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FINAL YEAR PROJECT REPORT

DEVELOPMENT OF OBSTACLE AVOIDANCE ALGORITHM FOR ROBOTIC WHEELCHAIR

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SUPERVISOR'S ENDORSEMENT

I hereby declare that I have read this report entitled "Development of Obstacle Avoidance Algorithm for Robotic Wheelchair" and found that it complies with the partial fulfillment for the awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation, and Automation).

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DEVELOPMENT OF OBSTACLE AVOIDANCE ALGORITHM FOR ROBOTIC WHEELCHAIR

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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering (Control, Instrumentation, and Automation)

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STUDENT'S DECLARATION

I hereby declare that this report entitled "Development of Obstacle Avoidance Algorithm for Robotic Wheelchair" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :………………… ………………..

Name : Amar Awad Mohamed Ahmed Ismail

Date :……………………………………

To my beloved mother and father and to my dearest brother and sisters.

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ABSTRACT

With the rising number of disabled people around the world and the increasing number of wheelchair users, research and developments have increased rapidly to produce autonomous and robotic wheelchairs that can avoid obstacles. This project proposes a behavior-based obstacle avoidance algorithm implemented using a fuzzy logic controller to ensure the safety of the wheelchair user. Two behaviors; Go-to-Goal and Avoid Obstacles are created using 11 fuzzy rules and are combined using rule weights. The proposed fuzzy logic controller has two inputs which are the target direction and the readings of three (IR) sensors attached to the right, left and front of the wheelchair and two outputs which are the linear velocities of the right and left motors. The testing and analysis of the controller are done using software simulation in MATLAB and Simulink environments. The results of the testing show that the proposed controller is effective in avoiding obstacles in low congested environments where the number of obstacles is low.

ABSTRAK

Dengan peningkatan bilangan orang kurang upaya di seluruh dunia dan peningkatan jumlah pengguna kerusi roda, penyelidikan dan pembangunan telah meningkat dengan pesat untuk menghasilkan kerusi roda autonomi dan robot yang boleh mengelak halangan. Projek ini mencadangkan algoritma mengelak halangan berasaskan tingkah laku dilaksanakan menggunakan kawalan logik kabur untuk memastikan keselamatan pengguna kerusi roda. Dua tingkah laku; Go-to-gol dan Elakkan Halangan adalah dicipta menggunakan 11 peraturan kabur dan digabungkan menggunakan berat peraturan. dicadangkan pengawal logik fuzzy mempunyai dua input yang menyasar dan bacaan tiga (IR) sensor dilampirkan ke kanan, kiri dan hadapan kerusi roda untuk mengesan dan mengukur jarak ke halangan. Ujian dan analisis pengawal dilakukan dengan menggunakan simulasi perisian dalam persekitaran MATLAB dan Simulink. Keputusan ujian menunjukkan bahawa pengawal yang dicadangkan berkesan dalam mengelak halangan dalam persekitaran yang sesak di mana bilangan halangan adalah rendah.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The World Health Organization (W.H.O.) has estimated that 10% of the world population have disabilities, i.e. around 650 million people. Researchers also show that almost 10% of these need a wheelchair. An appropriate wheelchair has been defined as a wheelchair that meets the individual's needs and environmental conditions, provides proper fit and postural support based on sound biomechanical principles, is safe and durable, is available and can be accessed, maintained and sustained in the country at the most economical and affordable price [1]. There are many types of wheelchairs to meet the different needs of users and the most used wheelchair type is the traditional manual wheelchair. A manual wheelchair is adequate for most users with physical disabilities but it is not suitable for individuals with a mixture of physical and cognitive disabilities. To accommodate users who find the manual wheelchair unsuitable, researchers have been developing smart/robotic wheelchairs. A robotic wheelchair is a standard powered wheelchair with a computer and a collection of sensors added [2]. One important feature of the robotic wheelchair is obstacle avoidance. A robotic wheelchair that provides obstacle avoidance but does not provide any path-planning assistance gives greater control to the user. Smart wheelchairs in this category would potentially be useful for wheelchair users with—

- Visual impairments who might not see obstacles but can navigate without visual cues.
- Physical impairments that can cause them to temporarily lose control of the chair.
- Cognitive impairments that make driving unsafe (e.g., poor impulse control).

