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***Abstract*— This article focuses on the challenge of mobile robot formation control. While previous research in this field has predominantly delved into classical control methods for maintaining formations of mobile robots, our study compares the performance and robustness of two distinct approaches: Fuzzy Logic Control (FLC), representing a model-free approach, and Backstepping, representing a model-based approach. A comprehensive robustness analysis is conducted, encompassing error modeling, parameter uncertainties, and actuator faults. The results obtained clearly demonstrate the robustness of the FLC controller in comparison to the Backstepping controller. The latter exhibits enhanced precision when an accurate model is taken into consideration.**

***Index Terms*—** Mobile robots, Backstepping, Fuzzy Logic Control, Robustness analysis.

I. INTRODUCTION

IN recent years, the Mobile robots are increasingly used in industry, in service robotics, for domestic needs (vacuum cleaners, lawn mowers, pets), in difficult-to access or dangerous areas (space, army, nuclear-waste cleaning) and also for entertainment (robotic wars, robot soccer).over the past decade, the attention has shifted from the control of a single non-holomonic mobile robot to the control of a navigation mobile robots (multi- robots mobile). Formation control of multiple autonomous mobile Robots and vehicles has been studied extensively for both theoretic research and practical.

There are several methodologies [2]-[9] to robotic formation control which include virtual structure approach, behavioral approach, and leader follower approach. Each of them has several advantages and weaknesses.

The virtual structure approach treats the entire formation as a single virtual rigid structure [1]-[2]. Desired motion is assigned to the virtual structure, as a result which will trace out trajectories for each robot in the formation to follow. It is easy to prescribe the behavior of the whole group and maintain the formation very well during the maneuvers. The main disadvantage of the current virtual structure implementation is the centralization, which leads a single point of failure for the whole system. By behavior-based approach, several desired behaviors are prescribed for each robot, and the final action of each robot is derived by weighting the relative importance of each behavior. Possible behaviors include obstacle avoidance, collision avoidance, goal seeking and formation keeping [3]-[5]. The limitation of behavior-based approach is that it is difficult to analyze mathematically, therefore it is hard to guarantee a precise formation control.

Among all the approaches to formation control reported in the literature, the leader-following method has been adopted by many researchers [4], [3], [6], [8], [9]. In this method, a follower robot stays at a specified separation and bearing from a designated leader robot. The controller that was analyzed to perform the comparison is: the Backstepping controller and the fuzzy logic controller.

In this paper, a leader follower approach will be developed using fuzzy logic controller (FLC) and compared with Backstepping approach. Robustness analysis is investigated using many realistic scenarios. The rest of paper is organized as follow, in section 3 we describe system molding and leader-followers formation control; in section 4 the controllers design is shown. In Section 5 simulation results with robustness analysis are illustrated. Finally, in section 6 conclusion and perspectives.

II. SYSTEM MODELING AND CONTROL FORMATION

A. Kinematic model

This study utilizes the Pioneer P3-AT mobile robot, developed by Active-Media, renowned for its application in scientific and research experiments. The robot is equipped with various sensors, including sonar sensors, laser telemeter, camera, and odometer sensors. Classified as a four-wheel skid steering mobile robot (SSMR), the P3-AT has fixed maximum translation and rotation velocities at 600 mm/s and 140°/s, respectively. Instantaneous linear and angular velocities are computed based on the disparity between the left and right wheel speeds, denoted as vl and vr (Figure 1).

The configuration of the mobile robot used in this paper is shown in Figure 1.

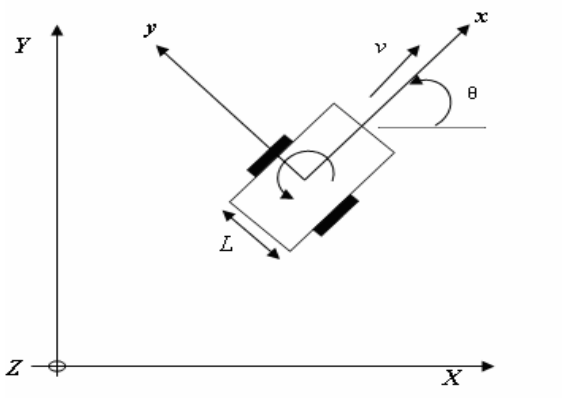

Figure1- Configuration of mobile robot

It has two parallel motor wheels with independent drives each other, and a free wheel (silly wheel or caster) and two driving wheels [14]. The posture of the robot is defined by the coordinates q=[x, y, θ]^{T} whose parameters define the configuration and its location on the Cartesian axis, where θ determines the angle of orientation of the robot. The position of the robot, defined in the cartesian axis system, is defined by the variables x and y. The center of mass of the mobile robot is located at the point C, located on the center of the axle of the wheels of robot with a distance L to each of the robot's wheels. It will be used as a reference point or point of interest for the control of the robot in the case of controllers Fuzzy and Backstepping.

