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Automatic Ackermann steering parking using fuzzy logic

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Abstract— The simulation of the autonomous self-parking car model is introduced in this paper. The system uses a fuzzy logic controller in monitoring the car into a parking spot. The industrial growth of the world which has led to the increase in the number of automobiles on the streets throughout the world has caused a lot of parking related problems. The slow-paced city planning has increased the problem even more. This has led to automatic parking technology gaining a lot of attention, and an increase in the correlative research. Automatic parking is a key part of autonomous driving technologies and it is one of the growing topics that claim to enhance the comfort and safety of driving. Automatic car parking obtains information about available parking space, processes it and then place the car at a certain position. It can help drivers automatically drive the vehicle in constrained environments where much attention and experience are required; thereby releasing the human driver from complicated parking procedures and parking the car more efficiently; as it is sometimes very difficult to find a suitable parking place in a parking lot. This research paper has proposed a suitable solution to this problem; in terms of an automatic car parking algorithm. The parking strategy is completed by means of coordinated control of the steering angle and taking into account the actual situation in the environment to ensure collision-free motion within the available space, by use of a fuzzy speed controller and a fuzzy steering controller in Simulink; MATLAB to compute the system. The Simulink has an easier way to set up the rules in fuzzy control. The system imitates human thinking in performing the parking whereby it controls the steering angle and speed of the car corresponding to the situation of the car.

Index Terms— Ackermann steering, Autonomous Car Parking, Fuzzy Logic Control, MATLAB Simulation, Parallel Parking, Path planning, Simulink

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1 Introduction

Currently, an increasing amount of the robotic researches has focused on increasing the autonomy of the vehicle. The increasing interest in automation of automobiles and the corresponding attraction to many researchers in recent years has led to the development of different algorithms [1] [2].

Many automobile industries are working in developing autonomous vehicle by putting artificial intelligence in machines and machine learning. Autonomous vehicle parking is also one part of the complete autonomous vehicle where a vehicle parks itself by sensing nearby conditions [1] [3] [4]. It comes with many challenges out of which few are being introduced in this paper.

Autonomous Parking is the ability of a vehicle to start from its initial location and posture and reach to its final location and posture in a parking area. Although choice of parking totally depends on actual environment conditions. Many literatures have discussed and proposed techniques for autonomous parallel parking. In most of the methods, steering control mechanism is described and experienced. Also, different trajectories are also described taking care of non- holonomic constraints [5]. Basically, controlling methods of vehicle to achieve parking are categorized into two approaches. One is path planning approach where feasible path is pre-planned taking account of environment and non-holonomic constraints [5] [6]. Control strategy generates commands to maneuver the vehicle on that path. Many trajectories have been used for such path generation but among them all the fifth order polynomial provides better steering control fulfilling differential drive mechanism [1] [5]. Second is soft computing-based approach, which uses feedback to decide each and every step size and motion of vehicle. Fuzzy, neural or genetics-based approaches have been used widely and so have become popular over the past years [5] [6] [7]. The advantage of second is it does not require pre-knowledge of environment and it can make decisions on its own during runtime in any difficult circumstances.

2 Parking Problem

Parking is the process of leaving the car temporarily in a parking area until it is required. The parking process seems easy but it has some difficulties especially for novice drivers. There are a lot of factors that affect the parking process, for example; length of the car, steering angle, size of the tires, angle of the road etc. Also, there is a problem about the parking area, because parking could be between two cars, by the side of the road, or in a parking space between poles etc. There is no standard parking space set in the world. Every country and local government has its own rules. This problem starts from that; not every car has the same length. That's why there is no standard variable for parking. Sometimes it's not easy to park in these spaces even for experienced drivers.

Basically, there are three common parking scenarios, namely parallel, garage or vertical and angle parking as shown in figure 1, figure 2 and figure 3 respectively. In this paper the focus is on the parallel parking problem.