One category of patients who will benefit from a robotic wheelchair with obstacle avoidance capability is quadriplegic patients [2]. Quadriplegia is a paralysis caused by disease or accidental injury that leads to the partial or full loss of use of all limbs and torso. A robotic wheelchair designed specifically for the aforementioned category would give those patients a form of independence and great mobility.

1.2 Problem Statement

Wheelchairs provide independent mobility for many of its users. However, this mobility is hindered by the many obstacles that exist in the environment. Many wheelchair users suffer from symptoms that make the task of safely avoiding obstacles along their path difficult or impossible to achieve independently. A robotic wheelchair that has obstacle avoidance capability could potentially benefit many wheelchair users suffering from various physical, cognitive, or perceptual symptoms associated with diseases such as spinal cord injury, multiple sclerosis, and cerebral palsy. As such, this project aims to develop an obstacle avoidance algorithm for a robotic wheelchair. However, developing such an algorithm can pose many challenges to the designer, some of these challenges can be attributed to:

- The fact that not all obstacles are the same, e.g., walls, objects, moving pedestrians, etc.
- The limitations of sensors, e.g., a single type of sensor might not be enough to detect an obstacle.
- The limitations of processing power.

1.3 Objectives

The objectives of this project are:

i. To develop an obstacle avoidance algorithm with fuzzy behavior-based controller for the modeled wheelchair using MATLAB/Simulink simulation.
ii. To simulate and analyze the developed algorithm in MATLAB/Simulink environment.

1.4 Scope

The scope of this project is:

i. The fuzzy behaviors to be designed includes:

    a. Go-to-Goal
    b. Avoid Obstacles

ii. Only static obstacles will be considered for the design.

iii. Only three IR sensors will be used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Researchers have been developing robotic wheelchairs for a long time, as such, many theories exist about controlling the robotic wheelchair. The robotic wheelchair can be classified as a differential drive mobile robot, making the theories implemented in controlling mobile robots applicable to the robotic wheelchair. Although the literature on controlling mobile robots covers a wide range of strategies, this review will focus on behavior-based mobile robots and the use of fuzzy logic. Given that the main objective of this project is the development of obstacle avoidance algorithm, this review will examine the literature on obstacle avoidance algorithms.

2.2 Wheelchair Kinematic Model

A wheelchair can be modeled as a differential drive mobile robot (DDMR) with two driving wheels and two free caster wheels (2DW/2FW). The caster wheels are ignored in getting the kinematic model of the system [3]. A kinematic model for differential drive mobile robot is presented in [4].

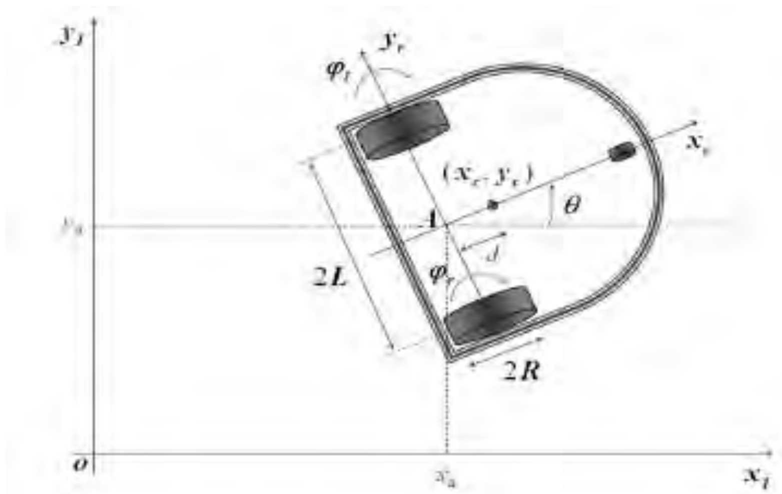

Figure 2.1: Differential drive mobile robot [4]

To determine the kinematic model, first, the coordinate system needs to be defined. Figure 2.1 shows the (DDMR) in the xy-plane with the parameters that define the model. The coordinate systems (frames) are:

i. Inertial Coordinate System: This coordinate system is a global frame which is fixed in the environment or plane in which the robot moves in. Moreover, this frame is considered as the reference frame and is denoted as $\{X_I, Y_I\}$.
ii. Robot Coordinate System: This coordinate system is a local frame attached to the robot, and thus, moving with it. This frame is denoted as $\{X_r, Y_r\}$.

