Trajectory Tracking Control for A Wheeled Mobile Robot Using Fuzzy Logic Controller

K. N. FARESS[1] M. T. EL HAGRY[1] A. A. EL KOSY[2]

[1] Electronics research institute, Cairo, Egypt.

[2] Faculty of Engineering, Cairo University, Egypt.

Abstract: A trajectory tracking control for a wheeled mobile robot using fuzzy logic controller (FLC) is presented in this paper. The control algorithm based on the errors in postures of mobile robot which feed FLC, which generates correction signals for the left and right motor speeds. The control strategy is based on a feed forward velocity profile and the correcting signal in the velocity generated from the FLC according to the postures errors. Simulation and experimental results demonstrate the effectiveness of the proposed algorithm, which proved the good tracking results and showed the robustness of the algorithm against the uncertainties in the system model.

Key-words:- velocity profile-trajectory tracking-postures control-fuzzy logic control-and low-level control system.

1 Introduction

Wheeled mobile robots (WMRs) are increasingly present in industrial and service robotics, particularly when flexible motion capabilities are required, on reasonably smooth grounds and surfaces. Several mobility configurations (wheel number and type, their location and actuation, single or multi-body vehicle structure) can be found in the application [5,6,8]. The most common for single – body robots are differential drive and synchro drive (both kinematically equivalent to a unicycle).

Beyond the relevance in applications, the problem of autonomous motion planning and control of WMRs has attracted the interest of researchers in view of its theoretical challenges. In particular, these systems are a typical example of nonholonomic mechanisms due to the perfect rolling constraints on the wheel motion (no longitudinal or lateral slipping) [5]. In the absence of workspace obstacles, the basic motion tasks assigned to a WMR may be reduced to moving between two robot postures and following a given trajectory.

The basic motion tasks that we consider for a WMR in an obstacle – free environment are:

Point- to- point motion: the robot must reach a desired goal configuration starting from a given initial configuration.

Trajectory following: a reference point on the robot must follow a trajectory in the Cartesian space (i.e., a geometric path with an associated timing law) starting from a given initial configuration.

Execution of these tasks can be achieved using either feed forward commands, or feedback control, or a combination of the two. Indeed, feedback solutions exhibit an intrinsic degree of robustness. The design of feed forward commands is instead strictly related to trajectory planning, whose solution should take into account the specific non-holonomic nature of the WMR kinematics.

Control of *WMRs* is generally divided into the following categories: (1) Path Planning (*PP*) (2) Trajectory generation (*TG*) (3) Trajectory tracking / Following (*TT/TF*) [2].

PP problem of characterizing the shortest path for a particle is by the determination of waypoints.

TG problem consider the design of the robot motion trajectory as a function of a time, as well as generate corresponding reference inputs to the trajectory tracking system (*TT*) the robot hence should move along a specified path. The robot trajectory planning is the second step after defining the waypoints of the robot travel (path planning), the purpose of trajectory planning takes into consideration the system dynamics and different constraints. The trajectory planning and generation consists of rotation planning and translation planning. In [4] a fuzzy controller is used to track a path of a bi-steerable cybernetic car, also it takes the velocity planning "on-line planning" into consideration in control system. Trajectory tracking problem has been treated. Several contributors have discussed this problem. Kanayama proposed that the mobile robot is controlled for running along specified path by a speed command including a feed-forward control and feedback control [1], but the proposed technique does not take the velocity profile planning into consideration. Matthew discussed the problem of path tracking problem-using feed forward and error based correction signal for the angular velocity for the robot and a look ahead distance using PI controller [2], but the velocity planning is not taken into consideration. Luis Conde handled the problem of path tracking of bi-steerable car using FLC based on the look ahead distance, angle error, and curvature as inputs to the FLC without using feed-forward component [3,4]. Hiroyuki presents PI controller using disturbance observer for trajectory tracking problem in [6]. Ti-Chung proposed a feedback controller with linear and angular velocities constraints in [8]. In this paper the system comprises two successive modules. The first is off line planned velocity trajectories of left and right motors "differential steering" which considered the approximate dynamics of the system in velocity planning during feed forward velocity trajectory generation. The second is the correction signal extracted from the error detected in the robot postures; FLC is proposed to overcome the system dynamic uncertainties. The velocity profile supplies the linear reference velocity, which is considered as a feed forward command to the control system, the errors in robot postures with respect to the planned path is compensated by fuzzy feedback controller. The feedback correction command is added to the feed forward command to track the given planned path. The path-tracking module uses the errors in robot postures as inputs to the fuzzy controller. These errors includes the errors in Cartesian coordinates (x, y) in local coordinates system also, include the heading error. The paper structure is as follows: section 2 presents the control system architecture, section 3 presents kinematics model of the robot. The velocity planned trajectories and path-tracking controller are described in sections 4, and 5 respectively. The simulation and experimental results and conclusion are presented in section 6, and 7 respectively.

