A novel fuzzy system for autonomous mobile robot navigation in unknown dynamic environment

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Abstract. This paper presents an intelligent approach for autonomous mobile robots navigation in unknown environments. With the proposed system, the robot should be able to avoid stationary and moving objects. This method made use of two parallel controllers for "target-seeking" and "obstacle avoidance". "Target-seeking" controller enhances the easy and patterned movement of the robot towards an obstacle. Upon approaching an obstacle, "obstacle avoidance" controller is activated and allows for a collision-free direction or easy manoeuvring of the robot's movement. Simulation results for a mobile robot navigating among moving obstacles demonstrated the acceptability and reliability of this method.

Key words. Mobile robots navigation, fuzzy system, obstacle avoidance, fixed and moving obstacles.

1. Introduction

A safe and intelligent navigation is of importance and necessity in any autonomous mobile robot when it is undertaking a task in a real-world environment. In a dynamic environment, objects may move or change positions, and other agents (human beings or robots) may also alter or affect the environment. In navigating in an unknown environment, the mobile robot needs to deal with the environment in a timely manner, which results in real-time demands on the navigation system. Also, the matter of isolation of the system from unwanted vibrations in any environment should be considered which is possible through different methods [8, 9]. Due to its simplicity and capability for real-time implementation, fuzzy logic is an excellent

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candidate for such applications. Fuzzy logic has had its wide applications in naviga-tion systems for mobile robots for over a decade. The main reason for its application is its dynamic nature of a real-world environment. Classical planning approaches [1, 2] are based on a model of the environment to generate a path for a mobile robot to follow. However, the large number of uncertainties makes it difficult or even impossible to obtain an accurate model of a dynamic environment. Therefore, the traditional planning approaches cannot generally deal with a large class of real-world navigation problems. With the development of sensor technologies, a number of reactive approaches to mobile robot control algorithms have been proposed [3–5] which are based on the ability of sensor data to generate control commands. The use of Fuzzy logic is a relatively recent innovation among the reactive approaches, and has demonstrated its efficiency [6]. Despite all the benefits offered by fuzzy-logic algorithm for mobile robot navigation systems, there still exist grounds for further exploration. As an example, fuzzy logic can be combined with other reactive methods [7, 10], or combined with an intelligent method such as neural network [11].

This paper proposes a fuzzy system for mobile robot navigation with its rule for operation extracted from the inspiration of a human driver. This approach enables the robot to manoeuvre smoothly around dynamic and stationary obstacles without any form of collision.

2. Kinematics model of the mobile robot

The design of the mobile robot used for the purpose of this simulation is a dif-ferential drive robot. It has two fixed wheels driven by different motors separately, and a passive omni-directional caster to maintain balance. The scheme is shown in Fig. 1.
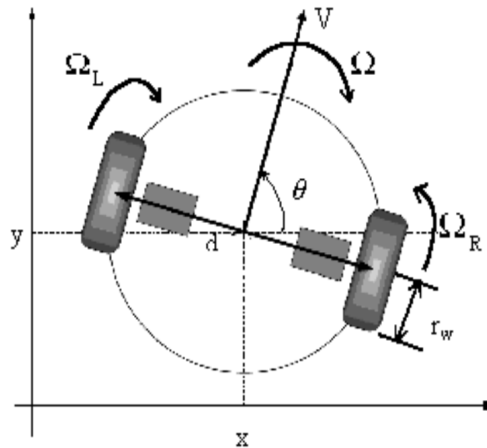

Fig. 1. Kinematic model of the mobile robot

Angular velocities of right and left wheels are shown with Ω_R and Ω_L as control

variables. The kinematics equations of the mobile robot with respect to the central point of the robot are given by

$$V(t) = \frac{r_\mathrm{w}}{2}(\Omega_\mathrm{L}(t) + \Omega_\mathrm{R}(t)), \ \Omega(t) = \frac{r_\mathrm{w}}{d}((\Omega_\mathrm{L}(t) - \Omega_\mathrm{R}(t)). \tag{1}$$