The variables that define the model are as follows:

- A: midpoint on the axis between the two wheels.
- (x_c, y_c): center of mass of the robot, assumed to be at the axis of symmetry, at a distance d from A.
- R: radius of the two wheels.
- 2L: Length between the two wheels.

The kinematic model is used to study the motion of the system without considering the forces that affect the motion. The goal of this model is to represent the robot velocities as a function of the driving wheels' velocity as well as the other parameters of the robot. The kinematic model of the differential drive mobile robot can be defined as follows:

$$v = \frac{v_R + v_L}{2} = R\frac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2} \tag{2.1}$$

$$\omega = \frac{v_R - v_L}{2L} = R\frac{(\dot{\varphi}_R - \dot{\varphi}_L)}{2} \tag{2.2}$$

Where v and ω are the linear and angular velocities of the DDMR respectively. The velocities are then written using point A velocities located in the center of the robot:

$$\begin{cases} \dot{x}_a^r = R\frac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2} \\ \dot{y}_a^r = 0 \\ \dot{\theta} = \omega = R\frac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2L} \end{cases} \tag{2.3}$$

Thus,

$$\begin{bmatrix} \dot{x}_a^r \\ \dot{y}_a^r \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{R}{2} & \frac{R}{2} \\ 0 & 0 \\ \frac{R}{2L} & -\frac{R}{2L} \end{bmatrix} \begin{bmatrix} \dot{\varphi}_R \\ \dot{\varphi}_L \end{bmatrix} \tag{2.4}$$

In the inertial frame, the velocities can be represented as follows:

$$\dot{q}^I = \begin{bmatrix} \frac{R}{2}\cos\theta & \frac{R}{2}\cos\theta \\ \frac{R}{2}\sin\theta & \frac{R}{2}\sin\theta \\ \frac{R}{2L} & -\frac{R}{2L} \end{bmatrix} \begin{bmatrix} \dot{\varphi}_R \\ \dot{\varphi}_L \end{bmatrix} \tag{2.5}$$

Alternatively, the kinematic model can be obtained by representing the velocities of the differential drive mobile robot using the linear and angular velocities of the robot.

$$\dot{q}^I = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ \omega \end{bmatrix} \tag{2.6}$$

In order to have a smooth drive, S. M. Lavalle proposed a second order differential drive model in [5]. This is done by setting the inputs u_l and u_r that accelerate the motors, instead of setting the velocities. Letting ω_r and ω_l represent the angular velocities of the right and left wheels respectively, the state transition equation is

$$\begin{aligned} \dot{x} &= \frac{r}{2}(\omega_l + \omega_r)\cos\theta \qquad & \dot{\omega}_l &= u_l \\ \dot{y} &= \frac{r}{2}(\omega_l + \omega_r)\sin\theta \qquad & \dot{\omega}_r &= u_r \\ \dot{\theta} &= \frac{r}{L}(\omega_r - \omega_l) \end{aligned} \tag{2.7}$$

2.3 Behavior-Based Robotics

Behavior-based robotics (BBR) is a robotic control strategy that tries to mimic the behaviors of living creatures. The combination and interaction of different behaviors give the desired result. Unlike classical Artificial Intelligence, BBR (shown in Figure 2.2), builds intelligent behaviors using a bottom-up approach [6]. Behavior-based robotics first emerged in the 1950s when Grey Walter invented the electronic tortoise, which was the first robot to have reactive behavior. The robot had the ability to react to different forms of light intensities in various ways without the robot having any model of its environment [7].