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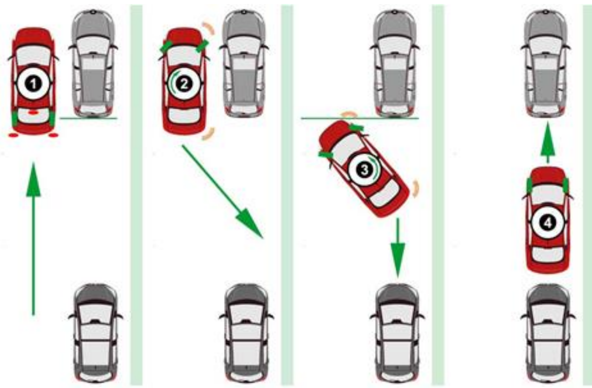
Figure 1: Parallel Parking

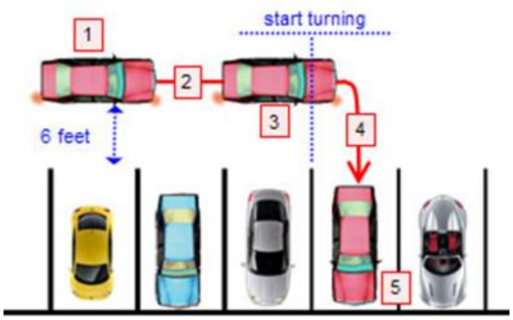

Figure 2: Garage Parking

Figure 3: Angle Parking

This paper describes difficulties present in parallel parking; where parking is being done parallel to curb of the road. Parallel parking has many advantages over the other types of parking like less space required, no need for specified parking slots and it can be used in streets, markets, and society anywhere.

3 Fundamentals of Parallel Parking System

In order to make the driving task safer and more comfortable considerable resources are being directed to developing systems for communication, information handling and automatic controls [2] [4] [8]. Traffic information, obstacle detection, in-vehicle warning systems, integrated telephones and motorist information are examples of systems available and under development. There has also been an increasing interest in automatic parallel parking [1] [4] [5]. Parallel parking in narrow spaces is often considered a tedious and annoying task by many drivers. The situation has become even harder when visibility behind the vehicle has decreased because of aerodynamic design. Thus, there is a demand for systems that perform the parking maneuver automatically.

4 Kinematic Model of Car Parallel Parking

4.1 Detection of Car Parking Spaces

Before the car automatically stops into the parking spaces, it must be able to detect around the parking spaces. The image sensor or ultrasonic sensor is installed around the car to detect the parking spaces [9] [10]. Thus, the image sensor photographed scenery around the car, combined with an algorithm, will enable the car to identify parking spaces.

4.2 The Establishing Reversing Model of Car Established

4.2.1 The Ackerman angle of motor two wheels in actual movement

In order to simplify the reverse model of the car, the car side-slip won't be considered and the parking speed is very low. Car wheels in the rotation follow the principle of Ackerman [11] angle as Figure 4.