Equation 1 represents a motion of the mobile robot. This model will be used in the development of the controllers Fuzzy and Backstepping.

$$\begin{aligned} \dot{x}(t) &= v(t)\cos\theta(t) \\ \dot{y}(t) &= v(t)\sin\theta(t) \\ \dot{\theta}(t) &= w(t) \end{aligned} \quad (1)$$

Where v and w are the linear and angular velocities of the robot, respectively.

B. Dynamic model

A Dynamic model of Mobil robot with n generalized coordinates and subject to m constraints can be described by the following equations of motion [12][13]:

$$M(q)\ddot{q} + V(q,\dot{q})\dot{q} + F(\dot{q}) + G(q) + \tau_d = B(q)\tau - \Lambda^T(q)\lambda \quad (2)$$

Where:
M(q) is an non symmetric positive definite inertia matrix, V(q, q̇) is the centripetal and coriolis matrix, F(q̇) is the surface friction matrix, G(q) is the gravitational vector, τ_d is the vector of bounded unknown disturbances including unstructured unmodeled dynamics, B(q) is the input matrix, τ is the input torque vector, $\Lambda^T(q)$ is the matrix associated with the kinematic constraints, and λ is the Lagrange multipliers vector.

The generalized coordinates are selected as follows:

$$q = [x_c \quad y_c \quad \theta \quad \varphi_R \quad \varphi_L]^T \quad (3)$$

With the pure rolling and no-slipping assumption in the ideal robot model, the following non-holonomic constraints hold,

$$\begin{cases} \dot{x}_c cos\theta + \dot{y}_c sin\theta + L\dot{\theta} = R\dot{\varphi}_R \\ \dot{x}_c cos\theta + \dot{y}_c sin\theta - L\dot{\theta} = R\dot{\varphi}_L \end{cases} \quad (4)$$

$$-\dot{x}_c \sin\theta + \dot{y}_c \cos\theta - d\dot{\theta} = 0 \quad (5)$$

Where equations (4) are the pure rolling constraints meaning that the forward velocity of the DDWMR is uniquely determined by the angular velocity of the two driving wheels, and equation (5) is the no-slipping constraint in lateral direction meaning that the lateral velocity of the WMR is always constrained to be zero.

Using the contact points velocities from equation (4) and substituting in the three constraint equations can be written in the following matrix form:

$$\Lambda q q = 0 \quad (6)$$

Where:

$$\Lambda(q) = \begin{bmatrix} -\sin\theta & \cos\theta & -d & 0 & 0 \\ \cos\theta & \sin\theta & L & -R & 0 \\ \cos\theta & \sin\theta & -L & 0 & -R \end{bmatrix} \quad (7)$$

The Lagrange equation can be written in the following form:

$$\Lambda \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = F - \Lambda^T(q)\lambda \quad (8)$$

Where L=T-V is the Lagrangian function, T, is the kinetic energy of the system, V is the potential energy of the system, are the generalized coordinates, F is the generalized force vector, Λ is the constraints matrix, and λ is the vector of Lagrange multi- pliers associated with the constraints.

The first step in deriving the dynamic model using the Lagrange approach is to find the kinetic and potential energies that govern the DDWMR motion. Furthermore, since the DDWMR is moving in the XI-YI plane, the potential energy of the DDWMR is considered to be zero.

Now, the obtained equations of motion can be represented in the general form given by equation (2) as follows:

$$M(q)\ddot{q} + V(q,\dot{q})\dot{q} = B(q)\tau - \Lambda^T(q)\lambda \quad (9)$$

Where:

$$(q) = \begin{bmatrix} m & 0 & 2\mathrm{dm_w}\sin\theta & 0 & 0 \\ 0 & m & -2\mathrm{dm_w}\cos\theta & 0 & 0 \\ 2dm_w\sin\theta & -2dm_w\cos\theta & I & 0 & 0 \\ 0 & 0 & 0 & I_w & 0 \\ 0 & 0 & 0 & 0 & I_w \end{bmatrix}$$

$$V(q,\dot{q}) = \begin{bmatrix} 0 & 0 & 2dm_w\dot{\theta}\cos\theta & 0 & 0 \\ 0 & 0 & 2dm_w\dot{\theta}\sin\theta & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$B(q) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\Lambda^T(q)\lambda = \begin{bmatrix} -\sin\theta & \cos\theta & \cos\theta \\ \cos\theta & \sin\theta & \sin\theta \\ 0 & L & -L \\ 0 & -R & 0 \\ 0 & 0 & -R \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{bmatrix}$$

$$I = I_c + m_c d^2 + 2m_w L^2 + 2I_m$$

where, $\mathrm{m_c}$ is the DDWMR mass without the driving wheels and actuators (DC motors), $\mathrm{m_w}$ is the mass of each driving wheel (with actuator), $\mathrm{I_c}$ is the moment of inertia of the DDMR about the vertical axis through the center of mass, $\mathrm{I_w}$ and $\mathrm{I_m}$ are the moment of inertia of each driving wheel (with actuator) around the wheel axis, and the moment of inertia of each driving wheel with a motor about the wheel diameter respectively.

