Fuzzy Logic based Real Time Go to Goal Controller for Mobile Robot

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ABSTRACT
For any mobile device, the ability to move smoothly in its environment is of the ultimate importance, which rationalizes the persistent work of researchers to find new technologies to achieve this target. In this work, we briefly describe the tough work done for designing a fuzzy logic controller (FLC) for the reacting behaviour in a mobile robot, namely "go-to goal" problem. This new technology allows optimal planning of movement in terms of path length and travel time; it is intended to achieve the shortest path followed by a mobile robot. The efficiency of the proposed motion control unit is checked against the results of other smart methods; its features make it an effective alternative way to solve the go-to goal problem for the mobile robot.

Keywords
Nonholonomic robots, Modeling, differential drive, Fuzzy logic, mobile robot, LabVIEW.

1. INTRODUCTION
The problem of designing a go-to goal controller for moving a Mobile Robot (MR) in real-time is a major problem in universal research today. Autonomous mobile robots have different applications in the military, industry and in all areas of life. Thus, the issue of controlling the auto-moving of wheeled robot devices has occupied a large part of the research interest in the field of robotics.

The go-to goal problem of any robot is how to create the required wheel velocities that lead the robot toward a predetermined target, that is, the error between the desired goal point and the robot starting point is convergence to zero. In recent years, there has been many researches on this orientation of robotics field, most of them include the kinetic model of MR while very little deals the dynamic of robot due to the model's complexity and high non-linearity.

Mainly we can classify the research directions that have been carried out in the field of robot navigation algorithms into one of six categories [1]:

(1) back-stepping [2], [3];

(2) linearization [4];

(3) sliding mode [5];

(4) fuzzy systems [6], [7];

(5) neural networks [8]; and

(6) neuro-Fuzzy systems [9].

In this work, we will introduce both the kinematics and the dynamic model of the most commonly used MR "differential drive mobile robot (DDMR)". After this, the model will be used to test the efficiency of a Fuzzy-based control algorithm. In the non-attendance of a workspace stumbling block, the basic control tasks assigned to the MR may be reduced to moving between two robot postures.

The arrangement of this paper comes as follows: in section II the basic framework, kinematic and dynamic modeling of DDMR are introduced. The fuzzy control (FC) algorithm architecture is introduced in Section III. Simulation results are shown in section IV. Finally, we conclude the paper in Section V.

2. MODELING OF DDMR
In this section the kinematic/dynamic models of a real DDMR are derived. The dynamic model is based on Lagrange analysis.

2.1 Co-ordinate System
Fig 1 Shows an overhead view of the DDMR used in this work, the MR configuration consists of a mainframe with two wheels attached to one axle with two identical motors and a free front steering wheel (castor). The motion of the MR is done by changing the relative velocities of the driving wheels. In order to describe the robot's state, we will define two coordinate systems, the reference frame $\{x_r, y_r\}$ and the vehicle frame $\{x_v, y_v\}$.

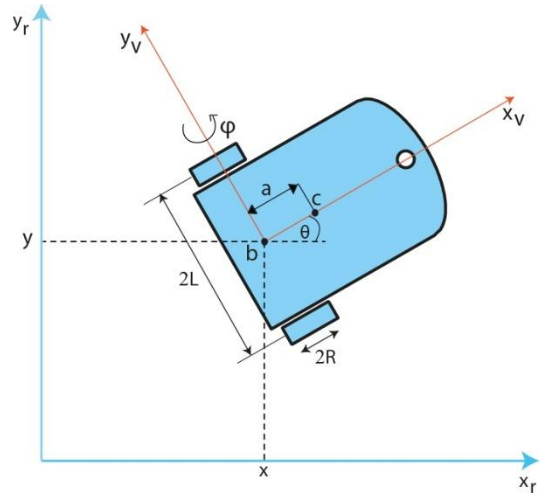

Fig 1: Differential Drive wheeled Mobile Robot

The robot state is represented in a reference frame by the position of point b, which lies in the middle of the wheel hub and the angle of the robot's front. Robot configuration in the reference frame is symbolized as

$$p = [x \quad y \quad \theta]^T$$

and in vehicle frame as

$$p_d = \begin{bmatrix} x_d & y_d & \delta \end{bmatrix}^T$$

The transformation of robot configuration from vehicle frame to reference frame can be done through the following transformation

$$P_r = R(\theta)P_v$$

Where:

$$R(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

2.2 Kinematic Model

For the DDMR, the basic target behind kinematic is to obtain the robot speeds as a function of the driving motors speeds. The linear and angular speeds of the DDMR in the vehicle frame can be calculated as

$$v = R\frac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2} \text{ and } \omega = R\frac{(\dot{\varphi}_R - \dot{\varphi}_L)}{2L}$$