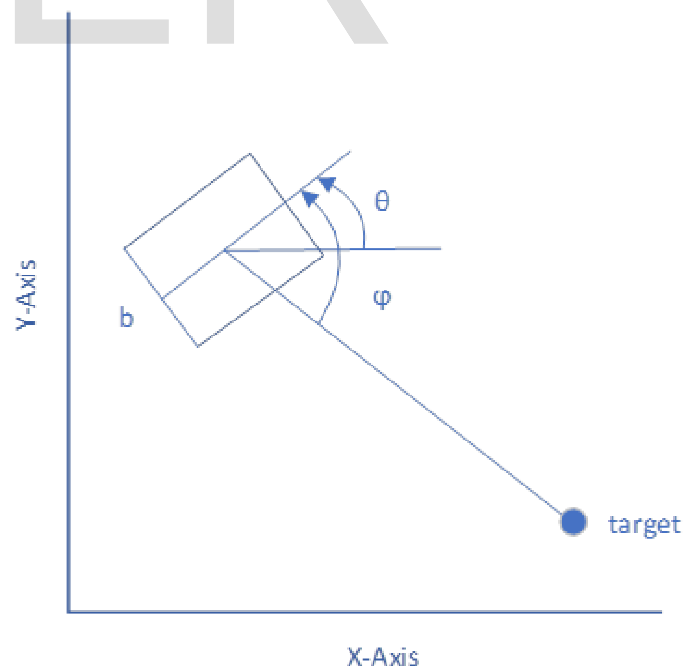

Figure 4: The Vehicle Kinematics and Heading Angle Difference

4.2.2 Car reversing model under the simplified model

According to Yanan Zhao and Emmanuel G. Collins, Jr [10]; the simulation of the parallel parking algorithm may be based on the kinematic model. As illustrated in Figure 4, let (x, y) denote the coordinate of the center of the vehicle in the local coordinate system, v the total translational velocity, vr and vl the velocity of the right side and left side wheels respectively, θ the angle between the positive x axis and the main axis of the vehicle, and $\ddot{\theta}$ the steering rate. Assuming constant velocity, the kinematic model of the vehicle can be described as [9]:

$$\theta(i + 1) = \theta(i) + \ddot{\theta}(i)dt, \quad (1)$$

$$x(i + 1) = x(i) + v(i + 1) \cos(\theta(i + 1))dt, \quad (2)$$

$$y(i + 1) = y(i) + v(i + 1) \sin(\theta(i + 1))dt, \quad (3)$$

where

$$(4) \quad v(i) = \frac{vr(i) + vl(i)}{2}$$

$$(5) \quad \ddot{\theta}(i) = \frac{vr(i) - vl(i)}{b}$$

At each sampling time, the velocities vr and vl can be obtained using (4) and (5). The motor coupled with the corresponding wheels can be adjusted to reach the desired speed by lower level controllers. Below, it is assumed that the steering rate is adjusted to maneuver the car while the translation speed v is taken as a constant. Hence, the process of accelerating the vehicle from rest and decelerating to rest is omitted from the simulation.

5 The Design of Controller of Car

Fuzzy controller is the core of Fuzzy control system, and the design of Fuzzy controller directly affects the accuracy of final control outcome. The design of the controller should apply moderate principles that represent not only high accuracy, but also simplified fuzzy inference operation relatively; because complex control system will lead to delayed response of system, that can have an influence on real-time control of car and will decrease accuracy of control in turn [1] [3] [5] [6].
The fuzzy logic control consists of many linguistic values IF-THEN rules, which describes the adequate control strategy. The rules basically form inference engine part as shown in Figure 5 [9], and are usually derived from the prior knowledge base or existing data pattern. In MATLAB, fuzzy logic toolbox can be used to integrate the fuzzy system into the simulation with SIMULINK. Previously such control design has been implemented in power electronics circuit design [11].
The result of fuzzy rule-based will be in the form of fuzzy sets [12] [13]. These linguistics results cannot directly produce the desired output in presentable form. Therefore, it needs to be going through with defuzzification method to obtain the result. Defuzzification is a reverse process of fuzzification that converts membership value into the crisp value [1] [5] [9]. In other words, defuzzification is a process that transforms the fuzzy set that is obtained by inference into a crisp value that can be used as the desired output where the inference engine is used to simulate human reasoning process by making fuzzy inference on the value of the input with the IF-THEN rules [14].

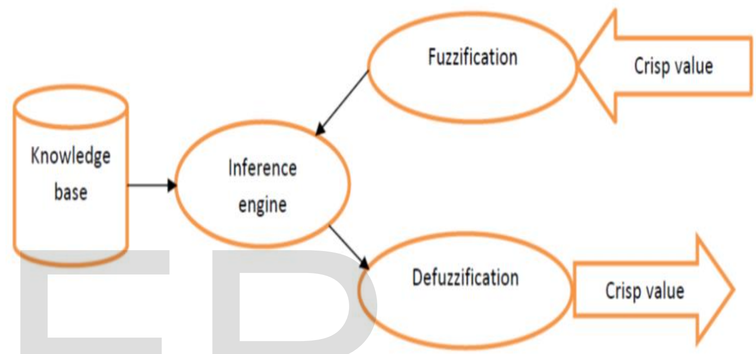

Figure 5: Fuzzy logic control

5.1 The Block Diagram of Fuzzy Controller

The process of fuzzy inference presents that according to the fuzzy rule base, and the database has been established, the fuzzy inputs are processed to generate the corresponding control inputs and control strategy.