Next, the system described by equation (9) is transformed into an alternative form which is more convenient for the purpose of control and simulation. The main aim is to eliminate the constraint term $\Lambda^{\mathrm{T}}(\mathrm{q})\lambda$ in equation (9) since the Lagrange multipliers λ_{i} are unknown.

This is done first by defining the reduced vector:

$$\eta = [\dot{\varphi}_R \quad \dot{\varphi}_L]^T \tag{10}$$

Then, we can obtain equation (11) by expressing the generalized coordinates velocities using the forward kinematic model such as:

$$\begin{bmatrix} \dot{x}_c \\ \dot{y}_c \\ \dot{\theta} \\ \dot{\varphi}_R \\ \dot{\varphi}_L \end{bmatrix} = \frac{1}{2} \begin{bmatrix} R(\cos\theta - \left(\frac{d}{L}\right)\sin\theta) & R(\cos\theta + \left(\frac{d}{L}\right))\sin\theta) \\ R(\sin\theta + \left(\frac{d}{L}\right)\cos\theta) & R(\sin\theta - \left(\frac{d}{L}\right)\cos\theta) \\ \frac{R}{L} & -\frac{R}{L} \\ 2 & 0 \\ 0 & 2 \end{bmatrix} \begin{bmatrix} \dot{\varphi}_R \\ \dot{\varphi}_L \end{bmatrix} \tag{11}$$

This can be written in the form:

$$\dot{q} = S(q)\eta \tag{12}$$

It can be verified that the transformation matrix is in the null space of the constraint matrix. Therefore, we have:

$$S^T(q)\Lambda^T(q) = 0 \tag{13}$$

Taking the time derivative of equation (12) gives:

$$\ddot{q} = \dot{S}(q)\eta + S(q)\dot{\eta} \tag{14}$$

By substituting equations (12) and (14) in the main equation (9) we obtain:

$$\begin{aligned} M(q)\left[\dot{S}(q)\eta + S(q)\dot{\eta}\right] + V(q,\dot{q})[S(q)\eta] \\ = B(q)\tau - \Lambda^T(q)\lambda \end{aligned} \tag{15}$$

Next, rearranging the equation (15) and multiplying both sides by matrix leads to equation (16).

$$\begin{aligned} S^T(q)M(q)S(q)\dot{\eta} + S^T(q)\left[M(q)\dot{S}(q) + \right. \\ \left. V(q,\dot{q})S(q)\right]\eta = S^T(q)B(q)\tau - S^T(q)\Lambda^T(q)\lambda \end{aligned} \tag{16}$$

Where the last term is identical to zero (equation (13). Now defining the new matrices:

$$\overline{M}(q) = S^T(q)M(q)S(q)$$
$$\overline{V}(q,\dot{q}) = S^T(q)\left[M(q)\dot{S}(q) + V(q,\dot{q})S(q)\right]$$
$$\overline{B}(q) = S^T(q)B(q)$$

The dynamic equations are reduced to the form:

$$\overline{M}(q)\dot{\eta} + \overline{V}(q,\dot{q})\eta = \overline{B}(q)\tau \tag{17}$$

Where:

$$\overline{M}(q) = \begin{bmatrix} \frac{R^2}{4L^2}(m(d^2+L^2) - 4d^2m_w + I) + I_w & \frac{R^2}{4L^2}(m(L^2-d^2) + 4d^2m_w - I) \\ \frac{R^2}{4L^2}(m(L^2-d^2) + 4d^2m_w - I) & \frac{R^2}{4L^2}(m(d^2+L^2) - 4d^2m_w + I) + I_w \end{bmatrix}$$

$$\overline{C}(q,\dot{q}) = \begin{bmatrix} 0 & \frac{R^2}{2L}dm_c\dot{\theta} \\ -\frac{R^2}{2L}dm_c\dot{\theta} & 0 \end{bmatrix}, \overline{B}(q) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Equation (17) shows that the DDWMR dynamics are expressed only as a function of the right and left wheel angular velocities$(\dot{\varphi}_{\mathrm{R}}, \dot{\varphi}_{\mathrm{L}})$, the robot angular velocity $\dot{\theta}$ and the driving motor torques$(\tau_{\mathrm{R}}, \tau_{\mathrm{L}})$. The equations of motion

(17) can be also transformed into an alternative form which is represented by linear and angular velocities (v, ω) of the DDWMR. It can be, easily, shown that the model equations (17) can be rearranged in the following compact form:

$$\begin{cases} \left(m + \frac{2I_w}{R^2}\right)\dot{v} - m_c d\omega^2 = \frac{1}{R}(\tau_R + \tau_L) \\ \left(d^2(m_c - 2m_w) + I + \frac{2L^2}{R^2}I_w\right)\dot{\omega} + m_c d\omega v = \frac{L}{R}(\tau_R - \tau_L) \end{cases} \tag{18}$$

C. Control formation

Various approaches and strategies have been proposed for the formation control of multiple robots. The formation considered in this study is the leader follower approach.

