Tracking and Formation of Wheeled Mobile Robot Using Fuzzy Logic

R.B.Meshram

Abstract— In this paper we propose a formation and motion control strategy for a group of wheeled mobile robot. Construction of perfect mathematical model is extremely complex due to inherent nonlinearities and other difficulties involved in obtaining reliable measurements. The aim of this work is to develop wheeled mobile robots, placed them in a leader follower framework and a motion controller based on Fuzzy Logic. Fuzzy logic gives human being like reasoning behaviour to a machine. It has been proved that fuzzy logic controllers are capable of using information retrieved from experienced human operator more effectively when compared with conventional controllers. The motion controller is designed using Interval type-2 Fuzzy logic. This will provide the robots the possibility to move from the initial to the final position. The simulation has been performed using MATLAB to investigate the performance of the proposed fuzzy controller

Keywords— Wheeled mobile robot, formation, leader-follower, Interval type 2 fuzzy logic, fuzzy controller.

I. INTRODUCTION

Wheeled mobile robots (WMR) have been gradually and widely used in several places and by industrial manufactures. Multi-robot systems have been suggested as a means to accomplish tasks on the battlefield and in other environments. The need for formation control of multi-robot systems performing a coordinated task has lead to the development of a challenging research field. The formation control problem is defined as finding a control algorithm ensuring that multiple autonomous vehicles can uphold a specific formation or specific set of formations while traversing a path. The main objective is the construction of such a system which is capable of moving in its environment without a help of human operator. The proposed work is limited to the case where robots workspaces free of obstacles. The robotic system considered is a vehicle whose kinematic model approximates the mobility of a car. The kinematic model for mobile robots which in our case is a car like model is quite commonly used as given in [1][2][3]. The conjuration of this robot is represented by the position and orientation of its main body in the plane, and by the angle of the steering wheels.

Moreover, the car-like robot is the simplest nonholonomic vehicle that displays the general characteristics and the difficult maneuverability of higher-dimensional systems. Many control approaches have been put forward to solving the problem such game theory, model predictive control and so on. We have use Fuzzy logic (type-2) in our case.

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Ritesh B. Meshram, Master of Engineering, Fr. Conceicao Rodrigues College of Engineering, Mumbai, India.

Fuzzy Logic is a tool for modeling uncertain systems by facilitating common sense reasoning in decision-making in the absence of complete and precise information. Fuzzy logic is also a true extension of conventional logic, and fuzzy logic controllers are a true extension of linear control models. Hence anything that was built using conventional design techniques can be built with fuzzy logic, and vice-versa. Controlling a motion of mobile robot to replicate that of manually handled in real world environments is a challenging and difficult task. Due to there are large amount of uncertainties and imprecisions present in such environments. Researchers have used the concept of fuzzy logic for wheeled mobile robot such as in [4][5][6][7]. Fuzzy logic has proven to be a convenient tool for handling real world uncertainty and knowledge representation. In our case the motion controller for multi-robots system is designed using Interval type-2 Fuzzy logic System (IT2-FLS).

Problem Statement

A robot group, comprised of n wheeled mobile robots Ri (i=1, 2…n), is assigned a group task. To successfully achieve the task, the robot group needs to form and maintain the desired formation shapes

In response to the problem statements described above we thereby categorize the objectives of this project into the following:

(1) Apply a leader-follower formation control between leaders and followers, for a group of nonholonomic mobile robots.
(2) Incorporate the Fuzzy logic controller strategy to control the motion of mobile robot.