2 Problem Formulation

Models of mobile robot systems cannot describe exactly its performance due to system uncertainties and shortage in parameter identification, so we proposed an intelligent controller to compensate for these shortages without the need for extra validation of the proposed dynamic model.

2.1 Kinematic model

The unicycle-modeled mobile robots considered in this paper are a class of computer-controlled vehicles whose motion can be described or transformed into the following model of constrained movement in a plane [5]:

$$\dot{x} = v\cos\theta, \dot{y} = v\sin\theta, \dot{\theta} = \omega \tag{1}$$

Where (x, y) are the Cartesian coordinates and θ is the angle between the heading direction and the x-axis. The non-holonomic constraint for the model (2) is:

$$\dot{y}\cos\theta - \dot{x}\sin\theta = 0 \tag{2}$$

It specifies the tangent direction along any feasible path for the robot and briefly shows that a mobile robot with two independent drive wheels can be described using the unicycle model (1). We assumed that the reference point lies at the midpoint of the two drive wheels. Let V_L and V_R denote the velocities of the left and the right wheel respectively. The linear velocity V and the angular velocity ω of the mobile robot can be described as:

$$\begin{aligned} v &= (v_R + v_L)/2 \\ \omega &= (v_R - v_L)/E \end{aligned} \tag{3}$$

where E represents the distance between two drive wheels. The current postures of the robot can be estimated as follows:

$$x_{new} = x_{old} + \Delta T.v.\cos(\theta_{old}) \tag{4}$$

$$y_{new} = y_{old} + \Delta T.v.\sin(\theta_{old}) \tag{5}$$

$$\theta_{new} = \theta_{old} + \Delta T.\omega \tag{6}$$

Where ΔT is the sampling period.

2.2 Velocity planning module

The velocity-planning (*VP)* module estimates the linear reference velocity in which the vehicle should travel. One main objective taken into account was to make the travel as comfortable as possible, i.e. to give the system the capability to fully control the smoothness of the acceleration and deceleration profiles [5].

2.3 Path tracking module

In this research the system comprises two successive modules. The first is off line planned velocity trajectories of left and right motors "differential steering" which considered the approximate dynamics of the system in velocity planning during feed forward velocity trajectory generation. The second is the correction signal extracted from the error detected in the robot postures; FLC is proposed to overcome the system dynamic uncertainties as well as problems generated due to line/circles representation of the trajectory. The velocity profile supplies the linear reference velocity, which is considered as a feed forward command to the control system, the errors in robot postures with respect to the planned path is compensated by fuzzy feedback controller. The feedback correction command is added to the feed forward command to track the given planned path. The path-tracking module uses the errors in robot postures as inputs to the fuzzy controller. These errors includes the errors in Cartesian coordinates (x, y) in local coordinates system also, include the heading error.

The path-tracking module (PTC) is divided into path tracking controller (high level control system), and low-level control system; the high-level path tracker generates the speed commands to the left and right motors, which is executed by the low-level speed control system. The fuzzy logic controller is adopted as the path tracker, which generates the command signals for the low-level control system.