Here, $V(t)$ and $\Omega(t)$ are the linear and angular velocities of the robot, d and r_w are the width (distance of two wheels) and radius of robots' wheels, respectively. The position of the vehicle $X = [x, y, \theta]$, relative to the world referential (see Fig. 1), evolves in a time according to

$$\dot{X}(t) = f(x(t), V(t), \Omega(t)) \tag{2}$$

Based on equations (1) and (2), the robot kinematics (3) can be expressed as

$$\dot{x}(t) = V(t)\cos\theta(t), \ \dot{y}(t) = V(t)\sin\theta(t), \ \dot{\theta}(t) = \Omega(t). \tag{3}$$

The implementation of dead-reckoning required a discrete version of the kinematics (4), considering a uniform sampling integral T and assuming that in the interval $[KT, (K+1)T]$ the robot follows a link segment with translation velocity $V(k)$ followed by a rotation of $\Omega(k)$. An approximate discrete kinematics is given by

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ \theta(k+1) \end{bmatrix} = \begin{bmatrix} x(k) \\ y(k) \\ \theta(k) \end{bmatrix} + \begin{bmatrix} V(k)\cos\theta(kT) \cdot T \\ V(k)\sin\theta(kT) \cdot T \\ \Omega(k) \cdot T \end{bmatrix}, \tag{4}$$

where the values of $V(k)$ and $\Omega(k)$ are given by the odometry data, assuming that

$$x(k+1) = x(t)\big|_{t=(k+1)T}. \tag{5}$$

Equation (5) is used to simulate the proposed fuzzy system.

3. Results

In order to examine the proposed dynamic fuzzy collision avoidance in a dynamic environment with moving obstacles, MATLAB was used to simulate the designed fuzzy systems. An environment model of a 30 by 30 meter area, including several stationary and dynamic objects was used. During simulation process, the robot's pose was calculated using kinematics model of the robot. In each simulation iteration, the distance from the robot and the obstacles and target were calculated using the current location of the obstacles and target. A verification of the simulation results with experimental results is necessary, therefore, real specification of the robot was used ($r_\mathrm{w} = 10$ and $d = 50\,\mathrm{cm}$). Three cylindrical moving objects with different radii (0.5, 1 and 1.5 meters) were considered as obstacles. These objects moved in randomly in different directions and with different velocities. Figure 2 illustrates the simulation results for different scenarios.

As indicated in each scenario, the start and target points, objects location and
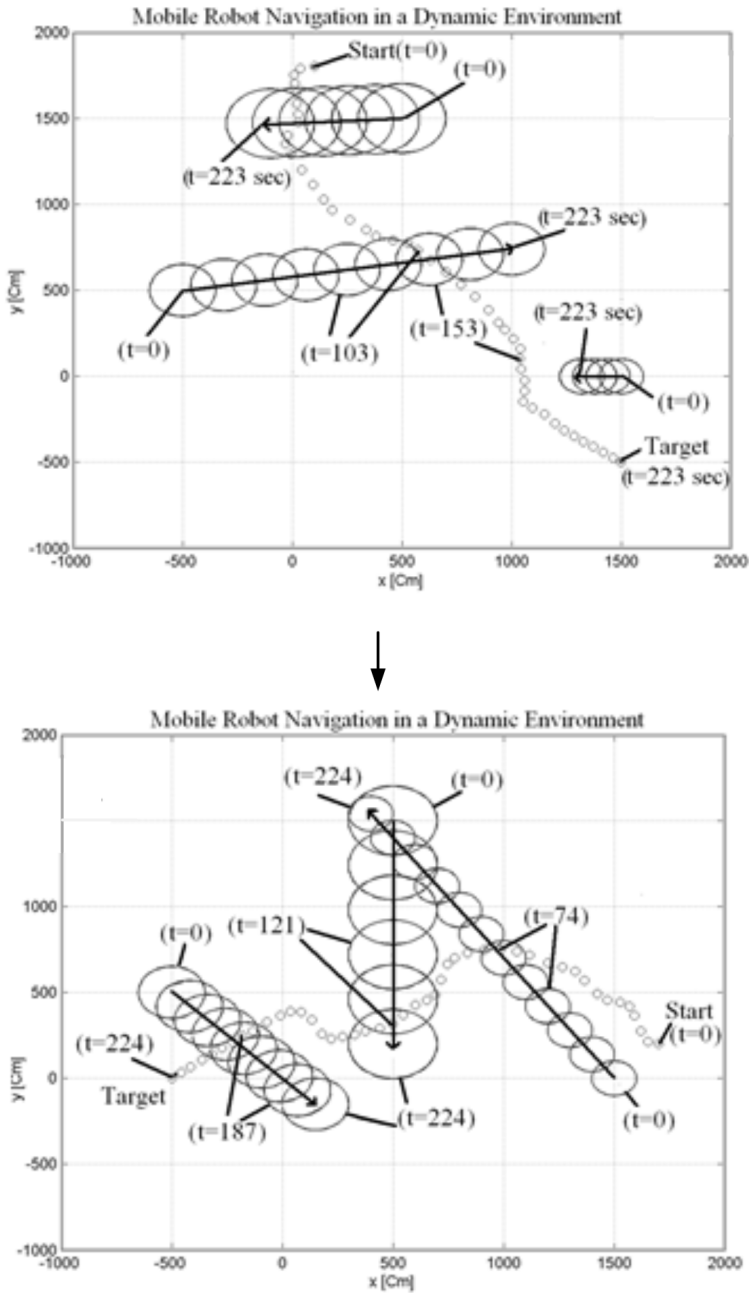
Fig. 2. Simulation results for moving objects

