Longitudinal and Lateral Control for Unmanned Ground Vehicles

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Abstract

This research aims to develop an autonomous control system of an unmanned ground vehicle by using a battery-powered car and focuses on longitudinal and lateral control of the car with fuzzy logic. Fuzzy control rules are derived by modelling a man's driving actions. Experiments are performed using the battery-powered car equipped with sensing devices and a microcontroller. The vehicle is a common battery-powered car, provided with automatic actuators operating on the car controls: steering & accelerator. These actuators work commanded by a fuzzy logic based control system. The input information of the control system comes from ultrasonic distance sensors, tachometer and the pot connected to the steering wheel. The speeds of electric motors are controlled by PWM signals. The desired position of the steering wheel is positioned by a servo motor connected to the steering shaft with appropriate rate gears. The environment information is taken by ultrasonic sensors. And the velocity information comes from encoder based on right rear wheel. Longitudinally and laterally motions are guided by actuators controlled by a microcontroller. The control architecture was tested at different vehicle speeds. Successful results were obtained after many experiments.

Key words: Unmanned Ground Vehicle, Autonomous, Fuzzy Logic, Intelligent Transportation Systems (ITSs), Longitudinal and Lateral Control

1. Introduction

Autonomous vehicles, once a dream, but now have very little time left in the countdown. The mayor producers have almost completed testing. After legalization of the related laws, we will see them on the roads.

It is unknown that how many traffic accidents happened since the car was invented, but according to the Turkish Statistical Institute's 2012 Traffic Accident Statistics report, only in 2012, in Turkey, 1.296.634 accidents happened [1]. It is highly probable that, the tangible and intangible losses coming from traffic accidents have serious impact to our country.

Before the full autonomy, there has been already lots of driving assistance systems in market to help us driving the vehicles. The connections of the separately developed systems have given us lots of advantages for the autonomous vehicles.

The first developments in the vehicle control systems were realized in 1960s by the General Motors [2]. The research group of the GM developed longitudinal and lateral control (steering & speed control) for automobiles. This research triggered the other groups. In the late of 1960s, Massachusetts Institute of Technology and Ohio State University worked on this field for solving

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the urban transportation problems [3].

Later, the major producers worked on advanced driver assistance systems [4]. There were cruise control [5], dynamic stability control [6], ABS [7], pedestrian detection systems [8], collision avoidance [9], and semiautomatic parking [10]. These developments have been made closer the automobile industry to the autonomous driving.

The developments in this area were almost in longitudinal control. But the electric-power-assisted (EPS) system developed the steering wheel system. EPS was a very important step to the lateral control of vehicles [11]. An improvement in this field was the addressing motor torque and steering motion by Güvenç and Güvenç [12].

In this paper, firstly, the control system design of the unmanned ground vehicle is described, and then the experiment results which have done with this system with different speeds are presented.

2. System Description

In this study, a battery-powered car has been used as an experiment test vehicle. The car's steering and longitudinal actuators have been modified.

2.1. Lateral Control

The steering system of the stock battery-powered car is based on Ackermann steering principle that steers the front wheels in different angles to slip motion during concerning [13]. (Fig. 1) This steering system from the original vehicle is conserved. The steering wheel is removed and a pulley belt system integrated. Steering is controlled by a DC Servo motor, through a gear ratio 4:1, fixed to the motor axle and the steering bar with belt & pulley.

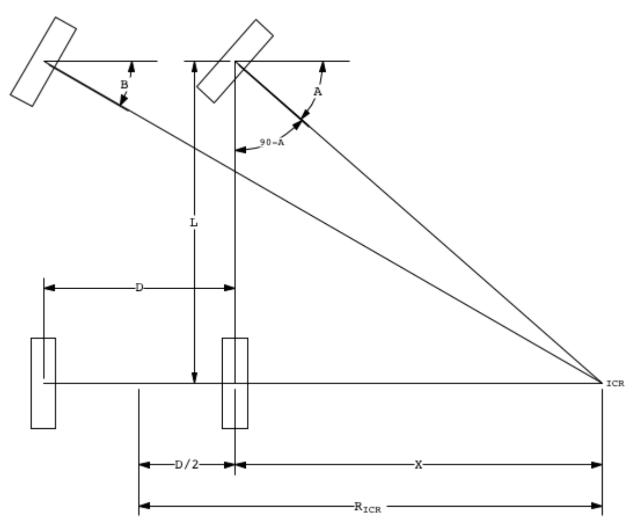

Figure 1. Turning radius illustration of an Ackermann steered vehicle

The DC Servo motor with metal gear has the maximum speed with a reduction ratio of 4:1 (to increase the torque and to reduce the speed of the original device), yields around 0,20 sec/15^{o} and the torque is 40 kg/cm. (at 4.8 V)

This motor can move the steering wheel as fast and as accurately as a human driver does.