Then the linear and the angular speeds of the DDMR in the reference frame can be calculated as follows

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

Now consider a DDMR at certain position (x, y, θ) which has a non-zero distance with the desired position (x_d, y_d, δ) as shown in Fig 2 The robot can be represented in polar coordinates involving distance error

$$\ell = \sqrt{(x_d - x)^2 + (y_d - y)^2}$$

and heading angle error

$$\psi = \delta - \theta$$

as in the following equation

$$\begin{bmatrix} \dot{\ell} \\ \dot{\psi} \\ \dot{\delta} \end{bmatrix} = \begin{bmatrix} -\cos(\psi) & 0 \\ \sin(\psi)/\ell & -1 \\ \sin(\psi)/\ell & 0 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

2.3 Dynamic Modeling

The dynamic model of the DDMR is very essential for simulation of any system and for applying control algorithms. In this work, a DDMR model established according to the Lagrangian approach is used. Dhaouadi et. Al, [10] dives a detailed derivation of the dynamic model and finally reached these two equations

$$(m + \frac{2}{R^2} I_w)\dot{v} - a m_f \omega^2 = \frac{(\tau_R + \tau_L)}{R}$$

, and

$$(I + \frac{2L^2}{R^2} I_w)\dot{\omega} + a m_f v\omega = \frac{L(\tau_R - \tau_L)}{R}$$

These 2 equations are used to simulate our real robot whose dynamic parameters are listed in Table 1.

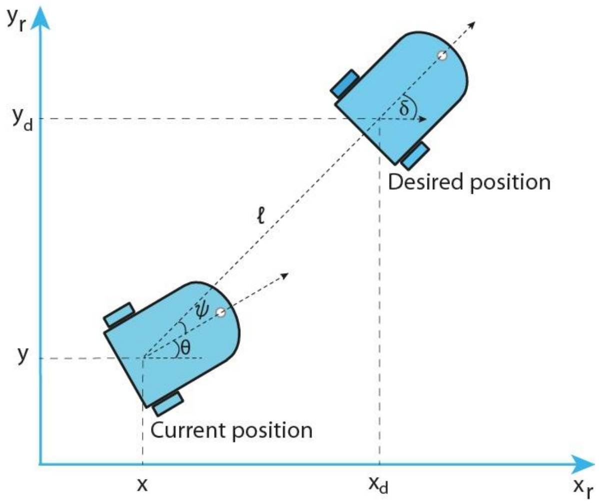

Fig 2: start and target Positions of robot

Table 1: Real Robot simulation parameters

PARAMETER	VALUE	DESCRIPTION
L	10 *cm*	The distance between the drive wheel and the axis of symmetry.
R	7.5 *cm*	Wheel radius.
a	5 *cm*	The distance between the center of mass and drive wheel axis.
m	6 *kg*	Total robot weigh with onboard load.
m_f	4 *kg*	Robot frame weigh.
I	5 $kg{:}m^2$	Mass moment of inertia about the center of mass *c*.
I_w	0.005 $kg{:}m^2$	Inertial moment of the motors and wheels about the wheel axis.

3. FUZZY CONTROL ALGORITHM

In this section, the control algorithm that we will use in this paper is introduced. The role of the control algorithm is to give the robot the ability to go to the destination goal. That is achieved by using the posture error to provide the robot with the reference wheel velocities. The characterization of the go-to goal problem can be as follows, given the desired robot posture $P_d = [x_d\ y_d\ \delta]^T$ while the robot currently is at $P = [x\ y\ \theta]^T$ and the controller must generate the angular wheel velocities such that the robot desired and current posture are the same. A general structure for the tracking control system is presented in Fig 3.

