Fig 1.

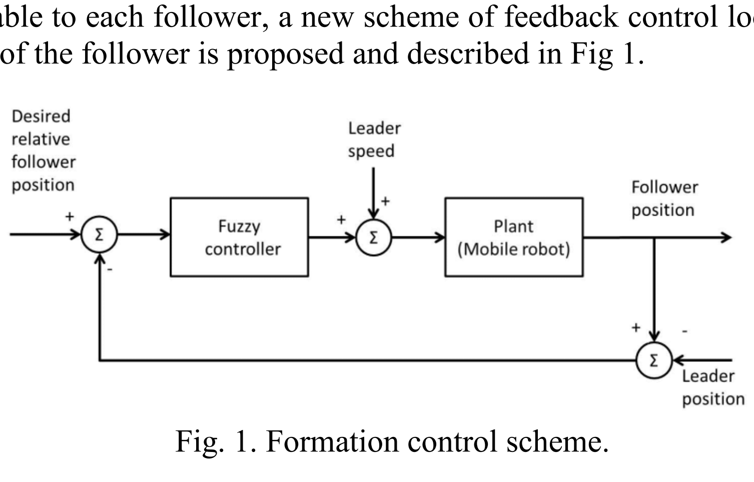

Fig. 1. Formation control scheme.

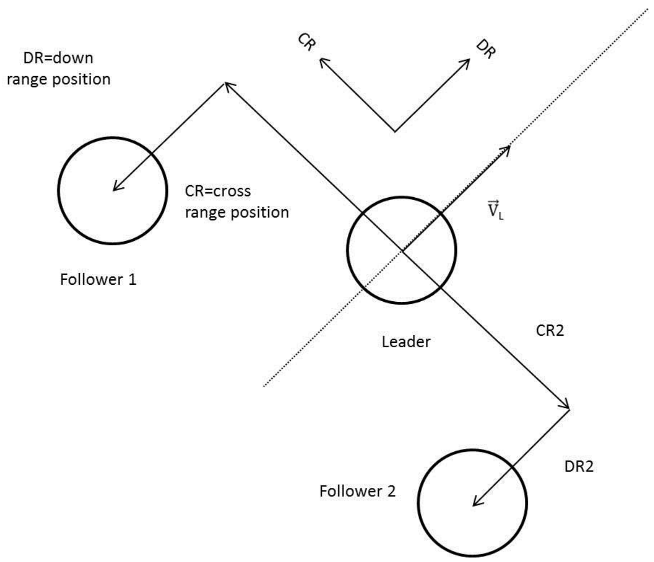

Fig. 2. Input metrics of fuzzy formation controller

Mostly different from the study in [6], this scheme only uses the relative position errors as the inputs of the fuzzy controller. As described in [6], the relative positions of the follower to the leader are represented on the coordinate system according to the leader heading direction. The down range (DR) position is the relative position of the follower measured in the direction of the leader heading, while the cross range (CR) position is perpendicular to the leading direction. Every follower has its own relative positions with respect to the leader. Fig. 2 illustrates an example that two followers and one leader are to form a triangular formation shape. The errors between the desired DR (CR) position and the actual DR (CR) position, respectively are the *inputs* to the fuzzy controller and are calculated by

$$\begin{aligned} e^i_{DR} &= DR^i_{desired} - DR^i_{actual} \\ e^i_{CR} &= CR^i_{desired} - CR^i_{actual}, \end{aligned} \tag{1}$$

where $DR^i_{desired}$ and $CR^i_{desired}$ are the desired positions of the ith follower robot relative to the leader for the specified formation.

The outputs of the fuzzy controller in each follower are the two basic velocity commands, $\vec{V}_{DR}$ and $\vec{V}_{CR}$, for the follower to respond to the errors e_{DR} and e_{CR}, respectively. Since the error e_{DR} is independent of the error e_{CR}, the fuzzy controller for each follower can be realized by two single-input-single-output (SISO) zero-order TSK-type fuzzy systems: the first fuzzy system with e_{DR} as the input generates the output $\vec{V}_{DR}$, and the second fuzzy system generates the output $\vec{V}_{CR}$ to respond to the