The control system commands the steering-wheel actuator and receives the actual steering-wheel position by a pot from the steering wheel. The duty cycle changed by microcontroller can change the steering wheel position easily. A PID Controller is used for smoothing out any sudden changes in the fuzzy control output signals.

Figure 2 shows the control diagram of the steering wheel system. (Lateral control)

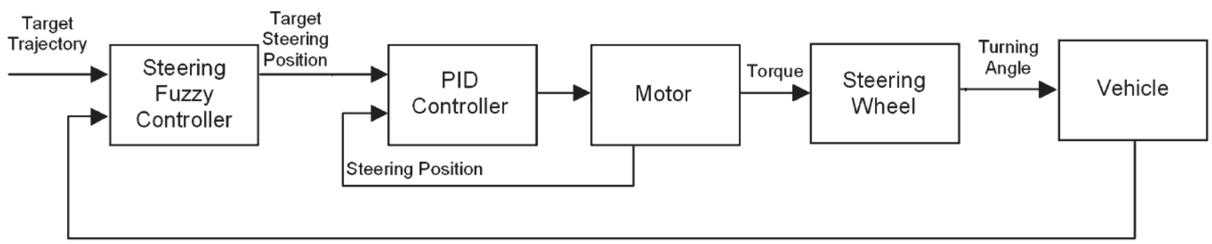

Figure 2. Lateral controller diagram

2.2. Longitudinal Control

The test vehicle used in this study is propelled by two dc motors. The PWM signals are used for actuating. The signals are produced by microcontroller. The microcontroller sends the target reference from the central program to the motors by duty cycle, for the desired velocity. The braking procedure was implemented in the code by changing the PWM signal duty cycle to zero. The real speed is read directly from the tachometer at the right rear wheel of the vehicle to close the longitudinal control loop. A PID Controller is also used for smoothing out any sudden changes in the fuzzy control output signals like lateral control system.

The DC motors used run with 12V and 10A.

Figure 3 shows the longitudinal controller diagram.

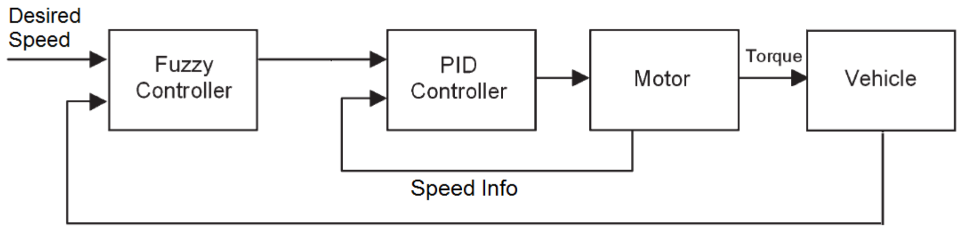

Figure 3. Longitudinal controller diagram

2.3. Environmental Sensing

Environmental sensing is a crucial feature of an unmanned vehicle, especially for applications that include full autonomy. Sensing the environment is very important for a successful motion planning and guidance. For these purposes sets of sensors are utilized on research platform and useful information taken from these sources is supplied either to the controller systems.

Most commonly used sensor types in studies are Light Detection and Ranging (LIDAR) sensors [14]. LIDAR is an optical remote sensing technology that can measure distance and direction to an object by emitting light, generally pulses from a laser. And the other choice is ultrasonic sensors. They can sense an object at most 4 meters from the vehicle so they are used especially for low-speed driving conditions.

Ultrasonic sensors work on a principle similar to radar or sonar which evaluates attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.

In this study, because of the LIDAR's high price and sufficient for our car's speed, we used 4 ultrasonic sensors, front, rear, right and left. They can measure the distance in cm up to 4 meters.

2.4. Fuzzy Logic

Over the past two decades, the field of fuzzy controller applications have been broadened to include many industrial control applications, and significant research work has supported the development of fuzzy controllers [15].

