Adaptive Speed Control for Autonomous Mobile Robot using Fuzzy Logic Controller

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Abstract. This paper deals with the development of an adaptive speed controller for autonomous mobile robot using a fuzzy logic controller.The analysis of performance between a system applying triangular membership and a system using gaussian membership is compared to distinguish their differences. The results have shown that the gaussian membership method has improved the tracking performance for the mobile robot to reach its target. This also suggest the same behavior even when a different mobile robot movements is assigned. This paper considers three, five and seven memberships for both techniques to determine their effectiveness and effects to the system performance. The investigation has leads to the conclusion that the gaussian membership has competently surpassed the triangular membership performances even when the robot has different movements to achieve its target.

Key words: Fuzzy Logic, speed control, mobile robot, membership

1 Introduction

Navigation always comes as the main issue in pursuing a real autonomous mobile robot behavior. Solving the navigation problem also means that mobile robot can move effectively to achieve its assigned task even if the environment is unknown or has unpredictable conditions. Navigation includes a simple task where a mobile robot only identifies itself location in an environment to a higher degree of complexity where a mobile robot is required to localize itself and maps its surrounding simultaneously such as reported in various research[1–3].

In deciding how to control a mobile robots effectively, a number of approaches have been proposed by using artificial intelligence system such as neural networks, fuzzy logic, and genetic algorithm. Between those techniques, fuzzy logic can be the best candidates for navigation[4–7] as it requires less computational

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cost, do not need training or iterations and have almost the same performance to any of available methods. Hence, the processing time can be shorten.

The research on fuzzy logic for mobile robot has been immensely proposed since two decades ago. Vamsi et al.[8] have developed a fuzzy logic controller to control the robot motion along a predefined path. They found that if the Fuzzy Logic is appropriately being designed, then it could give better performance of convergence. Another work were reported by M.K Singh et al. whose proposed a fuzzy control scheme that considered two inputs of the mobile robot which are the heading angle and the relative distance between mobile robot and any landmark. The study considered three different scenario of environment, and are analyzed both by simulation and experiments to determine the consistency of their proposed technique. A study on the effect of different fuzzy sets membership to the mobile robot navigation also has been proposed by R.Rashid et al[9]. They suggested the designer must choose the fewer membership in the fuzzy logic controller to achieve better and faster time reaching a target. They used triangular membership function to demonstrate their results as it is the commonly applied membership used for analysis. This result is acceptable as if fewer membership are applied then the processing time will be reduced which finally result in faster time of task completion.

Regarding the membership type used in Fuzzy Logic, other choices than the triangular membership are available such as the gaussian membership, trapezoid membership or sigmoid membership. As explained above, researcher usually applies the triangular membership as it is seems to be easier than other membership. Even if this is the factor, there were also some other findings that discovered very interesting results as shown by V.O.S Olunloyo et al.[10]. Based on their findings, the triangular membership can exhibit linguistic error as it may not defines properly the real system conditions. As a result, the gaussian membership can be the best membership to describe any practical system for most engineering application. Moreover, gaussian membership may surpassed triangular membership function if better tracking performance is being prioritized[11].

This work attempts to discuss the performance of a mobile robot using the Fuzzy Logic controller that incorporates the gaussian membership for mobile robot decision. Simulation setting in [9] is referred for verification and comparison to validate the performance between triangular and gaussian memberships. Gaussian membership is chosen as it correlates fairly fuzzy set and approximates the human sense.

The remaining of this paper is organized as follows. Section II described the mobile robot kinematics. Next section III, explains the fuzzy controller design which use the gaussian membership to present the fuzzy sets. This is followed by section IV that discusses the simulation results of the fuzzy logic controller for three different cases of gaussian memberships. Finally, section V concludes our paper.

2 Mobile Robot Kinematics

A mobile robot with two wheels is considered in this paper. With reference to the Instantaneous Center of Curvature (ICC), the mobile robot will only moves based on one axis for rotation purposes. Figure 1 is explains the kinematic structure of a mobile robot that consists of the velocity of the mobile robot v; v_l, v_r are for the left wheel and right wheel respectively. The diameter of the mobile robot is d and L is the distance between two wheels. x, y constitutes the x, y positions of the mobile robot respectively. $/theta$ is the mobile robot heading angle.