Leader follower strategy

Leader follower strategy can be of various types like there can many leaders and many followers or one leader and many followers and so on is shown in figure2. In our case we have use one leader and two followers' strategy. For Simplicity, we have assumed a precise trajectory in which the leader must follow him in formation with performance and Robustness [10].

The kinematic system of the leader follower robot is generated with the parameters that will be measured are the relative distance between the leader and the follower robot [16].

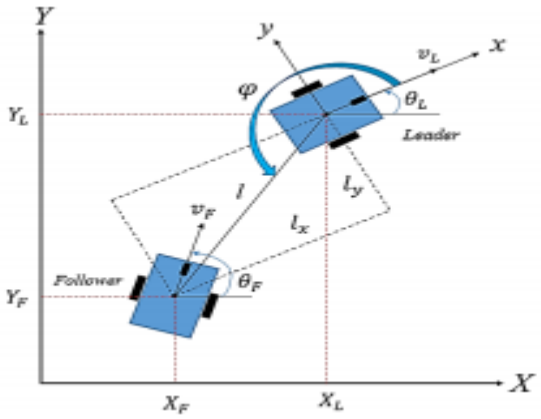

Figure2- Basic Leader-Follower setup

Let us consider the situation shown in Fig. 2. A leader and a follower robot are denoted as R_l and R_f, respectively [15], the states and the inputs of R_l and R_f, are newly denoted as, (x_l, y_l, θ_l), (x_f, y_f, θ_f) (v_l ,w_l) and (v_f ,w_f), where the subscript "l" and "f" mean *leader* and *follower*, respectively. The equations of motion of both robots are given by (1). The relative distance between the leader and the follower robot is denoted as d_{lf}=d_{fl} and the relative angles from their heading are denoted as θ_{lf}, they are given by Equation2.

$$d_{lf} = \sqrt{(x_l - x_f)^2 + (y_l - y_f)^2}$$
$$\theta_{lf} = \theta_f - \theta_l \qquad (19)$$

L-ψ approach

The main idea of the L-psi approach is to measure the angle between the follower leader and its distance, this method aims to control the stability of navigation and test the robustness of the system if necessary. The figure below using the method L-ψ.

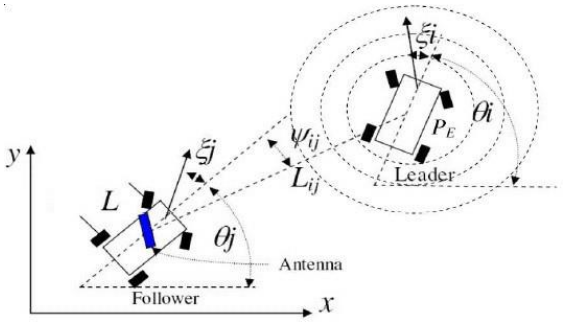

Figure3- L-PSI method in Leader-follower approach

Virtual structure approach

A virtual structure is made up of an arbitrary (but non zero) number of points which may include a passive element (i.e., a box being pushed). For our purpose we let the number of elements be equal to the number of robots we are interested in controlling. In order to align the virtual structure to the robots, we define a fixed one-to-one mapping between the points on the virtual structure and each robot. This mapping from robot to virtual structure is fixed and is determined when the robotic system is initialized. As described in the definition, the alignment is performed by minimizing the error between the actual positions of the robots and their corresponding virtual structure points [7].

The Leader-Follower approach was chosen on the basis of its advantages: the simplicity of calculation and simulation as well as it allows to add several Followers at the same time

III. CONTROLLER DESIGN

The main control objective is to ensure the asymptotic convergence of the robot despite all the uncertainties in both environment and trajectory. Thus, there is the need to propose a robust controller face parameters uncertainties and modeling errors. There are several controllers; in this article two controllers are studied.

The choice of the two controllers aims to compare between a command which is purely mathematical and which requires the model (Backstepping), another very well known for its flexibility since it does not depend on model (Fuzzy Logic).

