A Fuzzy Control Design for the Trajectory Tracking of Autonomous Mobile Robot

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Abstract

In this study, a fuzzy control design for the trajectory tracking of autonomous mobile robot (AMR) will be presented. This proposed fuzzy control approach can be applied to track the desired trajectory of AMR. The main objective and contribution are to indicate a fuzzy control law which can drive the AMR to track a desired trajectory for the nonlinear trajectory tracking control of AMR. Generally, it is a difficult task to derive the solution from this nonlinear trajectory tracking problem, so we will try to deal with this trajectory tracking problem by fuzzy control design approach. Finally, a testing scenario of S-type reference trajectory tracking is verified the tracking performance of AMR.

Keywords: Fuzzy control design; Trajectory tracking; Autonomous mobile robot (AMR)

Introduction

More and more autonomous mobile robots (AMRs) are extensively applied in various fields which include industry and service in the past decades. According to above reasons, the precise manipulations of AMR are very important and key in the trajectory tracking topic. A lot of existing research [1-10] about trajectory tracking problem are discussed. But these research are too complicated and not easy to be implemented. Based on this reason, we will propose a fuzzy control design for the trajectory tracking of AMR in this paper.

The Mathematical Model of AMR

The mathematical model and tracking error dynamic equation of AMR will be presented in this section. This approach purpose is to construct a fuzzy control method for the tracking error to close to zero quickly and let the AMR traces the desired trajectory successfully. Base on this mathematical model and the geometry relationship with the AMR, a nonlinear tracking error and tracking error dynamic equation for the controlled AMR can be described as following equations (1) and (2), respectively [11].

The definition of the tracking error between the desired tracking trajectory and AMR can be described as below equation.

$$e = \begin{bmatrix} \dot{\hat{r}} \\ \hat{r} \end{bmatrix} = \begin{bmatrix} \dot{r} - \dot{r}_r \\ r - r_r \end{bmatrix} \tag{1}$$

where: $r = \begin{bmatrix} x_c & y_c & \theta \end{bmatrix}^T$ and $r_r = \begin{bmatrix} x & y & \theta_d \end{bmatrix}^T$

and the tracking error dynamic equation is given as following equation.

$$\dot{e} = \begin{bmatrix} -H^{-1}(r)C(r,\dot{r}) & O_{3\times3} \\ I_{3\times3} & O_{3\times3} \end{bmatrix} e + \begin{bmatrix} -\ddot{r}_r - H^{-1}(r)C(r,\dot{r})\dot{r}_r \\ O_{3\times3} \end{bmatrix} + \begin{bmatrix} H^{-1}(r)T(r)\tau \\ O_{3\times3} \end{bmatrix} \quad (2)$$

where: $H(r) \in R^{3\times3}$ is a symmetric positive definite inertia matrix and $C(r,\dot{r}) \in R^{3\times3}$ is the centripetal and Coriolis matrix. $T(r) \in R^{3\times2}$ is the input transformation matrix and $\tau \in R^{2\times1}$ is the applied to the torque vector.

Autonomous Mobile Robot Fuzzy Controller Design

Fuzzifier:

The input and output variables of a fuzzy system are the linguistic variables and will be taken as fuzzification by membership function in this section. The input and output linguistic variables of fuzzy logic-based include:

1. Tracking error in X axis e_x.

2. Tracking error in Y axis e_y.

3. Rotation tracking error angle θ.

4. The output variable is control torques τ.

The linguistic values treat by these variables are expressed by linguistic sets. Each of linguistic variables is assumed to take five linguistic sets and are defined as large negative (LN), small negative (SN), zero (ZE), small positive (SP) and large positive (LP). The linguistic sets are described by their membership functions. From Figures 1-4, the membership functions are described for X-axis tracking error e_x is [-1, 1] meter, Y-axis tracking error e_y is [-4, 4] meter, angle tracking error θ is [-30, 30] degree and control torque output τ is [-2, 2] Nm, respectively. To simplify the computation in the actual operation, triangular membership functions are suggested.
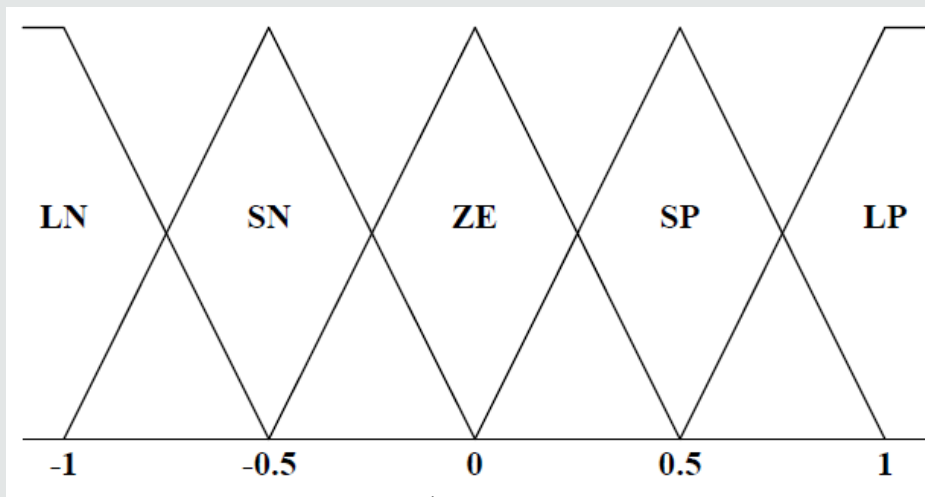

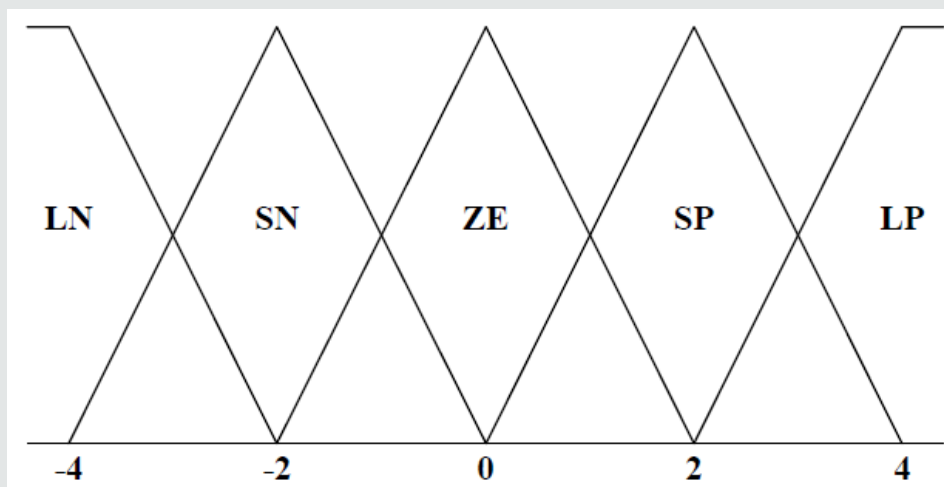
Figure 1: The membership function of X-axis tracking error

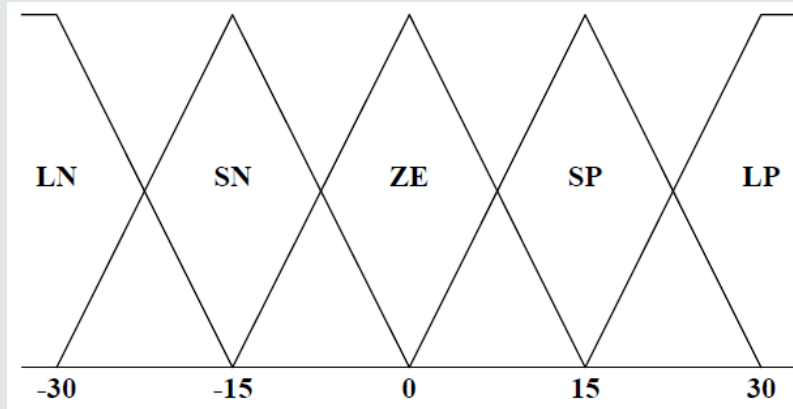**Figure 2:** The membership function of Y-axis tracking error.