The structure of the control system for trajectory tracking is shown in figure (1)..The postures estimator block estimates the postures of the mobile robot via the speed measurement of the right and left motor from the right and left shaft encoders, this estimation according to equations (4-6). The errors of the postures in equation (7) is feed to the fuzzy logic controller, also the reference linear and angular speeds generated from the trajectory generator block, V_r and ω_r, are feed to the fuzzy controller through which, are considered the feed-forward signals. The output of the fuzzy logic controller is the right and left compensating signals that adapt the feed-forward signals according to the dynamics and disturbances conditions, then the modified linear and angular velocities feed to the velocity transformation block to supply low level system with references for right and left motors. The low level speed control system blocks is responsible for tracking the left and right speed profiles generated from the high level control system.

$$x_e = (x_r - x_c)\cos\theta_c + (y_r - y_c)\sin\theta_c$$
$$y_e = (x_r - x_c)\sin\theta_c + (y_r - y_c)\cos\theta_c$$
$$\theta_e = \theta_r - \theta_c \qquad (7)$$

The errors in equation (7) are the inputs to the fuzzy logic controller and the outputs of the controller are the correction of the speed signals, which modify the feed forward speed signals.

3. Simulation and experimental results

The MATLAB simulink tool is used for simulation. Figure (2) shows the actual right and left speed trajectories according to the planned velocity

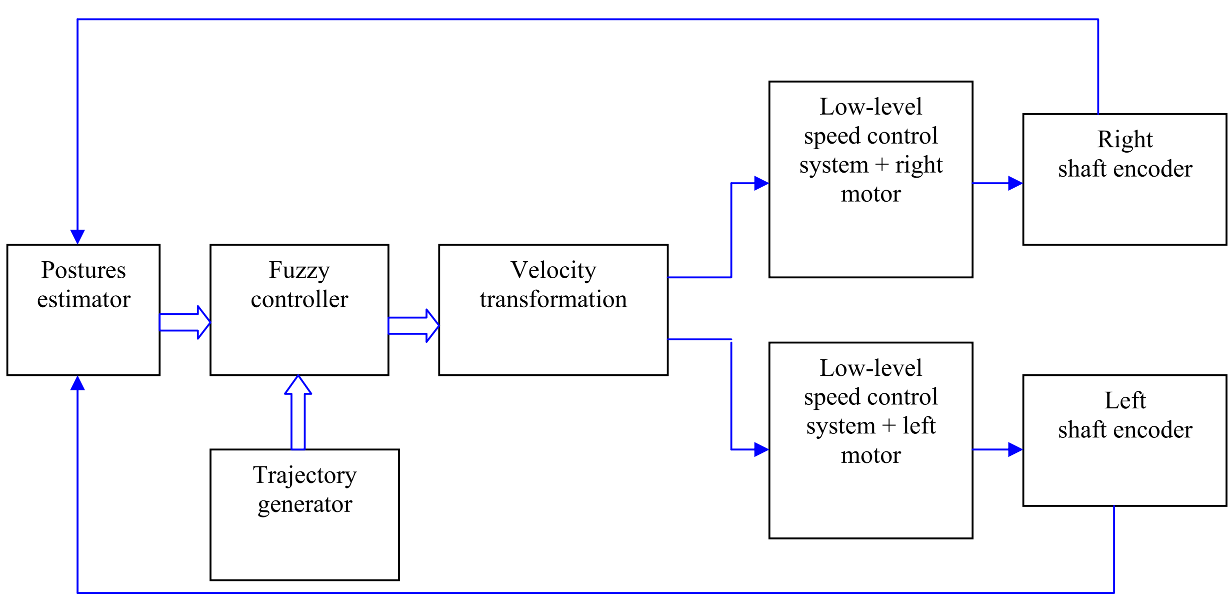

Fig.(1) Simulated and experimental system description profiles for left and right motors using the FLC controller in low-level control system. The corresponding reference and actual trajectories of the robot motion is shown in figure (3), which shows a good tracking performance that uses the proposed path-tracking algorithm described above. The experimental verification of the proposed controller is under work now. Figures (4,5,6,7) show the experimental reference and actual velocity profiles for the left and right motors using FLC controllers. Referring to these figures we notice that the agreement of the actual with the reference velocity profile in left and right motor using FLC. The application of high level proposed trajectory controller in the experimental verification is under work.