The paper is organized as follows. Section 2 presents an model of Wheeled mobile robot and formation strategy. Section 3 gives an overview of fuzzy logic (IT2-FLS) and its control model. Section 4 reports the implementation done in MatLab environment, while the conclusions are drawn in Section 5

II. WHEELED MOBILE ROBOT

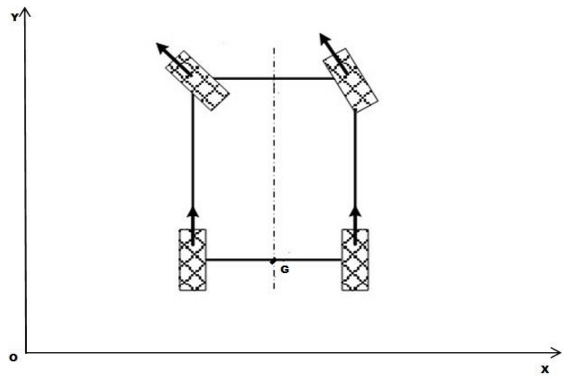

Figure1: WMR model

The robot can be described in terms of the two coordinates X, Y of the origin G of the moving frame and the orientation angle θ of the moving frame and front wheel angle δ , both with respect to the base frame with origin at O. Hence the robot position is given by the (4 x 1) vector,

$$p = \begin{bmatrix} X \\ Y \\ \theta \\ \delta \end{bmatrix}$$

A. Steering Method

We can model this vehicle by just two wheels as described in figure 2. This is called the bicycle model. In the simplest form of steering, both the front wheels always point in the same direction. You turn the wheel, they both point the same way and around the corner you go [19].According to the Ackerman-Jeantand model of steering when vehicle is running, as be shown in Figure 2, we define L is the distance between front and rear wheel, δ is average steering angle of two front wheels

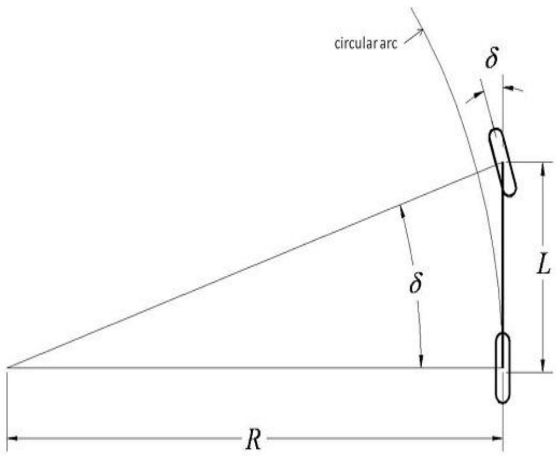

Figure 2: Geometric Bicycle Model

Depending on the above analysis, when the vehicle is steered with an angle δ, the turning radius R can be expressed by:

$$R = \frac{L}{\tan\delta} \quad (1)$$

The equations of motion for the kinematic bicycle model of a car are readily available in the literature [8]. Restricting the model to motion in a plane, the nonholonomic constraint equations for the front and rear wheels are:

$$\dot{x}_f \sin(\theta+\delta) - \dot{y}_f \cos(\theta+\delta) = 0 \quad (2)$$

$$\dot{x}\sin\theta - \dot{y}\cos\theta = 0 \quad (3)$$

Let (x, y) be the global coordinate of the rear wheel, (x_f, y_f) be the global coordinate of the front wheel, θ be the orientation of the vehicle in the global frame, and δ be the steering angle in the body frame. As the front wheel is located at distance L from the rear wheel along the orientation of the vehicle, $(\dot{x}_f, \dot{y}_f)$ may be expressed as:

$$x_f = x + L\cos\theta$$
$$y_f = y + L\sin\theta \quad (4)$$

B. Leader-Follower Formation Strategies

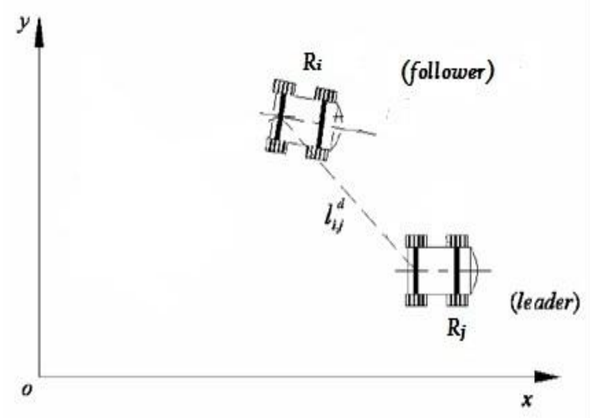

Figure 3: Leader-Follower Formation

In leader-follower approaches the robots maintain some desired distance to some of their neighbors and/or virtual points. Some robot members are designated as leaders while other robots are designated as followers. The structure is dependent on the architecture utilized. There can be as few as one leader, or there can be several leaders with a hierarchical structure. There are many approaches for maintaining formations utilizing a leader-follower method. In our case the objective is to maintain a desired length from leader robot.

Under the formation control strategy, R_i follows R_j with a desired separation $l_{i,j}^d$ where θ_i and θ_j are the orientation of R_i and R_j respectively. To solve the formation problem for each robot as shown in Figure 3, the desired position of the follower R_j is given by

$$x_i^f = x_j + l_{i,j}^d$$
$$y_i^f = y_j + l_{i,j}^d \quad (5)$$
$$\theta_i^f = \theta_j$$

Where the posture of the leader R_j , which is assumed pre-acknowledged to the follower R_i.

III. FUZZY LOGIC

The concept of a type-2 fuzzy set was introduced by Zadeh (1975) as an extension of the concept of an ordinary fuzzy set (henceforth called a "type-1 fuzzy set"). A type-2 fuzzy set is characterized by a fuzzy membership function, i.e., the membership grade for each element of this set is a fuzzy set in [0, 1], unlike a type-1 set where the membership grade is a crisp number in [0, 1]. Such sets can be used in situations where there is uncertainty about the membership grades themselves, e.g., an uncertainty in the shape of the membership function or in some of its parameters. Consider the transition from ordinary sets to fuzzy sets. When we cannot determine the membership of an element in a set as 0 or 1, we use fuzzy sets of type-1. Similarly, when the situation is so fuzzy that we have trouble determining the membership grade even as a crisp number in [0,1], we use fuzzy sets of type-2 [9]. Hence, in this paper, we will present an controller using Interval Type - 2 Fuzzy Logic System (IT2-FLS). Jerry Mendel from his papers [11]-[17]

has taken the IT2-FLS to a new high. Whereas Dongrui Wu in [18] explains the basic ideas of interval type-2 (IT2) fuzzy sets and systems in a simplest form.

Definition 1: A type-2 fuzzy set $\tilde{A}$ is characterized by a type-2 membership function $\mu_{\tilde{A}}(x,u)$ where $x \in X$ and $u \in J_x \subseteq [0,1]$ [13]

$$\tilde{A} = \{((x,u), \mu_{\tilde{A}}(x,u)) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1]\} \tag{6}$$

Where $0 \le \mu_{\tilde{A}}(x,u) \le 1$ and is typically written as

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} \mu(x,u)/(x,u) \quad J_x \subseteq [0,1] \tag{7}$$

Where $\iint$ denotes union over all admissible x and u

From (6) and (7), $J_x \subseteq [0,1]$ is a restriction that is equivalent to $0 \le \mu_A(x) \le 1$ for type-1 membership function and J_x denotes primary membership of $\tilde{A}$ where $J_x \subseteq [0,1]$ for $x \in X$.

Definition 2: The IT2 FLS can be expressed as [13]

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} 1/(x,u) \quad J_x \subseteq [0,1] \tag{8}$$

Where the position of $\mu(x,u)$ in (7) is replace by 1. When all $\mu_{\tilde{A}}(x,u) = 1$ then $\tilde{A}$ is an interval T2 FS (IT2 FS). There exist an uncertainty in the primary membership of a type-2 fuzzy set $\tilde{A}$ consists of a bounded region known as footprint of uncertainty (FOU) as in figure 4.