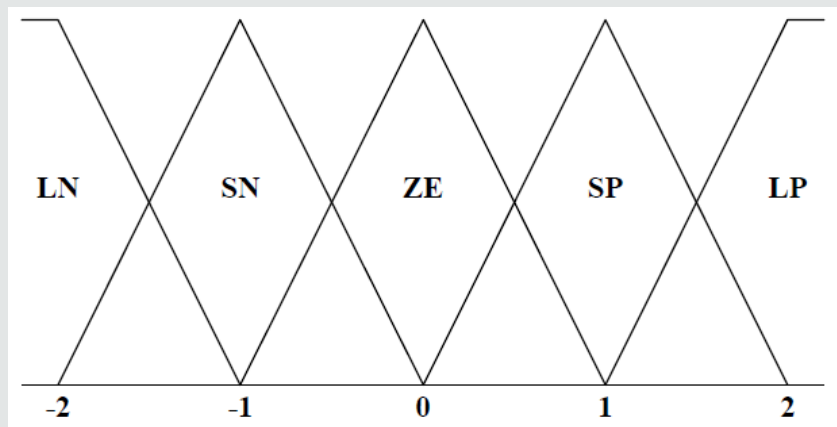**Figure 3:** The membership function of angle tracking error.

Figure 4: The membership function of control torque output.

Defuzzifier:

The outputs of the linguistic rules are fuzzy sets, but the control command must be a single crisp value. Therefore, the outputs of linguistic rules must be defuzzified before inputting to the AMR system. The fuzzy results will be converted into a single crisp value with respect to a fuzzy set and calculated by using the center-of-gravity (COG) defuzzification process.
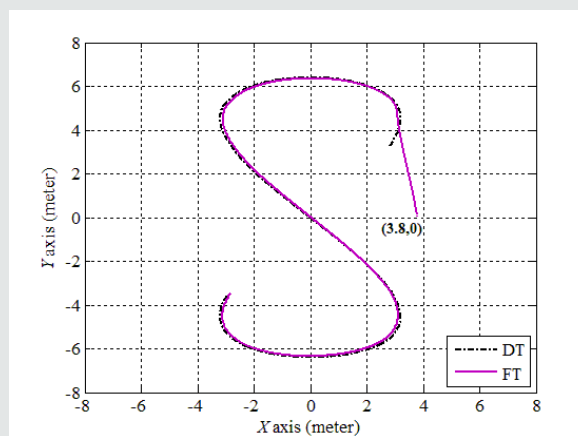
Simulation Result

Figure 5: S-type trajectory tracking result from (x = 3.8 meter, y = 0 meter). (Desired Trajectory (DT): back line and (Fuzzy Trajectory (FT): purple line)

A desired S-type reference trajectory tracking will be verified by this proposed fuzzy control design in this section. From simulation results, the verification result of the proposed method of a desired S-type reference trajectory tracking with a radius of 3.8 meters shows in Figure 5. As the significant results of the tracking error of the proposed method to the desired S-type trajectory reveal an outstanding performance from Figures 6-10. According to the obvious simulation results, this proposed method can guide the controlled AMR to track the S-type reference trajectory precisely and quickly.
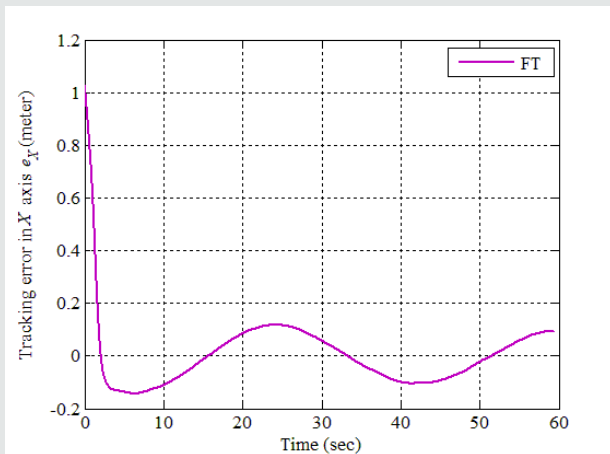

Figure 6: The tracking error result of X axis from (x = 3.8 meter, y = 0 meter).
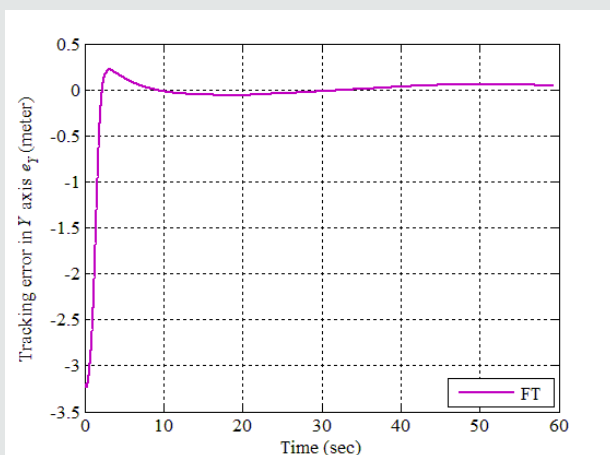