Fuzzy logic enables the designer to make very clear statements from loosely defined parameters. By fuzzy logic, the machine can behave like a human being. Fuzzy logic provides an alternative solution to non-linear control because it is closer to the real world [16].

In this study, we used fuzzy logic for making decision on lateral and longitudinal control systems. Fuzzy control rules are derived by modelling a man’s deriving actions. Fuzzy logic control gives emulating a human driver’s driving behaviors. The actuators are commanded by the fuzzy logic based control system. The input information of the control system comes from ultrasonic distance sensors, tachometer and the pot connected to the steering wheel.

The fuzzy control is divided into three stages: fuzzification, inference and defuzzification [17].

The input values are transformed and interpreted as fuzzy data in the fuzzification stage process. Each variable is defined by a membership function involving its corresponding linguistic labels, which represent in the rule base.

In tracking the front object we need two analog signals: vehicle speed and a measure of the distance from the object in front of. A fuzzy logic control system will process these giving a single output, which controls the brakes and throttle.

Figure 4 shows the working principle of the longitudinal control with fuzzy logic.

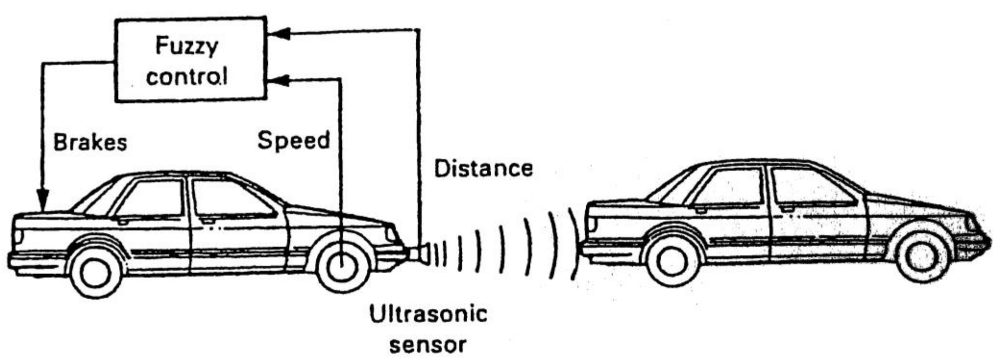

Figure 4. Working principle of the longitudinal control with fuzzy logic

In following figures (Fig 5, Fig 6, Fig 7), the membership functions of the research car are shown in the figure. These functions derived from human driver’s driving behaviors.

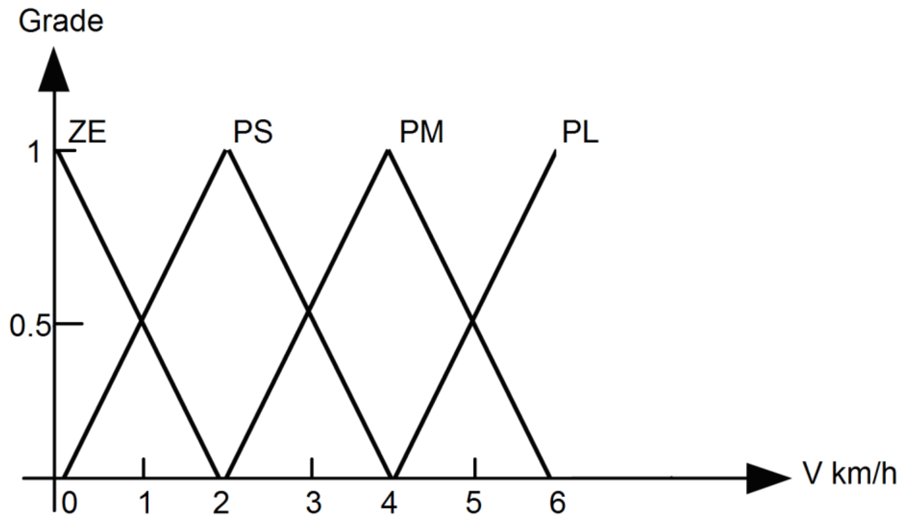

Figure 5. Membership functions of the vehicle speed

Where;