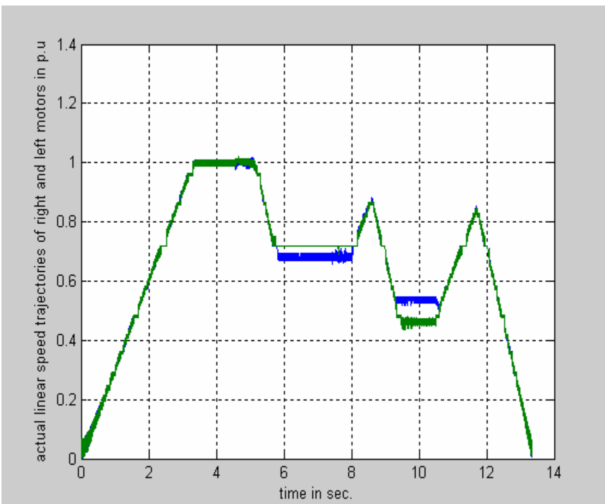

Fig.2. Simulated actual linear speed trajectories of right and left motors in p. u.

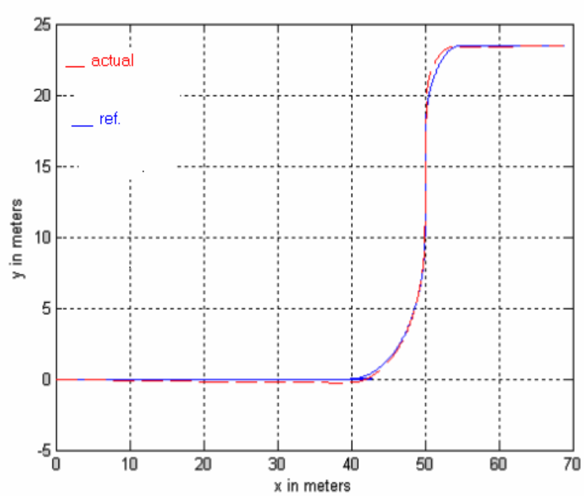

Fig. 3 Simulated reference and actual trajectories using feed-forward and feed back FLC.

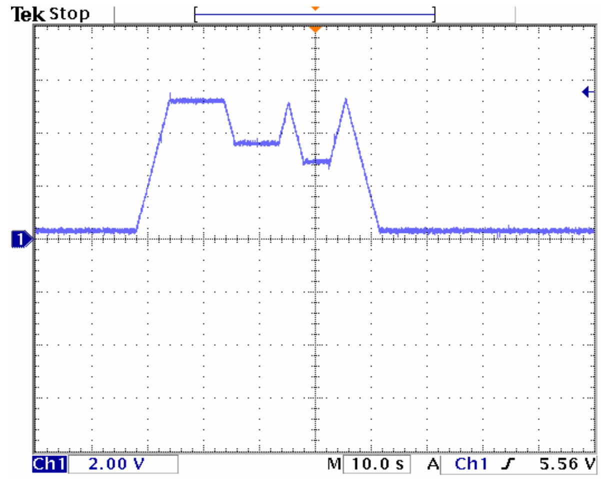

Fig. 4 Experimental reference velocity profile of the left motor.

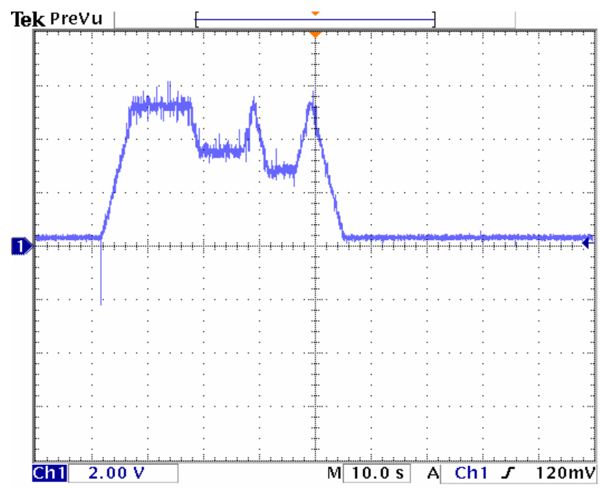

Fig. 5 Experimental actual velocity profile of the left motor using FLC.