Definition 3: There are two type-1 membership functions that bound the $FOU(\tilde{A})$ that is lower membership function (LMF) denoted by $\underline{\mu}_{\tilde{A}}(x), \forall x \in X$ and upper membership function (UMF) denoted by $\bar{\mu}_{\tilde{A}}(x), \forall x \in X$ [13]

$$\underline{\mu}_{\tilde{A}}(x) \equiv \overline{FOU(\tilde{A})} \quad \forall x \in X \tag{9}$$

And

$$\bar{\mu}_{\tilde{A}}(x) \equiv \underline{FOU(\tilde{A})} \quad \forall x \in X \tag{10}$$

for an IT2 FS

$$J_x = [\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)], \forall x \in X. \tag{11}$$

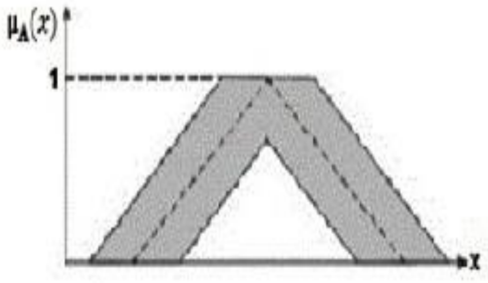

Figure 4: The shaded area is called the footprint of uncertainty (FOU).

A. Fuzzy controller

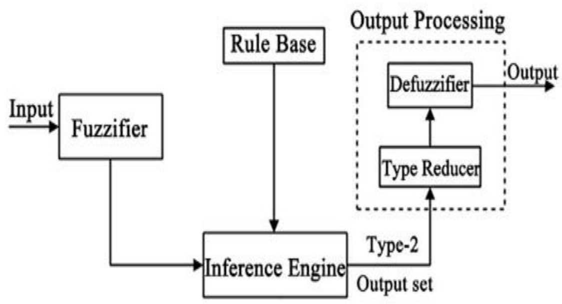

Figure 5: Type-2 fuzzy logic system

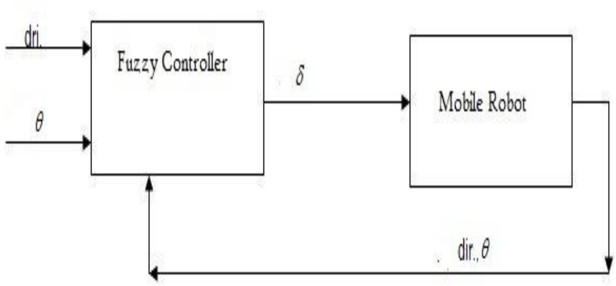

Figure 6: General structure of motion control.

As shown in section II. the vehicle coordinates are denoted in configuration $q = [x, y, \theta, \delta]^T$ relative to base frame coordinate. For controlling the motion of vehicle we are considering its x-axis coordinate, which will be denoted by 'dir.' and vehicle angle θ with respect to base frame. We first define the state variable of the controller. The state variables were the vehicle angle, θ, the vehicle x-axis coordinate, dir. and the control variable is the steering-angle signal, ϕ. The dir. ranges from 0 to 240, θ ranges from -110 to 280. Different vehicles have different maximum turning angle ranging from 23 to 45 degree. So in our case we considered the steering angle 38. So δ ranges from -38 to 38.

1) Linguistic Variables and Rule Base

We consider a fuzzy system with two inputs and one output. The two inputs are the vehicle's current x-axis coordinates and orientation. The output is the steering command in terms of steering angle. Therefore the three linguistic variables are x- axis coordinates (dir.), Angle (θ) and Steering (δ). x-axis coordinates has 5 linguistic values whereas Angle and Steering have 7 linguistic values. The linguistic terms for Angle and Steering are *NB*, negative big; *NM*, negative medium; *NS*, negative small; *ZE*, zero; *PS*, positive small; *PM*, positive medium; and *PB*, positive big. The linguistic terms of dir. are NH, negative high; NL, negative low; ZE, zero; PL, positive low; PH, positive high.