5.2 Block Diagram of the Fuzzy Controller

The main differences between fuzzy control system and ordinary computer numerical control system are the use of a fuzzy controller.

5.2.1 The fuzzy Controller Design

A fuzzy logic controller can accept input from a diverse range of sensors. Ultrasonic sensors can detect the distance between the car and obstacles [10–12]. Global positioning systems can detect the car's current position [13–15]. With fuzzy inference, the final output enables a car to differentiate between various environments and to perform the behaviors desired by the designer. For example, differences in wheel speeds can enable a wheeled robot to turn at an angle and roll in a new direction to avoid an obstacle. The final input may be the rotational angle or forward velocity [10–17].
However, because the process of reversing is very

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complex, we need to design a complex fuzzy controller so that the car can be controlled precisely.

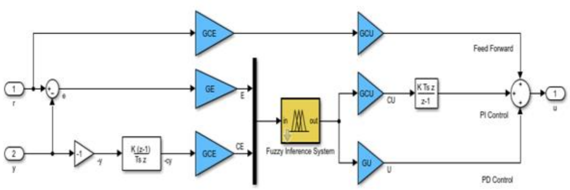

Figure 7: Fuzzy controller

6 Control Response Analysis

Since the vehicle auto-parking control process has a non-autonomous property and uncertainty behavior, each parking trajectory and initial and target positions are different. In addition, the real state variables are unmeasurable and the motion dynamics have an internal dynamics behavior. Usually, the purpose of the 2D parking path-tracking control is executed by monitoring the front-wheel steering angle only [18]. The X- and Y-axis motion path components are not measurable and directly control state variables. The controller only generates the steering-angle command for indirectly regulating the motion trajectory. It is an indirect and incomplete control problem [9–22]. In addition, the complicated vehicle dynamic model is not well known for state estimation. Hence, the simplified 2D bicycle kinematics model is employed to design a nonlinear input–output feedback linearization controller as suggested by Zhu and Rajamani [22].