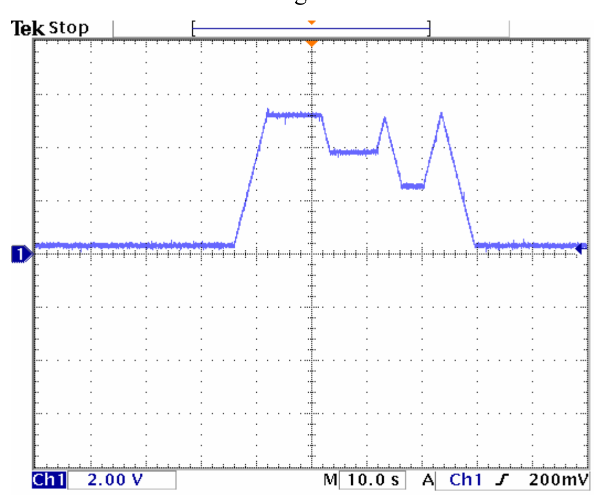

Fig. 6 Experimental reference velocity profile of the right motor.

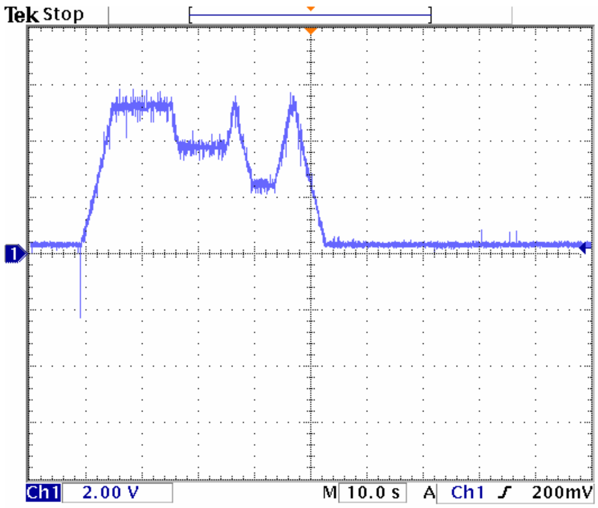

Fig. 7 Actual velocity profile of the right motor using FLC.

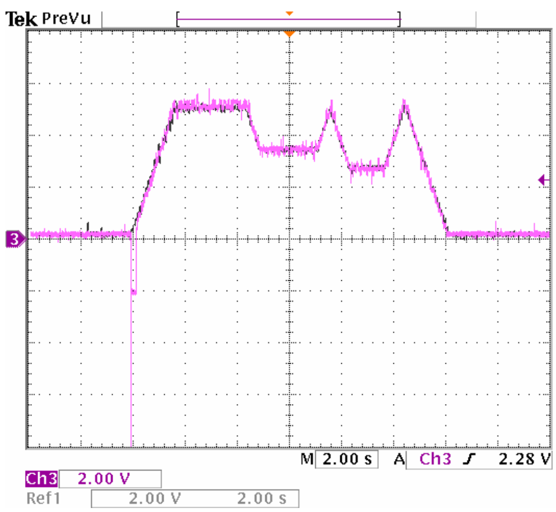

Fig. 8 Experimental reference and actual velocity profile of the left motor using FLC.

4 Conclusion

A FLC for trajectory tracking is proposed. The FLC developed compensates for system dynamics uncertainties, and accordingly simplified the development of dynamic model of the system. Simulated and experimental results showed good agreement. Simulation and experimental work demonstrate the effectiveness of the proposed algorithm with the two-wheeled mobile robot and proved that this method is characterized by its robustness with uncertainties in the system model.

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