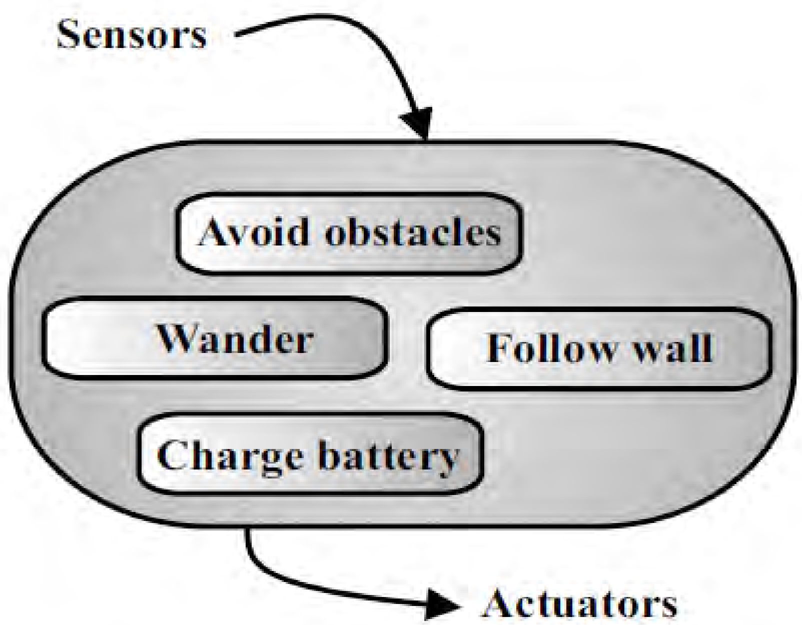

Figure 2.2: Behavior-based robot [6]

Walter's invention and others paved the way for the development of the more organized hierarchal paradigm. In the hierarchal paradigm, the robot systems are designed to follow a rigid order of states defined as "SENSE", "PLAN" and "ACT". In the "SENSE" stage, the robot senses its environment and creates a world model. Then, the "PLAN" stage develops an action strategy based on the received world model. Finally, the "ACT" stage performs the actuator commands set in the "PLAN" stage. This cycle of "SENSE", "PLAN", and "ACT", is repeated until the robot reaches its goal. However, this hierarchal paradigm faced two major challenges. The first issue is that, in the hierarchal paradigm the world is assumed to be closed, i.e., the robot has all the information about the environment. The second issue is called the frame problem, which is the incapability of modeling all environment information required by the robot in an efficient way [7].

The drawbacks of the hierarchical paradigm led to researchers to look for new robotic control paradigm. The technological leaps achieved in cognitive psychology and ethology paved the way for researchers to study animal behavior and implement it in robotics control which led to the development of behavior-based architecture (Figure 2.3).

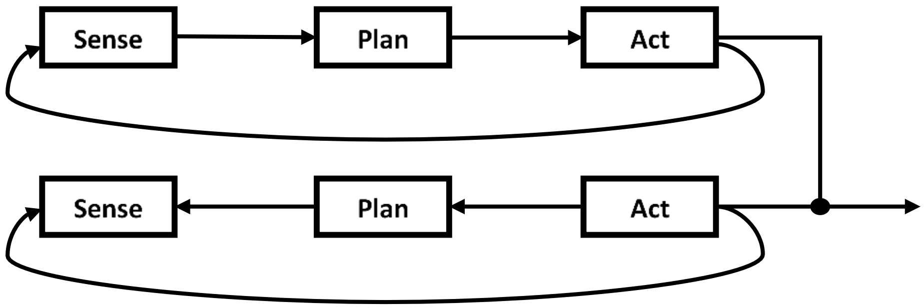

Figure 2.3: Behavior-based architecture [7]

The building of the behavior-based architecture begins with the definition of a behavior. The simplest behavior is basically a mapping of sensor input to actions that achieve a given task. Researchers have categorized animal behaviors to three categories. Namely, reflexive behaviors, reactive behaviors, and conscious behaviors. Reflexive behaviors produce an action that is a direct response to a stimulus without the involvement of a planning stage, for example, tapping of the knee produces a reflexive response. Reactive behaviors are behaviors that are learned over time such as learning to ride a bicycle. Conscious behaviors, on the other hand, require conscious thinking to perform actions. In mobile robotics, reactive behaviors are used more often. Table 2.1 shows the difference between reactive and deliberative architectures.