Figure 7: The tracking error result of Y axis from (x = 3.8 meter, y = 0 meter).
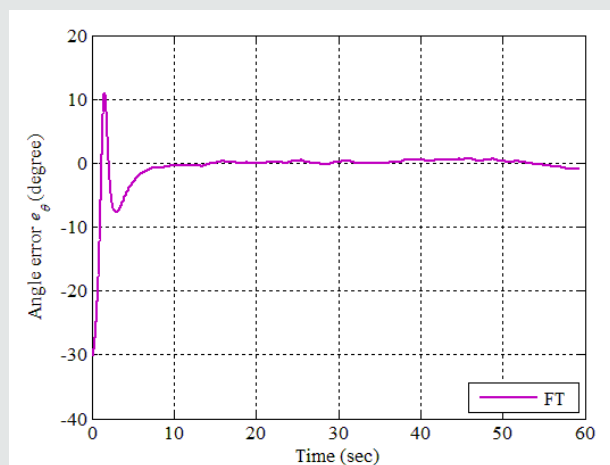

Figure 8: The tracking error result of angle from (x = 3.8 meter, y = 0 meter).
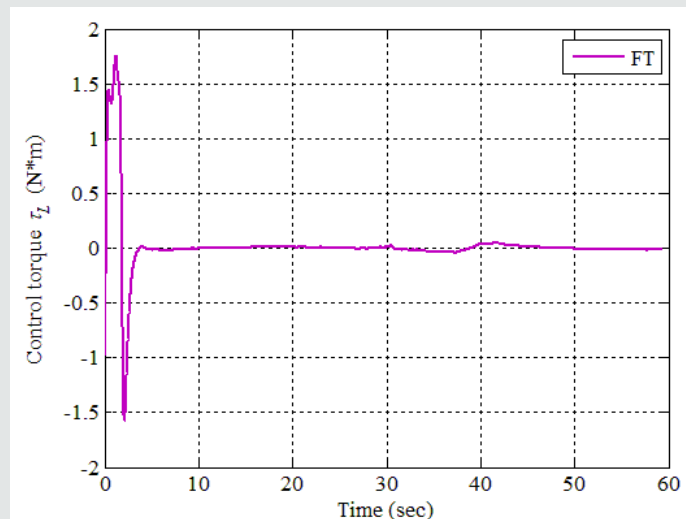
Figure 9: The output result of left torque from (x = 3.8 meter, y = 0 meter).
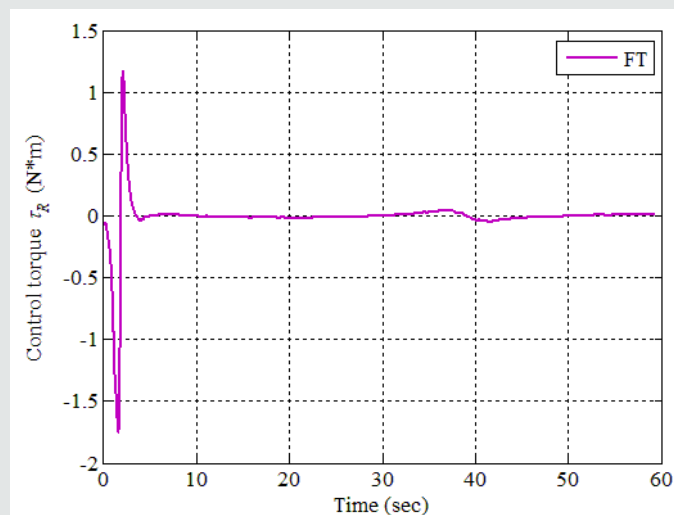

Figure 10: The output result of right torque from (x = 3.8 meter, y = 0 meter).

Conclusion

In this manuscript, a proposed fuzzy control design approach is successfully developed for improving the S-type reference trajectory tracking capability of nonlinear AMR system. As the simulation results, the proposed fuzzy control design approach demonstrates a satisfactory performance for tracking the desired trajectory in S-type reference trajectory.

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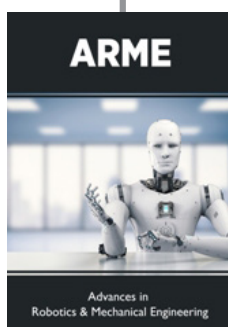
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