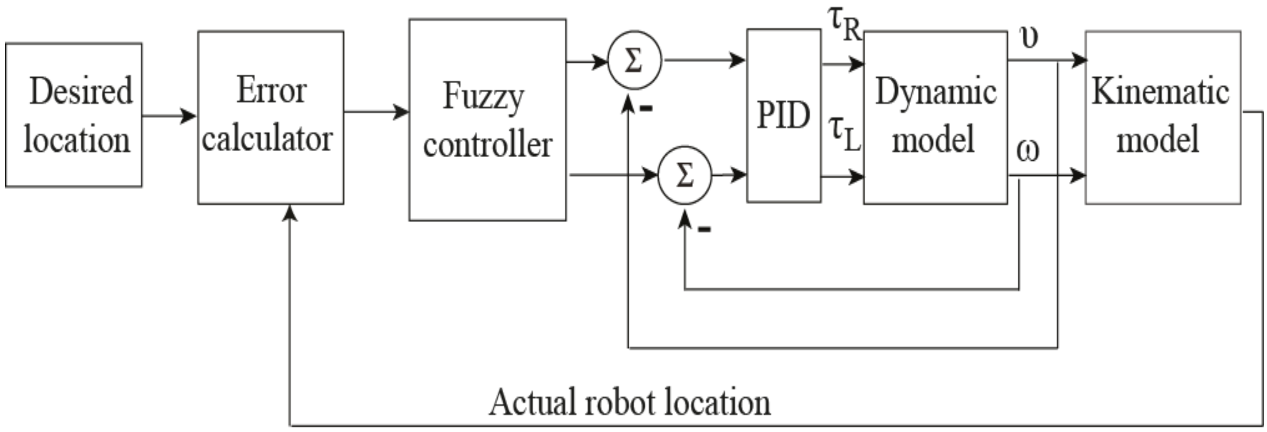

Fig 3: Controller system architecture

The structure of any fuzzy based controller is shown in Fig 4 The FC mainly contains three operations:

1) Fuzzification,

2) Inference and

3) Defuzzification.

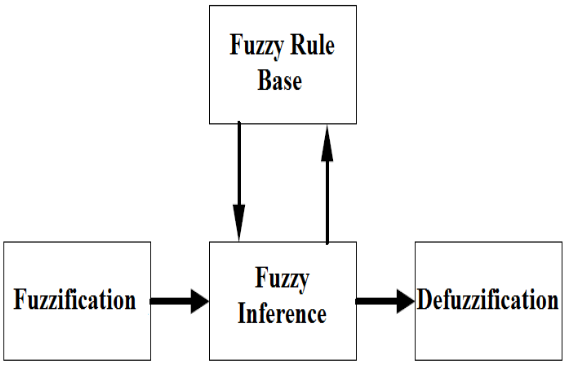

Fig 4: Fuzzy controller structure

As an initial step, we need to identify the input and output variables linguistically and to define the fuzzy sets. After that, we come to the first step - fuzzification or fuzzy classification- in which we convert a set of crisp data into a set of fuzzy variables using the membership functions (fuzzy sets). The second stage Inference is how to use rule base to determine what control actions to perform in response to inputs. A rule base is a group of IF-THEN rules which relates input sets and output sets. Finally, the defuzzification operation converts the output from a fuzzy set to a crisp output[11].

The FC is intended to move the DDMR to its target smoothly. Two values - heading angle error and distance from the robot to the target - are used as inputs to the controller, while the outputs are mainly the speed of the robot wheels. Through our implementation of the controller, we split the universe of discourse of each input into seven membership functions as indicated in figures 5 and 6.

The linguistic variables used to represent the membership functions of FC first input "heading angle between error" are N: Negative, SN: Small Negative, NNZ: Near Negative Zero, Z: Zero, NPZ: Near Positive Zero, SP: Small Positive and P: Positive, while those are used for second input "distance error" are Z: Zero, NZ: Near Zero, N: Near, M: Medium, NF: Near Far, F: Far and VF: Very Far.

As for input, our FC uses seven-membership functions for each output (left & right wheel velocities) as illustrated in Fig. 7. The linguistic variables used to represent the FC output memberships are Z: Zero, S: Slow, NM: Near Medium, M: Medium, NH: Near High, H: High and VH: Very High. The if-then rules are constructed to represent the model of the FC of autonomous mobile robot navigation. These if-then rules summery are listed in Table 2.