ZE Approximately Zero
PS Positive Small
PM Positive Medium
PL Positive Large

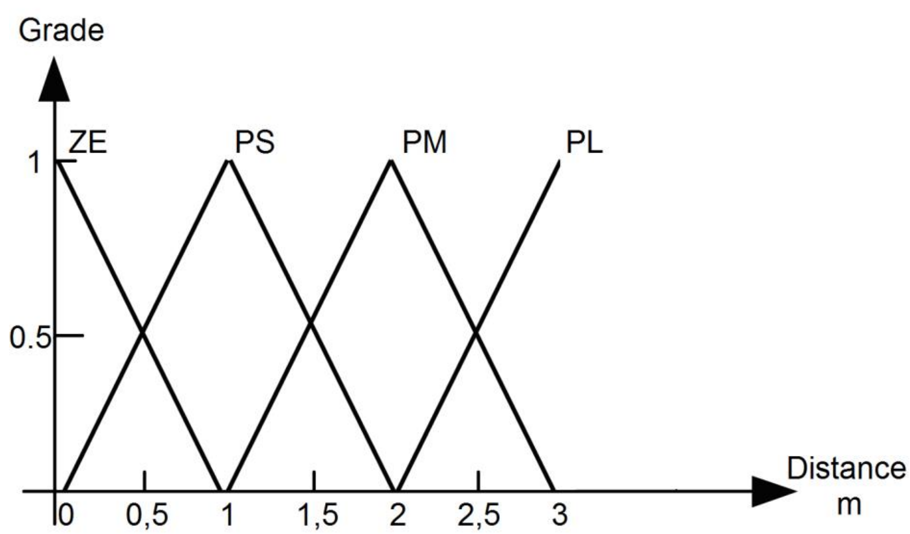

Figure 6. Membership functions of the distance from the car to the front object

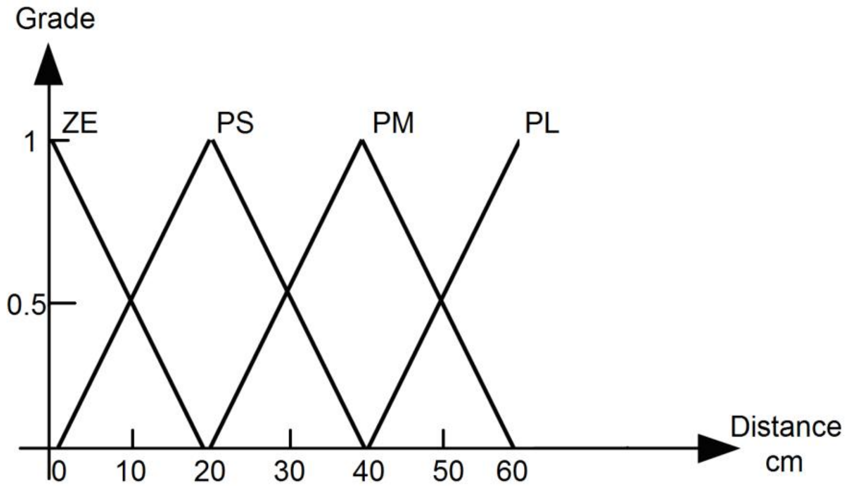

Figure 7. Membership functions of the distance to the right

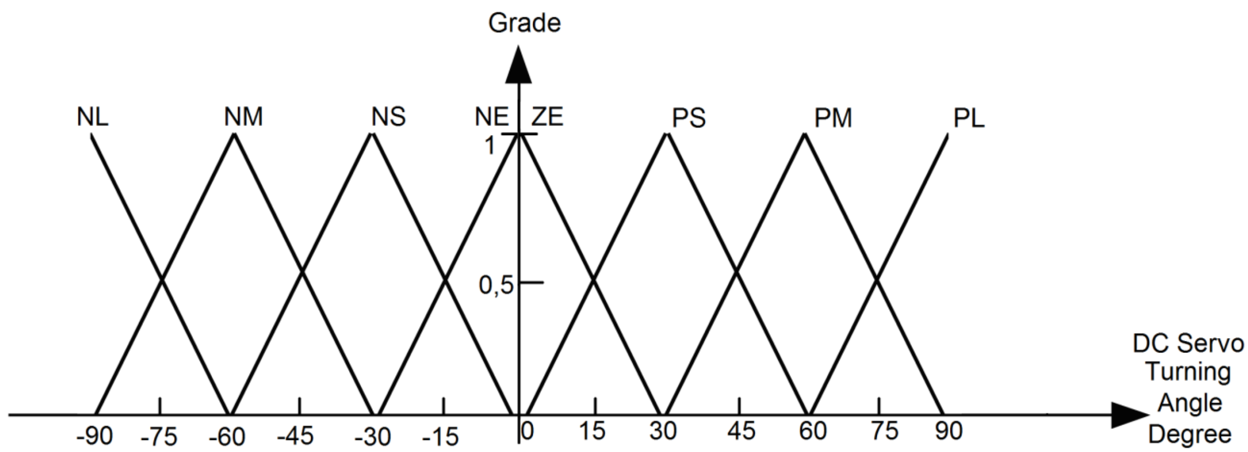

Figure 8. Membership functions of the DC Servo Turning Angle

Then the rule definition has to be done. If we had to describe a braking strategy in English, we would probably come up with something like:

Rule 1: If the distance between the cars is small and the car speed is rather high then brake hard.

Rule 2: If the distance between the cars is moderately long and the car speed is high then brake moderately hard.

Rule 3: If the distance to the right is small then turn left small.

Rule 4: If the distance to the right is large then turn right large.

If we define our signals

Speed: V
Distance: D
Braking: B
Distance2: D2
Angle: A

then we can rewrite these rules using IF-THEN construct

Rule 1: IF D is PS and V is PM, THEN B is PL.

Rule 2: IF D is PM and V is PL, THEN B is PM.

Rule 3: IF D2 is PS, THEN A is NS.

Rule 4: IF D2 is PL, THEN A is PS.

With these rules, the defuzzification process can be done easily. The number of the rules can be increased.

Fuzzification is the stage in which the crisp values are transformed into fuzzy data. Inference is the procedure whereby the values of the fuzzy variables are informed from a rule base, generating a fuzzy value for the output variable. The final stage, defuzzification, transforms this output fuzzy value into crisp data that can be sent to an actuator.

3. Experiment

This system was implemented and tested in our battery-controlled vehicle. The resulting experiments showed that humanlike trajectory tracking is feasible, and very good results were achieved.

Firstly, in order to obtain the membership functions explained in the previous section, several tests were performed. With these membership functions, fuzzification, inference and defuzzification steps have been performed and the crisp data was obtained.

For testing, we prepared a track in Middle East Technical University. The path used has the angles at the curves varied from 10^o to 70^o. The total road is about 60 m in length. The speeds used in the experiments were between 1 and 6 km/h. For following the road, we used the distance on the vehicle's right side to the bend.