A. Backstepping Controller

Backstepping is a technique developed circa 1990 by Petar V. Kokotovic and others for designing stabilizing controls for a special class of nonlinear dynamical systems. These systems are built from subsystems that radiate out from an irreducible subsystem that can be stabilized using some other method. Because of this recursive structure, the designer can start the design process at the known-stable system and "back out" new controllers that progressively stabilize each outer subsystem. The process terminates when the final external control is reached. Hence, this process is known as backstepping. The equations below present the inputs

equations of Backstepping where Ra is the leader robot and Rb and RC are the followers robots respectively.

$$\begin{aligned} e1 &= (xr - xa)cos\theta + (yr - ya)\, sin\theta \\ e2 &= (yr - ya)\cos\theta + (xr - xa)sin\theta \\ e3 &= \theta r - \theta a \\ e4 &= (x_a + L\cos\left(\theta_a - \frac{\pi}{2}\right) - x_b)\cos\theta_b \\ &\quad + \left(y_a + L\sin(\theta_a - \frac{\pi}{2}\right) - y_b)sin\theta_b \end{aligned} \tag{20}$$

$$\begin{aligned} e5 &= \left(y_a + L\sin(\left(\theta_a - \frac{\pi}{2}\right) - y_b\right)\cos(\theta_b) - \\ &\quad \left(x_a + L\cos\left(\theta_a - \frac{\pi}{2}\right) - x_b\right)\sin\theta_b \\ e6 &= \theta_a - \theta_b \\ e7 &= (x_a - L * \cos\left(\theta_a - \frac{\pi}{2}\right) - x_c) * \cos\theta_c \\ &\quad + \left(y_a - L * \sin(\theta_a - \frac{\pi}{2}\right) - y_c)sin\theta_c \end{aligned} \tag{21}$$

$$\begin{aligned} e8 &= \left(y_a - L\sin(\left(\theta_a - \frac{\pi}{2}\right) - y_c\right)\cos(\theta_c) - \\ &\quad \left(x_a - L\cos\left(\theta_a - \frac{\pi}{2}\right) - x_c\right)\sin\theta_c \\ e9 &= \theta_a - \theta_c \end{aligned} \tag{22}$$

The outputs equations of Backstepping are:

$$\begin{aligned} Ua &= [v_r\cos(e3) + k1e1; w_r + k2v_r e2 + k3v_r \sin(e3)] \\ Ub &= [v_r\cos(e6) + k1e4; w_r + k2v_r e5 + k3v_r \sin(e6)] \\ Uc &= [v_r\cos(e9) + k1e7; w_r + k2v_r e8 + k3v_r \sin(e9)] \end{aligned} \tag{23}$$

Where k1, k2 and k3 are tuning parameters of Backstepping controller, they are tuned experimentally after many tests. Ua, Ub, Uc are the outputs of the controller.

B. Fuzzy Controller

The application of fuzzy logic control in robotics is to produce an intelligent robot with the ability of autonomous behavior and decision. In this section, the problem of how to set the control parameter values for desired robot behavior is solved [11].

We choose the Takagi-Sugeno Type.

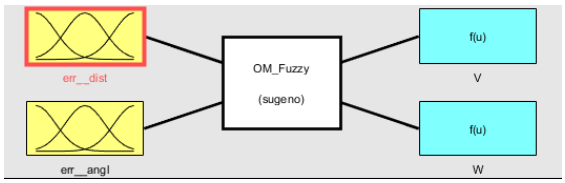

Figure4- fuzzy controller design

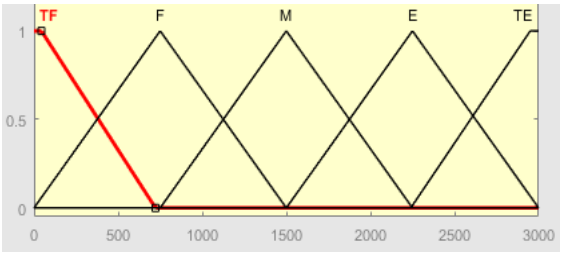

Figure5-Input membership function of Distance

Linguistic variables for inputs membership function Of distance are denoted as Tres Faible (TF) Faible (F) Moyen (M) Elevé (E) Tres Elevé (TE).

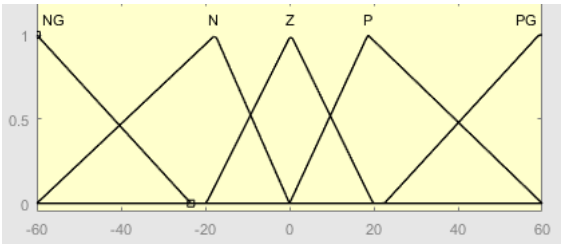

Figure6- Input membership fuction of Angle

Linguistic variables for inputs membership function of Angle are denoted as Negative Grand (NG) Negative (N) Zero(Z) Positive (P) Positive Grand (PG).

The robot will be controlled by total 25 rules.