Table 2: Fuzzy rules

Angle / Dis.	N	SN	NNZ	Z	NPZ	SP	P
Z	L^{Z}	L^{Z}	L^{Z}	L^{Z}	L^{NM}	L^{NM}	L^{M}
	R^{M}	R^{NM}	R^{NM}	R^{Z}	R^{Z}	R^{Z}	R^{Z}
NZ	L^{S}	L^{S}	L^{Z}	L^{S}	L^{M}	L^{NH}	L^{H}
	R^{H}	R^{NH}	R^{M}	R^{S}	R^{Z}	R^{S}	R^{S}
N	L^{S}	L^{S}	L^{S}	L^{NM}	L^{NH}	L^{H}	L^{VH}
	R^{VH}	R^{H}	R^{NH}	R^{NM}	R^{S}	R^{S}	R^{S}
M	L^{S}	L^{S}	L^{S}	L^{M}	L^{H}	L^{H}	L^{VH}
	R^{VH}	R^{H}	R^{H}	R^{M}	R^{S}	R^{S}	R^{S}
NF	L^{S}	L^{S}	L^{NM}	L^{NH}	L^{NH}	L^{H}	L^{VH}
	R^{VH}	R^{H}	R^{NH}	R^{NH}	R^{NM}	R^{S}	R^{S}
F	L^{S}	L^{S}	L^{M}	L^{H}	L^{NH}	L^{H}	L^{VH}
	R^{VH}	R^{H}	R^{NH}	R^{H}	R^{M}	R^{S}	R^{S}
VF	L^{S}	L^{S}	L^{NM}	L^{VH}	L^{NH}	L^{H}	L^{VH}
	R^{VH}	R^{H}	R^{NH}	R^{VH}	R^{NM}	R^{S}	R^{S}

4. SIMULATION RESULTS

In this section, the performance of suggested FC is examined using NI-LabVIEW control design and simulation toolkit. In this section, we will show the results of two different simulation experiments that prove the stability and convergence of the used controller.

In the first experiment, the desired goal for the robot was described as X_d = 5 and Y_d = 4. Goal point is sent to the FC which directs the vehicle towards the goal. The robot starts at (-1, 0, 0). Fig. 8. shows the tracking performance of the robot in *XY*-plane.

Again in Fig. 9, we can see the tracking performance of the robot in *XY*-plan of the second experiment in which the desired goal for the robot was described as X_d = -1 and Y_d = 4 and the robot starts at (4, 0, 45^{O}).

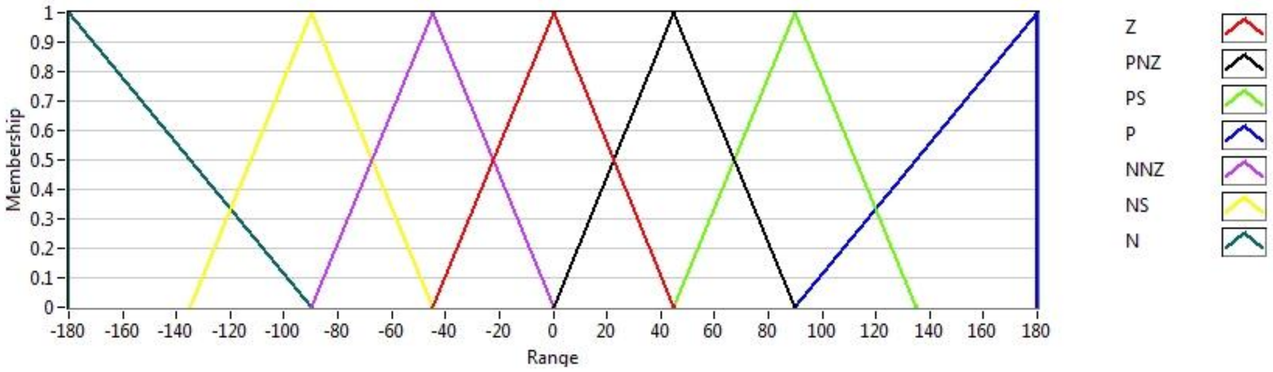

Fig 5: Membership functions for the error in angle.

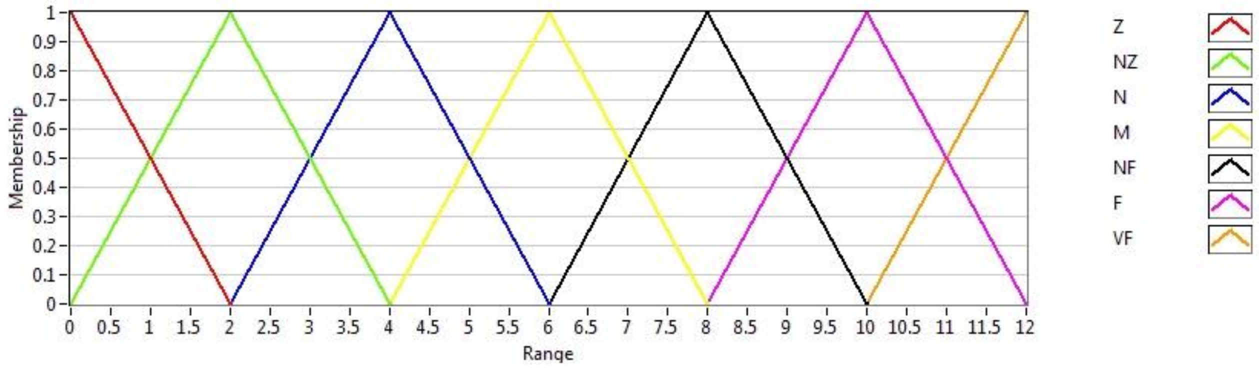

Fig 6: Membership functions for the distance.