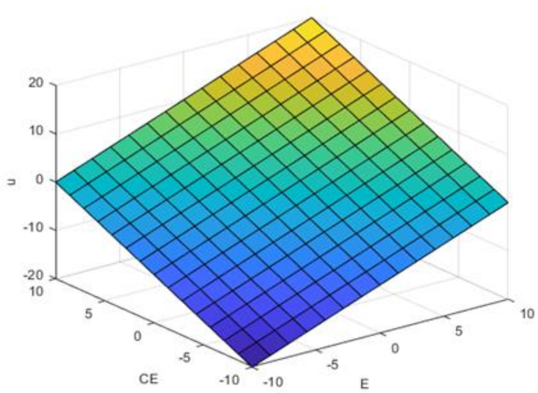

Figure 8: Traditional linear controller

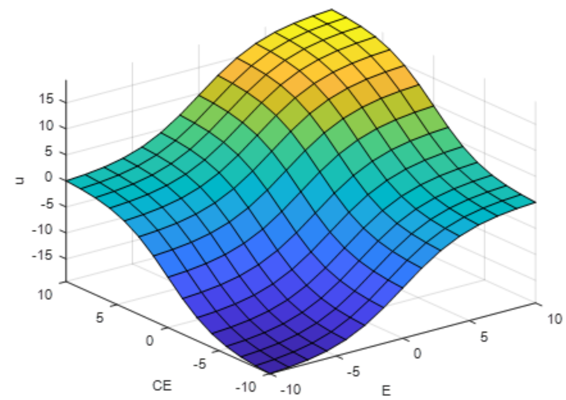

Figure 9: Nonlinear fuzzy controller

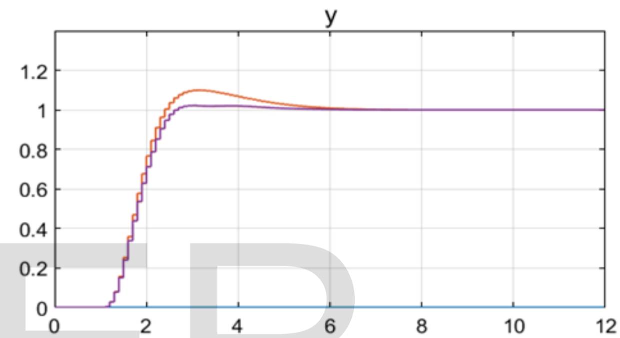

Figure 10: Nonlinear fuzzy controller

Compared with the traditional linear controller (the response curve with large overshoot), the nonlinear fuzzy controller reduces the overshoot by 50%. The two response curves from the nonlinear fuzzy controllers almost overlap, which indicates that the 2-D lookup table approximates the fuzzy system well.

7. Simulation results

The simulation assumes that the car is already in a Ready-to-Reverse Position. As discussed in several papers, usually the first step of an automatic parking system after sensing the parking space and the environment around the car is to move into a ready-to-reverse position. This process is completed by a goal-seeking behavior followed by an orientation adjusting behavior.

7.1 Fuzzy Logic Control (FLC) for Reversing the Vehicle into the Parking Space

The reverse maneuvering into the parking space requires a more complex fuzzy logic controller. The coordinate of the left rear corner of the vehicle in the local coordinate system is defined as (xa; ya), and the coordinate of the right rear corner of the vehicle is defined as (xd; yd). Two new variables, xa1 and yd1, are defined by xa1 = xa=lp and yd1 = yd=hp; they represent the relative position of the rear of the vehicle with respect to the origin of the space. The fuzzy logic controller for this step has three inputs, xa1, yd1 and the orientation angle θ. The output is the steering rate θ. The rationale behind several of the rules is presented here.

- If θ is negative and xa1 is small and yd1 is small, then $\ddot{\theta}$ is positive big, i.e., when the vehicle is very close to both of the boundaries, and its orientation angle is negative, the steering rate should be a big positive number to make the orientation angle positive
- If θ is zero and xa1 is very big and yd1 is very big, then $\ddot{\theta}$ is zero, i.e., when the vehicle is parallel to the parking space, and the vehicle is outside the parking space, the vehicle should continue to reverse in the same direction.
- If θ is positive and xa1 is big and yd1 is big, then $\ddot{\theta}$ is zero, i.e., when the vehicle is in the middle of the parking space, and the orientation angle is positive, the vehicle should keep the same steering angle.

7.2 FLC for Navigating the Vehicle Forward Inside the Parking Space

The developed fuzzy logic controller has one input, orientation angle θ, and one output, the steering rate $\ddot{\theta}$. The membership functions and fuzzy inference rules are exactly the same as that of the orientation adjustment described in the first step since this step accomplishes essentially the same task that is adjusting the orientation while simultaneously moving the vehicle forward.

7.3 Fuzzy Membership Function

As used by A.Z.Ahmad Firdaus et al [19] and adopted for this paper the fuzzy membership function is to determine the degree of trueness or percentage of agreed on the particular membership function. Each membership function has a range, and the degree of trueness is determined within the range. Seven membership functions in each parameter are zero, positive and negative range of maximum, average and minimum value respectively [10–21]. The steering angle has the similar labelled membership function as the input parameter.

8. Algorithm Summary

The three major steps of the parallel parking algorithm are (i) Reaching a Ready-to-Reverse Position, (ii) Reversing the Vehicle into the Maneuvering Space (iii) Adjusting the Vehicle Forward in the Space [23]. Only two fuzzy controllers were designed; for step (ii) and (iii). The car is assumed to be in a ready-to-reverse position, then using the fuzzy logic algorithm, the vehicle reverses into the parking space until it is very close to the parking boundary. Then the vehicle navigates forward inside the parking space. The forward navigation stops when either the target parking position is reached or when the vehicle is very close to the front boundary of the parking space. In the latter case, the vehicle will perform the second and third steps repeatedly until the target parking position is reached.