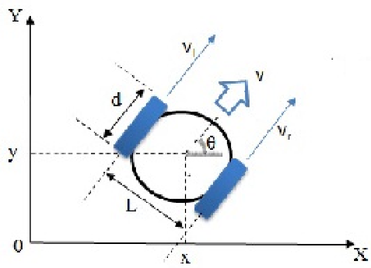

Fig. 1. Mobile robot kinematic

The mobile robot right and left velocities are provided as follows.

$$v_r = \frac{d}{2}\omega_r, \quad \frac{d}{2}\omega_l \tag{1}$$

$$\omega = \frac{v_r - v_l}{L}, \quad v = \frac{v_r + v_l}{L} \tag{2}$$

where ω_r, ω_l are the right and left wheel angular velocities. From above equations, the following are obtained.

$$\omega = \frac{d}{2L}(\omega_r - \omega_l) \tag{3}$$

$$v = \frac{d}{4}(\omega_r + \omega_l) \tag{4}$$

Using above information and notations, the mobile robot velocity v can be divided to its respective axis of x and y frames i.e v_x and v_y. The angular acceleration ϕ can also be derived from those equations and is shown as follows.

$$v_x = v\cos\theta, \quad v_y = v\sin\theta, \quad \phi = \omega \tag{5}$$

According to the above information, now it is possible to determine the x, y, θ of the mobile robot.

$$x = \int_0^t v(t) \cos\theta(t) dt \tag{6}$$

$$y = \int_0^t v(t) \sin\theta(t) dt \tag{7}$$

$$\theta = \int_0^t \omega(t) dt \tag{8}$$

Alternatively, (6),(7) and (8) can be represented by

$$\begin{bmatrix} v_x \\ v_y \\ \theta \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix}$$

$$= \begin{bmatrix} \frac{(v_r+v_l)\cos\theta}{2} \\ \frac{(v_r+v_l)\cos\theta}{2} \\ \frac{(v_r-v_l)\cos\theta}{2} \end{bmatrix} \tag{9}$$

Equation (9) described the kinematic model of the mobile robot. The associated noises to the robot motion are also required to be considered as this will be effecting the performance of the mobile robot during position and orientation acquisition.

3 Fuzzy Logic Controller Design

Fuzzy Logic Controller (FLC) is designed to control the nonholonomic mobile robot in providing the suitable velocities on both wheels. Our approach is similar to R.Rashid et al. This is made purposely to ease the comparison between our results and their results. The inputs of the FLC are the angle and distance error between mobile robot and any objects found during mobile robot observations. In this paper, the mobile robot must follow the wall in a pre-determined range as well as to avoid collision. The FLC generates the right and left wheels angular velocity for the output. The heading angle is defined such that if robot turn left, then the heading angle is negative. This definition is used for our evaluation presented in section IV later. The designed Fuzzy Logic is comprises of three general procedures as follows.

1. Fuzzification
   In this step, the inputs are classified to the identified fuzzy sets i.e for the far, medium, near for the distance error fuzzy and negative, zero, positive for the angle. The fuzzy sets values of the fuzzy variables are defined in Table 1.
2. Creating Fuzzy Rules
   This step explains the fuzzy rules design for our system. The fuzzy rules which associated to Table 1 are not included as it defines the same descriptions as presented by Rashid et al.

Table 1. Fuzzy Logic : Fuzzy sets Input

Angle Error	Dist. error
Negative	Far
Zero	Medium
Positive	Near

3. Defuzzification
   This step computes the output (angular velocity) of the fuzzy logic. Mamdani technique is used and the output is calculated through MATLAB Simulink environment. Based on the given output, mobile robot then moves accordingly until it reach its target.

4 Preliminary Results and Discussions

Gaussian membership is proposed in this paper for the mobile robot to make its decision. This method is proposed referring to the claims that the membership can considered as more practical than the triangular membership. To determine and evaluates the results, performance between a model that used the triangular membership and a model which applies the gaussian membership function is presented. The analysis are also considers the effect of increasing number of membership to the mobile robot tracking;3 memberships, 5 memberships and 7 memberships cases. In this simulation, the mobile robot is randomly placed in an unknown environment and assigned to follow a wall until it has reached its target. Remark that, this performance is not considering any sensors failures as such situation may exhibits system error and collisions.

Based on figure 2 for 3 memberships condition, the gaussian membership has exhibits better tracking movements than the triangular membership. A different mobile robot movements case was also examined using the same simulation settings in figure 3. As illustrated in these figures, the results have positively supported our claims. Similar performance have also been identified for the case of 5 and 7 memberships as shown in figure 4 and figure 5 respectively. Again, compared to triangular membership, it is clear that gaussian memberships is able to guarantee better solutions than the triangular membership.