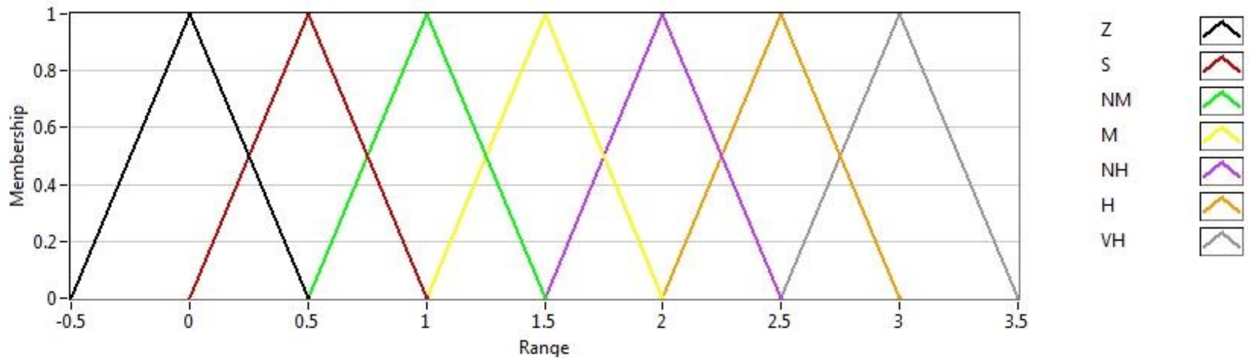

Fig 7: Membership functions for the left and right velocity

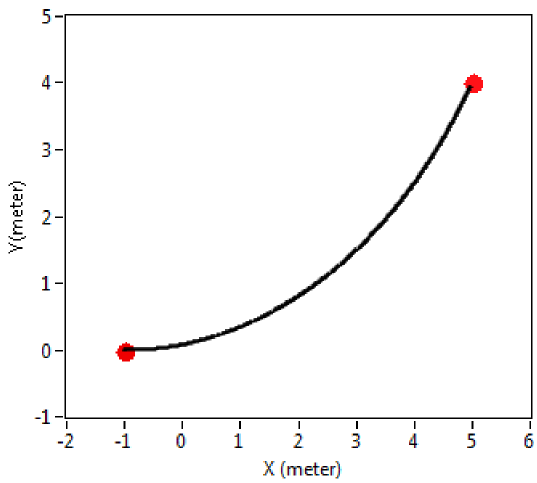

Fig 8: Go to goal tracking performance experiment 1

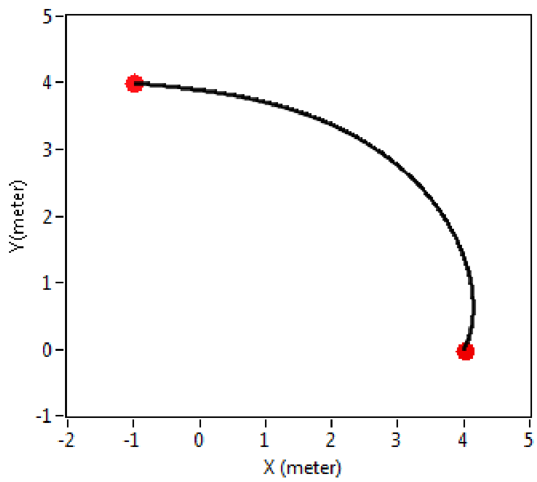

Fig 8: Go to goal tracking performance experiment 2

5. CONCOLUSION

In this paper, the kinematic and dynamic models of DDMR are introduced. The present study also outlines the important features of FC concept for the use in go-to goal control for the autonomous mobile robot navigation. This work can be used in different workspaces for material handling. In the end, the simulation work has been carried out using a real robot parameter so as to be as close to the scene in the real world.

Based on the simulation results, we can extend this controller to a group of MRs easily. Further, experimental outcomes have advocated the targeted algorithm by generating smooth path by using the FC in environments.

For the future plane, the proposed wireless control of a DDMR should be extended to a swarm of MR. Analysis of the effect of produced time delay from the wireless communication of the networked MRs is worthy of further consideration. Also, we may add a controller for obstacle avoidance.

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