Table 1.1: Reactive versus deliberative architecture [7]

Deliberative (symbolic)	**Reactive (reflexive)**
Speed of response →	
← Predictive capabilities, completeness of world model	
Needs internal representation slow response High-level intelligence (cognition)	No internal representation Real-time response Low-level intelligence Simple (analogue) computation

2.4 Fuzzy Logic Control

Fuzzy control is based on fuzzy logic, which is a logical system that is much closer to human thinking and natural language than traditional logical systems. The fuzzy logic controller based on fuzzy logic provides a means of converting a linguistic control strategy based on expert knowledge into an automatic control strategy [8]. Fuzzy Controllers have been proposed for physical systems that are difficult to model mathematically, and hence, cannot be controlled by traditional control design techniques. Instead, control variables are represented by fuzzy variables which let the level of uncertainty of the variables be modeled in a systematic way [9].

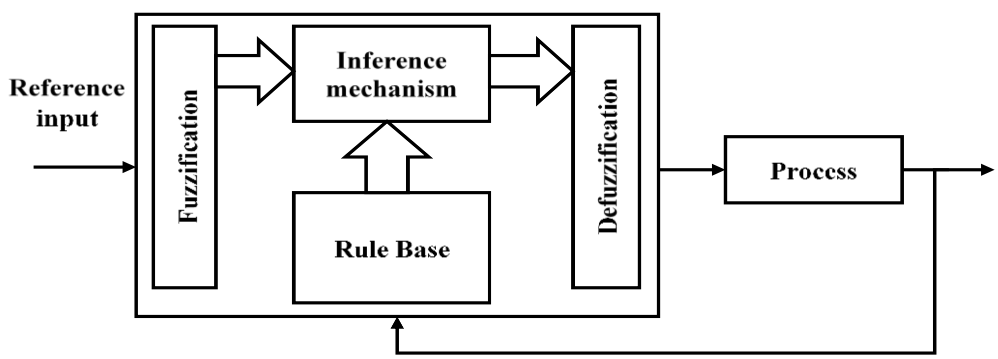

Figure 2.4: Fuzzy logic controller [10]

The fuzzy logic control is a method of artificial intelligence designed to control something usually mechanical. The fuzzy logic controller consists of several components, namely, the rule-base, fuzzification, inference mechanism and defuzzification as shown Figure 2.4 [10]. In traditional set theory built on Boolean or crisp variables, the value can only be either 1 or zero. However, in fuzzy set theory, a variable can have a membership or grade of zero to one, and this makes it different from the crisp set [9]. In Figure 2.5, a comparison between crisp and fuzzy set for a membership function is shown of the fuzzy variable "No. of individuals".

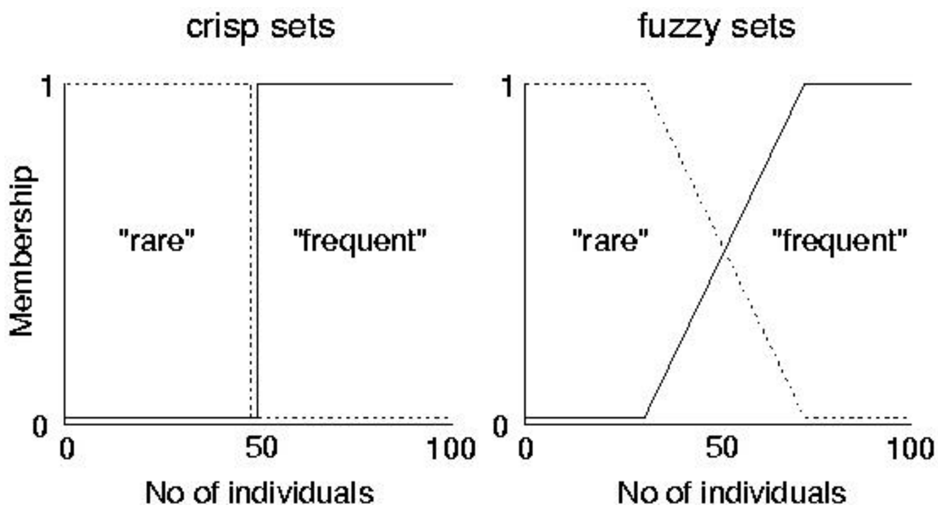

Figure 2.5: Comparison between crisp and fuzzy sets [9]