TABLE 1. Rules table of output 'V' Fuzzy logic controller

	NG	N	Z	P	PG
TF	TF	TF	TF	TF	TF
F	F	F	M	F	F
M	M	M	M	M	M
E	E	E	E	E	E
TE	TE	TE	TE	TE	TE

TABLE 2. Rules table of output 'W' Fuzzy logic controller

	NG	N	Z	P	PG
TF	VN	N	Z	P	PG
F	VN	N	Z	P	PG
M	VN	N	Z	P	PG
E	VN	N	Z	P	PG
TE	VN	N	Z	P	PG

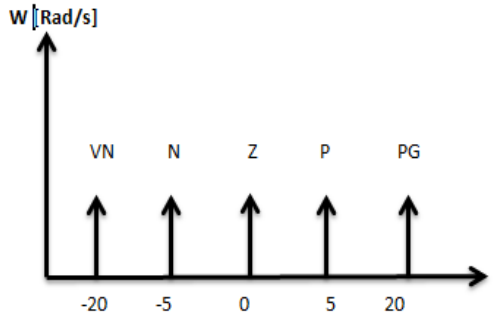

Figure 7- Output membership fuction of Angle

IV. Simulation Results

Below the model of robot use for this simulation.

Figure 8- model of robot

We consider: R g = 0.2m, L= 0.4m.v =300mm/s, L1=L2= 0.5. L1 is the distance between the leader and follower robot 1 and L2 represent the distance between the leader and follower Robot 2.

A. Path tracking for mobile robots formation using Backstepping controller

For the Backstepping controller parameters are $V = 0.1\,m/s, W = 0.001\,rad/s, k1 = 2.7, k2 = 290,\ \ k3 = 13$ these parameters have been set after several simulation tests.

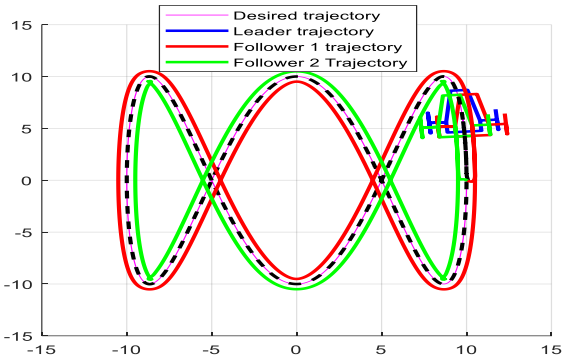

Figure9- Navigation Robot of Backstepping Controller

The obtained results for path planning of Formation robots using Backstepping controller are illustrated in Figures 9, 10, 11, 12 and 13. As can be seen Figure 8 shows the mobile robot trajectory using Backstepping. The mobile robots follow accurately the desired path. This result is confirmed by Figure 9 where very small errors following x, y and θ are obtained. Figure 10; illustrate the evolution of linear and angular velocity of the three mobile robots (One leader and two followers).