The structure of type-1 and type-2 FLS is nearly same, the only difference is in defuzzification block. In type -2 FLS the type-1 defuzzification block is replaced by type reducer and defuzzifier blocks. Total 35 rules are used for WMR. The rule base table 1 for the FLS used in this work is listed below. Generalize rule base statement of multiple input ant single output FLS for M rules. [9]

R^i : IF x_1 is $\tilde{F}_1^i$ and ….. and x_p is $\tilde{F}_p^i$, THEN y is $\tilde{G}^i$
$i = 1 \ldots\ldots M$

Table 1: Fuzzy rules base table

θ / dir.	NB	NM	NS	ZE	PS	PM	PB
NH	NB	NB	NB	NM	NM	NS	PS
NL	NB	NB	NM	NM	NS	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PM
PL	NS	PS	PM	PM	PM	PB	PB
PH	NS	PS	PM	PM	PB	PB	PB

2) Type-reducer and defuzzification

The output processor includes a type-reducer and defuzzifier. The type-reduction method is an extension of type-1 defuzzification obtained by applying the Extension Principle to a specific defuzzification method. The type-reduced set using the Center of Sets (COS) can be expressed as [10][11].

$$Y_{TR}(x) = [y_l(x), y_r(x)]$$
$$= \int_{y^i \in [y_l^i, y_r^i]} \cdots \int_{f^i \in [\underline{f}^i, \bar{f}^i]} 1 \Big/ \frac{\sum_{i=1}^{M} f^i y^i}{\sum_{i=1}^{M} f^i} \qquad (12)$$

Where $Y_{TR}(x)$ is an interval type-1 fuzzy set determined by its two end points $y_l(x)$ and $y_r(x)$ and M is the number of rules. For type-reduction $[\underline{f}^i, \bar{f}^i]$, is the firing interval and $[y_l^i, y_r^i]$ is the centroid of the consequent set of the i th rule. The output of defuzzification step of FLS is obtained by summing the value of $y_l(x)$ and $y_r(x)$ obtained from type reduction step and divide it with two, as shown on equation, this will give us the steering value δ.

$$\delta = y(x) = \frac{y_l + y_r}{2} \qquad (13)$$

IV. SIMULATION

The effectiveness of the fuzzy controller is demonstrated here. This chapter lays out the simulation environment created in MatLab, and its results. The simulation was designed to match the car as closely as possible. At first we will enter the number of vehicle we want for our simulation. The controller counter is set at 70, means controller will take the inputs and will give the output 70 times. Total 7 vehicles are designed. Once the numbers of vehicles are entered. We will enter the (x, y) coordinates of first vehicle.

The output of simulation is shown below;
Enter the no. of vehicles: - 7
Enter position 1 or 2: - 1
enter x location 10 to 150: - 150
enter y location : - 10 to 80 : - 80

The output from controller is steering angle δ. The lists of steering commands and new position of rear axle mid-point given to the robots are shown as follow;

δ ={31.4854,32.6794,33.2936,33.0526,34.1389,32.4145,20.7650………… 0.1559,0.1571,0.1534}

(x, y) ={(153.3972,80.7571),(156.4680,82.3933),(158.9671,84.8137),(160.6947,87.8337),(161.4984,91.2178),(161.3253,94.6933),(160.3982,98.0544),……………..(100.0693, 196.9666), (100.3498, 200.4460)}