Classical control theory relies on the availability of a mathematical model of the plant (process) to be controlled. However, when the physical system is time varying and nonlinear - which is the case in most physical systems, techniques such as adaptive and robust methods are used to for corrective measures. Fuzzy set theory is used to model the nonlinearities and uncertainties of plant or control variables. In fuzzy control algorithm, the control law is described by a set of IF…THEN rules similar to an expert system based control. A typical rule has the following format:

IF x is A and y is B THEN z is C

Where x, y, and z are fuzzy control variables, and A, B, and C are the fuzzy subsets in the universe of discourses (all the possible values that a variable can assume) X, Y, and Z, respectively [9].

H. Murakami and H. Seki developed in [11] a fuzzy logic based obstacle avoidance algorithm to control an electric powered wheelchair equipped with ultrasonic sensors. Their control system was constructed based on four signals, the joystick command T_j, the distance to the obstacle d, the difference angle θ_g, between the joystick command Tj and the driving direction θ_d, and the velocity v of the wheelchair. Another variable introduced by the authors is the driving risk r, which is determined based on fuzzy control. The driving control system flowchart is shown in Figure 2.6. The fuzzification of the variables T_j, d, θ_g, and v are shown in Figure 2.7. For the fuzzy variable T_j, the symbols “LB”, “LM”, “ZO”, “RM”, and “RB” stands for Left-Big, Left-Middle, Zero, Right-Middle, and Right-Big respectively. For the fuzzy variable d, the symbols "S", "M", and "L" stands for Short, Middle, and Long respectively. For the fuzzy variables θ_g and θ_d, the symbols "SS", "S", "M", "B" and "BB" stands for Small-Small, Small, Middle, Big, and Big-Big respectively.

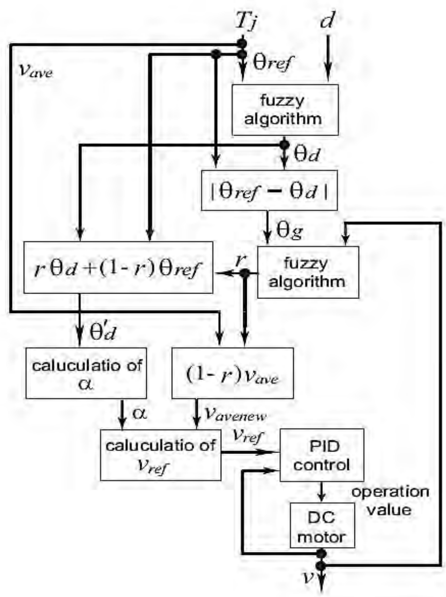

Figure 2.6: Driving control system [11]

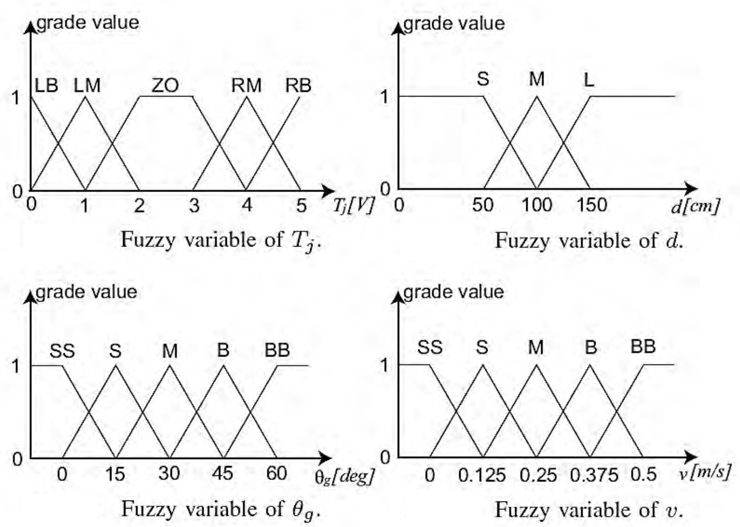

Figure 2.7: Fuzzification of the variables T_j, d, θ_g, and v [11]

The authors used four ultrasonic sensors to detect obstacles. Figure 2.8 shows the sensor placement on the wheelchair as well as the driving direction of the wheelchair.