Through those figures, it can be explained that the gaussian membership could offer a better choice for navigation than the triangular membership. We also noticed that, in the case of gaussian membership, if more membership is being applied to the system, then the mobile robot achieved better tracking result. Interestingly, the performance seems to arrive at its maximum performances when the system has 7 memberships. Even if this is the case, we still perceived the very same results proposed above i.e more membership is preferable for tracking purpose in Gaussian membership case. In fact, the result of using triangular membership also support our claims that if more membership are being assigned, then the mobile robot shows better tracking. Our results also supports what has previous findings in [11] suggested that the gaussian membership is suitable for better tracking performance in comparison to the triangular membership.

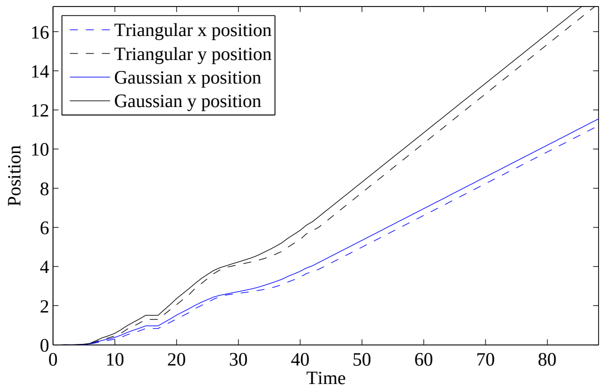

Fig. 2. Comparison between 3 triangular membership function and 3 gaussian memberships function for mobile robot x,y positions

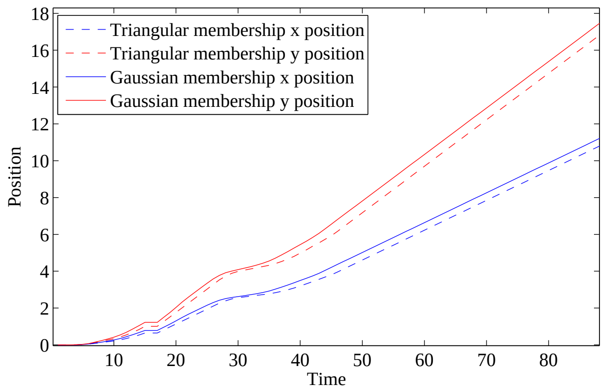

Fig. 3. Comparison between 3 triangular membership function and 3 gaussian memberships function for mobile robot x,y positions with different mobile robot movements

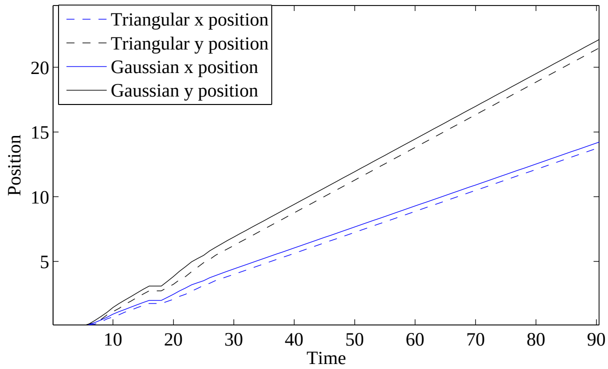

Fig. 4. Comparison between 5 triangular memberships function and 5 gaussian memberships function for mobile robot x,y positions

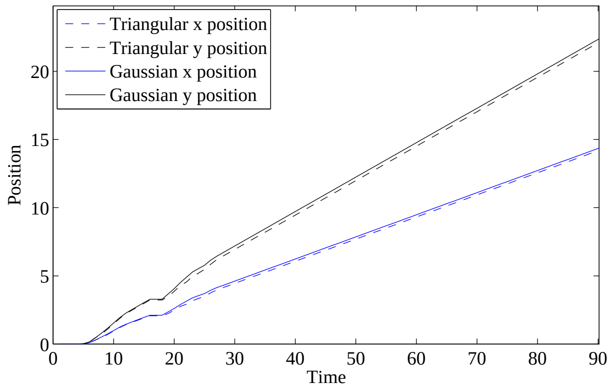

Fig. 5. Comparison between 7 triangular memberships function and 7 gaussian memberships function for mobile robot x,y positions

5 Conclusion

This paper proposed the study of different membership function for FLC in a mobile robot application. The results have shown that, the gaussian membership function can delivers better and good tracking performance for the mobile robot. Besides, we discovered that if more membership is applied in the fuzzy sets, then the mobile robot could perform the best tracking performance. However, based on the analysis, there are not much changes if the membership function has more than 5 memberships.

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