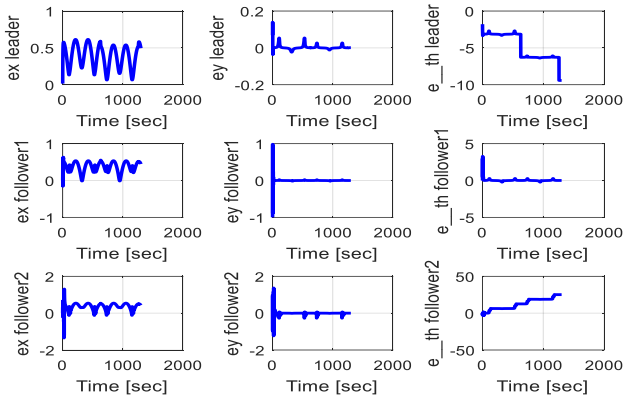

Figure10- the Backstepping errors for mobile robot navigation

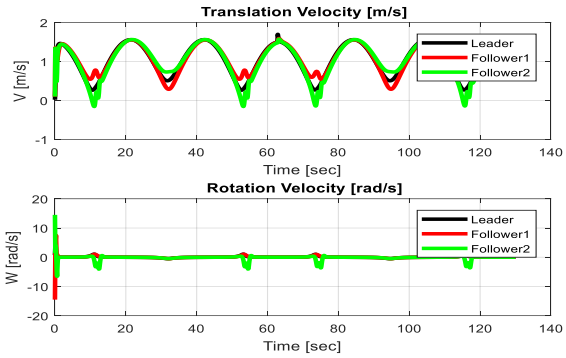

Figure11- Linear and angular velocity

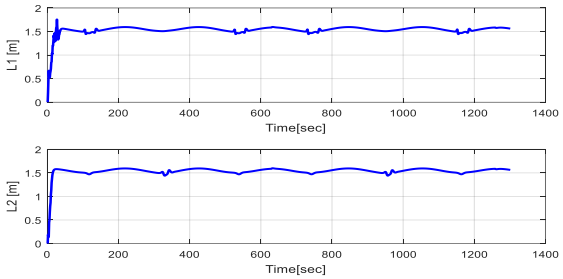

Figure12- Distance Leader-Folower1, Leader-Folower2

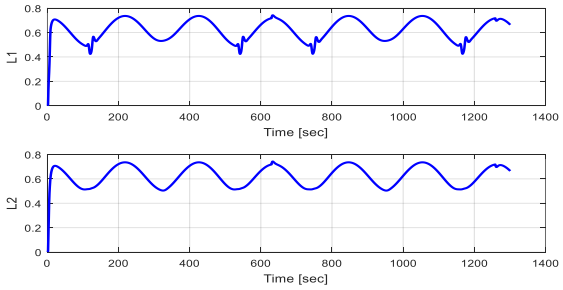

Figure13- Distance Leader-Folower1, Leader-Folower2

Figure 12 and 13 illustrate the two distance L1 (Leader-Follower1) and L2 (Leader – Follower2) for two cases L_{ref}=1.5m and L_{ref}=0.6m respectively. Good accuracy has been obtained. In both cases $1 \approx L2 \approx L_{ref} \mp 0.1m$.

B. Path tracking for navigation robot using Fuzzy Logic controller (FLC)

The obtained results for the navigation robots of path planning using FLC are illustrated in Figures 14, 15 and 16, 17. As can be seen Figure 14 the mobile robots follow accurately the desired path as well as the two followers. These results are confirmed by the small value of errors (error distance and error angle) illustrated in figure 15. Translation and rotation velocity provided by the FLC are illustrated in Figure 16.

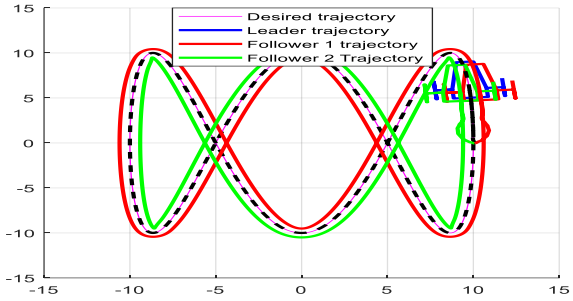

Figure14- Navigation Robot of FLC Controller

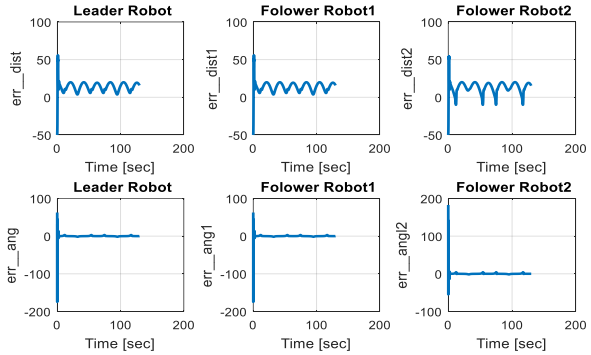

Figure15- The FLC errors for the navigation

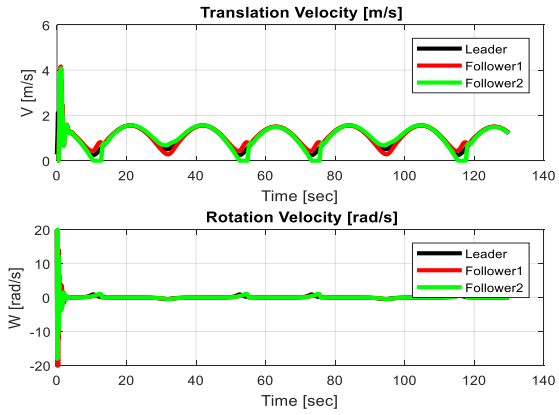

Figure16- Linear and angular velocity

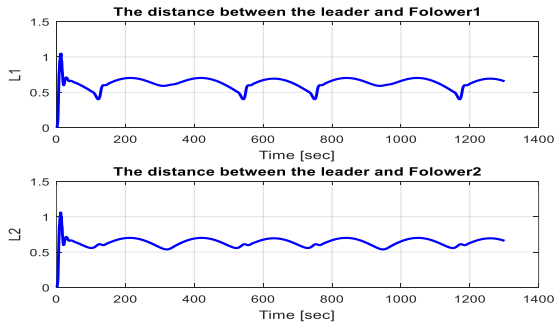

Figure17- The distance between the leader-folower1 and Leader-folower2

C. Robustness analysis results

Robustness evaluations were conducted face parameters uncertainties:

For parameters uncertainties, two parameters are considered the radius of the left wheel, Rg and the length L (distance between the two wheels of the Robot). In order to compare clearly the robustness of the two controllers we consider parameters change affecting the mobile robot parameters Rg+ΔR at T=20. For the left wheel radius different uncertainties ΔR are considered as the deflation percentage of the wheel