their velocities were varied in order to examine different situations. It should be

noted that the motion and position of the obstacles with respect to the robot are shown using time labels. The arrows indicate their motion direction. As the high-level controller defines the robot velocity depending on the obstacles distance and velocity, the robot velocity in the simulation results should be shown. Therefore, according to Fig. 2, the distance between circles illustrates the velocity of the robot. Closer circles represent slower motion of the robot. The robot's pose and target point are

$X_0 = [1, 18, 180]$, $T = (15, -5)$.

Obstacles start point, size and directions are

$So_1 = (5, 15)$, $Ro_1 = 1.5\,\mathrm{m}$, $Do_1 = 183$ degrees,

$So_2 = (-5, 5)$, $Ro_2 = 1\,\mathrm{m}$, $Do_2 = 9$ degrees,

$So_1 = (15, 5)$, $Ro_3 = 0.5\,\mathrm{m}$, $Do_3 = 180$ degrees.

According to simulation results in the first scenario the robot reached the target position after 223 seconds. It is also clear that in spite of possible collision with moving objects none were observed. As earlier mentioned, the velocity of the robot decreased when approaching obstacles and increased while bypassing obstacles. In the second scenario indicated by Figure 10, the robot's pose and target point are: $X_0 = [17, 2, 180]$, $T = (-5, 0)$. Obstacles start point, size and directions are

$So_1 = (15, 0)$, $Ro_1 = 0.5\,\mathrm{m}$, $Do_1 = 125$ degrees,

$So_2 = (5, 15)$, $Ro_2 = 1.5\,\mathrm{m}$, $Do_2 = 270$ degrees,

$So_1 = (-5, 5)$, $Ro_3 = 1\,\mathrm{m}$, $Do_3 = 315$ degrees.

According to simulation results in the second scenario, the robot reached the target position after 224 seconds. It is also clear that in spite of possible collision with moving none was observed. Here, the velocity of the robot increased while approaching the 1st and 2nd obstacles, and moving from the front of the obstacles. This velocity decreased with third obstacles while moving from the behind the obstacle and reaching the target position. The third scenario of robot's movement simulation, with different conditions. In this case, also, the robot reached the target position after 267 seconds. This behaviour is rather acceptable and promising when the robot confronts obstacles.

4. Conclusion

In the proposed intelligent approach for autonomous mobile robot navigation, it is assumed that inputs of the fuzzy controllers are calculated using kinematics equation. With reference to the simulation results, the robot's behaviour, from the presented approach, is fairly acceptable and promising. Accordingly, it seems that, if the inputs of the proposed system are available with the little of errors, the presented approach can be applicable in real robots. This method is implemented on a real mobile robot but the experimental results are still in the process and might be ready prior presentation of the paper. In order to make this method more intelligent and efficient, a new research program is activated. This new method is based on learning from human driver reaction while driving or controlling the robot using neural network.

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