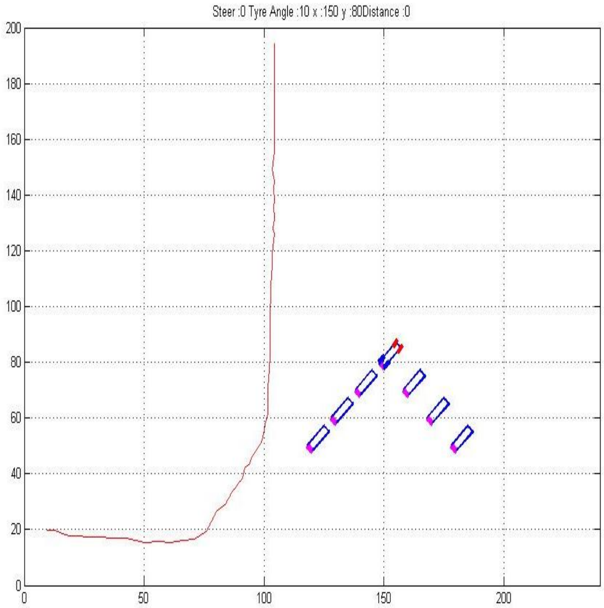

Figure 7: Initial position of robots

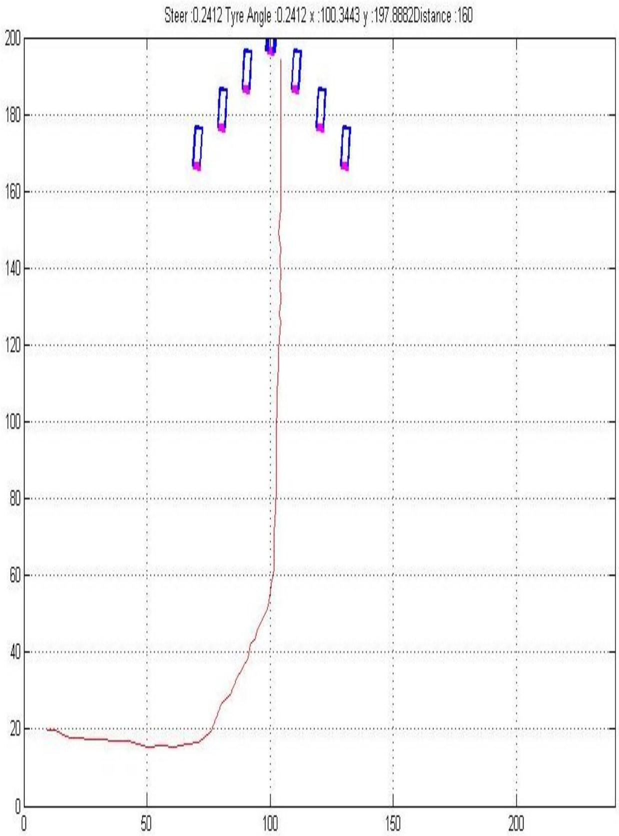

Figure 8: Final position of robots

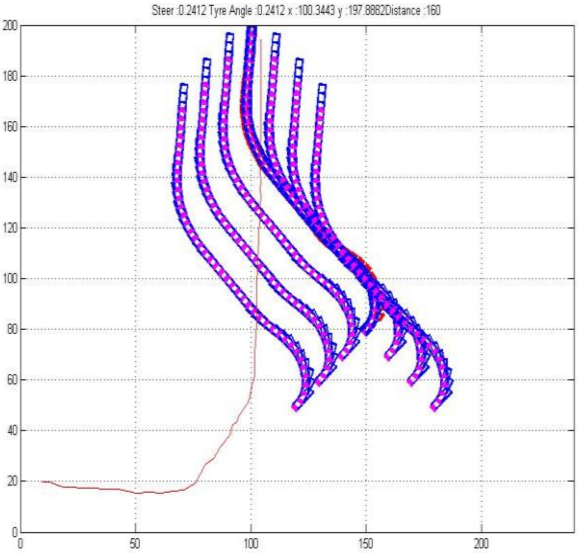

Figure 9: Trail of robots

V. CONCLUSION AND FUTURE WORK

In this paper, we show the formation strategy for wheeled mobile robot in leader-follower framework. The effectiveness of Interval type2-fuzzy controller is also shown for controlling the motion of group of mobile robots while they are in motion which is verified by simulation results. The controller is based on simple if and then rules.

The future research work will focus on extending the simulation results to more general applications such as employing real time continuous path tracking and maintaining formation between leader and follower robots taking into consideration of robot dynamics, model uncertainties and noise along with controlling separation, bearing, and orientation deviation between leaders and followers together.

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