For supplying the accumulator on the battery-powered car has been used. (12 V, 10 A)

These experiments showed good performance of the lateral and longitudinal controls. In most of the tests, the vehicle has kept to the road successfully. In the section of the road with disabilities, the vehicle was able to pass the obstacles.

In the overtaking test, the vehicle successfully overtook the barrier, if it had enough space on the left. In other cases, the vehicle safely stopped.

Thanks to the PWM signals that set the speed of the vehicle, the longitudinal control was accomplished successfully. The PID controllers made the output values much smoother.

The ultrasonic sensors showed a very good performance. They have worked almost flawless. The distance information has taken from them, and the vehicle moved smoothly.

The steering system also showed a very good performance but because of the narrowness of the steering angle, the rotation speed of the vehicle was slowly, about 3 km/h.

In the tests performed in both earth and grass the performance of the vehicle almost didn't change. Nevertheless, it is probably that, at higher speeds, this performance will be changed by friction factor.

4. Conclusion

In this paper, we have presented a control system for managing an autonomous-vehicle lateral and longitudinal control. This control system is based on the fuzzy logic control paradigm.

The fuzzy controller mimics human behaviour, which rules out the need to design complex mathematical models or piecewise linear models that are unable to deal with nonlinear behaviour. The fuzzy controller is designed and tuned according to a verbal description of driver experience. The PID controller provides functionality to a well-known regulating system so that a servo motor attached to the steering bar obeys the commands of the fuzzy controller.

The experiments were performed in different speeds with the structure presented and the good results have been obtained. In future work, other kinds of input sensors (GPS, LIDAR etc.) may be added to the architecture.

It seems that, the autonomous vehicles will be in our lives in the near future. They will make our lives easier like other autonomous technologies. This will eliminate human error, and no one will die because of these accidents.

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