For L1= L2= 1.5 m.

$$\Delta R = \frac{DR}{R} * 100 = 0.10/0.2 * 100 = 50\%$$

$$0.06/0.2 * 100 = 30\%$$

$$0.04/0.2 * 100 = 20\%$$

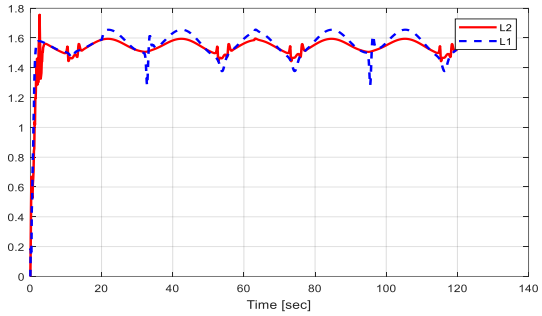

Figure 18- The Comparison between L1 and L2 at R=50% (Backstepping Controller)

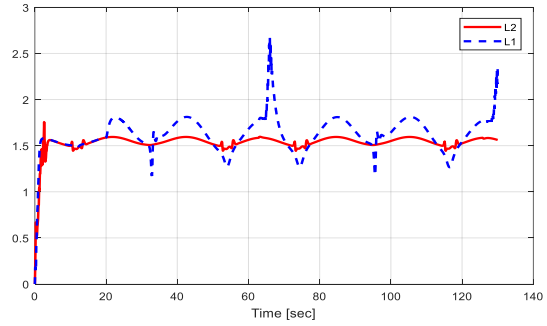

Figure 19- The Comparison between L1 and L2 at R=30% (Backstepping Controller)

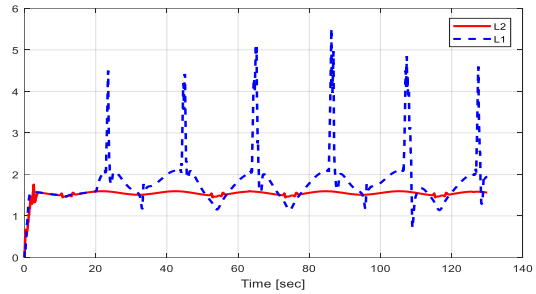

Figure20- The Comparison between L1 and L2 at R=20% (Backstepping Controller)

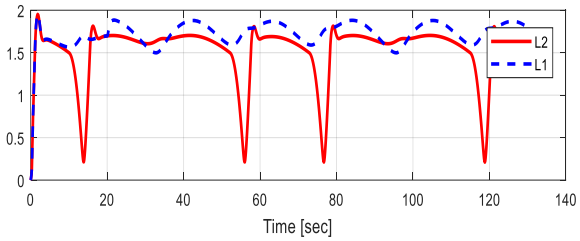

Figure 21- The Comparison between L1 and L2 at R=50% (FLC Controller)

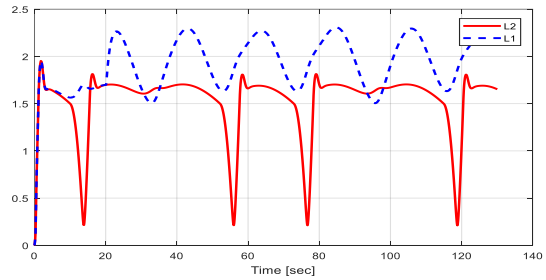

Figure 22- The Comparison between L1 and L2 at R=30% (FLC Controller)

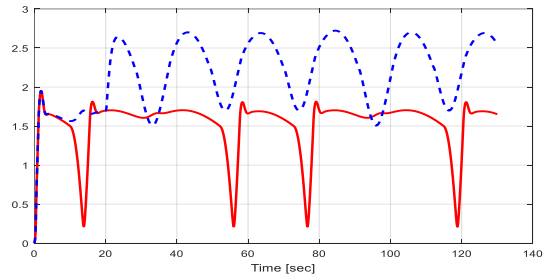

Figure 23- The Comparison between L1 and L2 at R=20% (FLC Controller)

Below the table confirm our comparison between the two controllers.

RMSE[R]		100%	50%	30%	20%
Backstepping Controller	Distance	13.93	20.59	29.69	50.33
	Theta	3.95	4.69	7.30	179.40
FLC Controller	Distance	15.81	28.78	60.14	103.43
	Angle	0.11	5.49	14.41	26.64

V. Conclusion

In this Paper, we show the performance between controllers FLC and Backstepping in mobile robot Formation, applying the Leader follower method and the L-Psi approach, after several tests the FLC controller shows more performances comparing the Backstepping controller especially when significant parameters uncertainties is considered. The future research work will focus on extending this study in the case of micro aerial vehicle.

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