8.1 Results

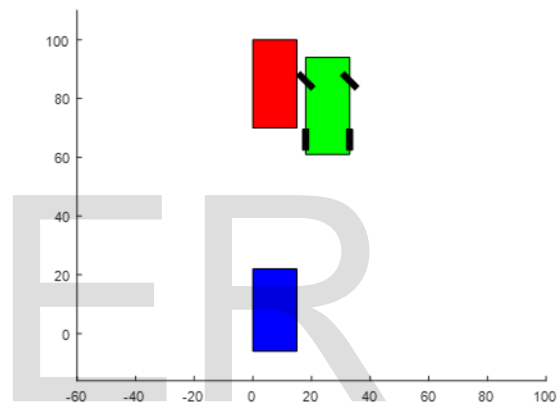

Figure 11: Wheels turned using Ackermann angle ready to reverse

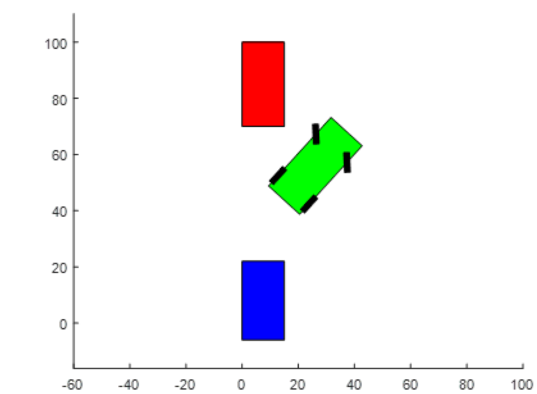

Figure 12: Reversing the Vehicle into the Maneuvering Space

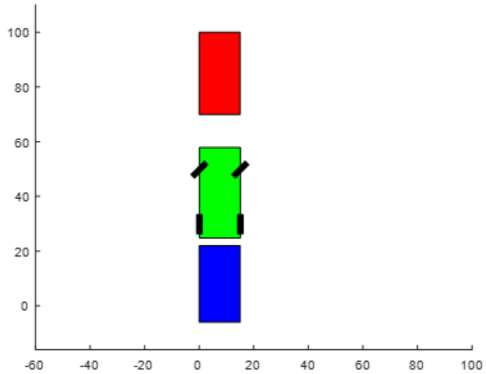

Figure 13: Adjusting the Vehicle Forward in the Space

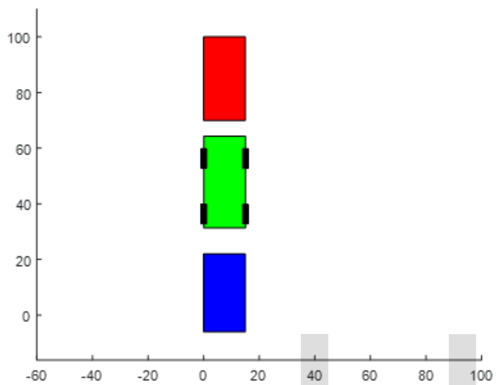

Figure 14: Vehicle in final destination

8 Conclusion

The design of the model in autonomous self-parking system is approached to achieve the objective. In order to park the car into the parking space without crashing neighboring cars or obstacles, a collision-free path planning calculation is developed, corresponding to the actual parameters of the car and also the parking space dimension. The basic kinetic mechanism has been applied in designing the general motion for the path planning along with xy-axis. For 90degree angled parking, the final orientation of the car must be perpendicular to the original orientation of the car.
This system is capable of making usual parking procedures reliably. But, also, any extraordinary event that interferes with any of the procedures could make this system prone to failure, like long distance to the sidewalk, a long or ample car, ample obstacles, etc. Since this system is unable to track other objects, any object not considered here could be overrun by the car. More sensors and more rules could make this system more reliable, but also more prone to other problems which have been discussed here.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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