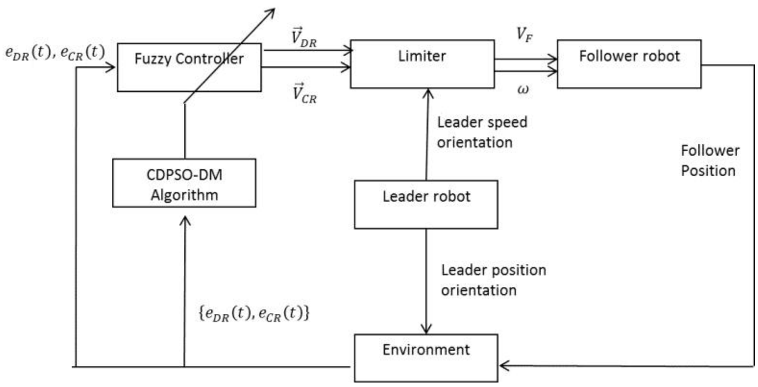

Fig. 3. Evolutionary fuzzy control for robots formation

input e_{CR}. Since the leader moves, the leader speed should be combined into the basic velocity command $\vec{V}_{DR}$ to provide the control input for the follower to track the leader. The move of the follower will be controlled by the resultant translation speed and steering angular speed derived by these two perpendicular velocity commands. However, if the translation speed control is beyond the hardware capability of the robot, the velocity command in the DR direction will be preferred than the CR direction. If the resultant angular speed control is beyond than the capability, the maximum allowable angular speed is assumed.

B. Design of Fuzzy Formation Controller

Based on the proposed scheme, the learning configuration for designing (optimizing) the fuzzy controller is depicted in Fig. 3. Excited by the relative position errors, the fuzzy controller generates two basic velocity commands. Combining the leader speed with the fuzzy output $\vec{V}_{DR}$, the resulting limited velocity commands for conforming to the hardware capability of the robot are transformed to the translation speed and angular speed to control the move of follower. In the next time step, the relative position errors are computed again to derive the control commands for the follower. Repeating such procedure, the errors are computed and accumulated. Then evolutionary algorithms are used to identify the parameters in a zero-order TSK-type fuzzy controller by minimizing the accumulated errors. This study uses the central-distributed particle swarm optimization incorporating dynamic mutation (CDPSO-DM) proposed in [13] for optimization.

The objective function used for optimization in the CDPSO-DM is defined by

$$f = \frac{1}{E}\sum_{l=1}^{E}\left(\sum_{t=1}^{T_{stop}^{l}}\frac{1}{T_{total}}\sqrt{\left|e_{DR}^{l}(t)\right|^{2}+\left|e_{CR}^{l}(t)\right|^{2}}+\left(T_{total}-T_{stop}^{l}\right)\right). \tag{2}$$

The value in (2) basically is the average of the position errors for the follower to track the leader during the training period T_{total}. If the follower robot moves outside of the pre-specified training area at the time step T_{stop}, the robot stops. A number of *E* initial positions are selected for the follower to start in the learning process.

III. SIMULATION AND EXPERIMENT

A. Computer Simulation

Educational e-puck robots and Webots software for robot simulation are used to demonstrate the proposed design, which were reported in our study [12, 14]. The membership functions for the fuzzy sets in the antecedent part of the zero-order TSK-type fuzzy system are Gaussian functions. The fuzzy controller for the follower consists of three rules. The 20 particles are used in CDPSO-DM. In the learning process, the leader stands in the fixed position (0, 0) and is assumed to move in the positive horizontal direction. The fuzzy controller for the follower is trained and expected to move from the four initial positions (0.25, 0.25), (0.25,-0.25), (-0.25, 0.25), and (-0.25,-0.25), respectively to (0, 0) within 40 steps. Each run of optimization by the CDPSO-DM stops after 25 iterations. The allowed maximum velocity for the follower robot is limited to 0.1m/s.

The designed fuzzy controller was tested by demonstrating the robots formation of triangular shape: the desired positions of the follower 1 with respect to the leader are $DR^1_{desired}$ = -0.1m and $CR^1_{desired}$ = -0.1m and the desired positions of the follower 2 with respect to the leader are $DR^2_{desired}$ = -0.1m and $CR^2_{desired}$ = 0.1m. The simulation results of the formation control when the leader moves in nonlinear motion with the velocity of 0.05m/s and the followers are initially far away from the desired positions are demonstrated in Fig. 4.

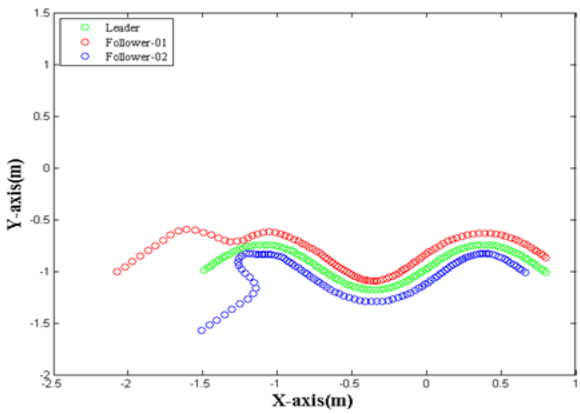

Fig. 4. The trajectories of the three robots moving in nonlinear motion.

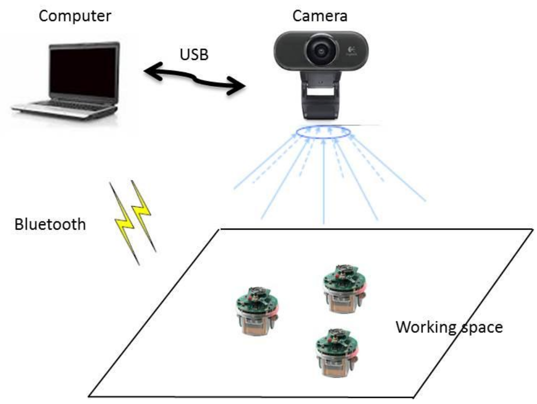

Fig. 5. Experimental system setup

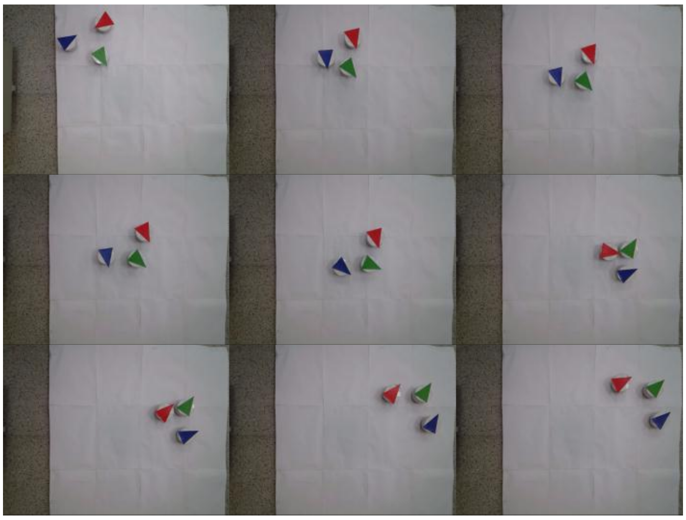

Fig. 6: Experimental results of formation control when the leader (green) moves in nonlinear motion. Camera snapshots: 1st row: 1-2-3; 2nd row: 4-5-6; 3rd row: 7-8-9.

B. Experiment

The experimental system setup shown in Fig. 5 consists of a host personal computer, a camera, and three e-puck robots, which are two followers and one leader. The camera is utilized to obtain the position and orientation of each robot by the image processing techniques. For simplification, the experiment uses the only host personal computer to implement the fuzzy controllers for all follower robots and send the control signals to all robots via Bluetooth communication links. The formation is a triangular shape.

The leader moves with the velocity of 0.025m/s in nonlinear motion. The camera snapshot results shown in Fig. 6 validates the success of the proposed design.

IV. CONCLUSION

This paper proposes a new design scheme of fuzzy controllers to provide the formation control of a multi-robots system using the leader-follower approach. In the proposed scheme, the position errors of the follower on the coordinate system varying with respect to the heading direction of the leader are the only inputs to the fuzzy controller. The outputs of the designed fuzzy controller are the two orthogonal velocities. The fuzzy outputs combine the leader speed to generate the control inputs for the follower robot. This scheme simplifies the design of the controllers for the robots formation. Instead of time-consuming manual effort, the fuzzy controller to be designed then is optimized using a modified particle swarm optimization to minimize the relative accumlated position errors for robots formation. The learned fuzzy controllers can be adopted for the changes of different formation shapes without additional learning. The computer simulation and experiment using the educational e-puck robots demonstrated the success of formation control with the proposed design.

ACKNOWLEDGMENT

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