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Automatic Car Control with GPS and Camera based on Fuzzy Logic

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Abstract: *Automatic control is a principal concept of modern technology and plays a major role in robotics, aviation, defense industry and is an integral part of modern production and industrial processes. This concept has wide ranging applications in design of controlled machine tools, drones and light and heavy vehicles. The variables used in this paper for automatic control of the vehicle include distance from front vehicle, wheel position, steering wheel angle, and vehicle speed. The automatic control is carried out using fuzzy logic and GPS systems in four scenarios. In each scenario, simulation is performed on 10 films prepared for this purpose. The results point to success of implemented approach in speed control, overtaking process, and control of steering wheel angle with respect to car's movements.*

Keywords: *Automatic control, GPS, fuzzy logic*

1. Introduction

Over the past decade, nearly 350,000 fatal road crashes were reported in the United States, but continuous improvement of traffic and vehicle safety has triggered a steady decrease in the annual number of such accidents.

The process of automatic parking usually consists of three steps: detection of parking space, route planning, and route tracking [3].

Another example of machine aided parking is the parallel parking discussed in [2].

In [1], a scheme for wireless communication control system of mechanical equipment is presented. This system consists of components such as vehicle control system, ground control system, installed on the lower level of the car, photoelectric rotary encoder and a coaxially connected cloth wheel, a PLC programmable controller, wireless communication transceiver and a UPS power supply, the ground wireless communication transceiver with radio signals connected with the vehicle wireless communication transceiver.

In [7], a comprehensive car model is combined with a driver model. One of the common methods in the design of the driver model is the simulation of driver's functional behavior with a delay transfer function. The car's automatic path tracking system receives the target path as input and applies necessary adjustment on steering angle (lateral dynamics) and the throttle (longitudinal dynamics) to provide smart cruising on the desired path. The functions of this control system is based on vehicle's feedback parameters such as longitudinal and lateral speeds, rotational speed, lateral acceleration, and longitudinal and lateral position, as well as the use of optimal control theory and PID. In this paper, the evaluation of accuracy of driver model for tracking multiple paths on a comprehensive car model with steerable front wheels and front wheel drive was conducted by simulation in MATLAB / Simulink software.

The work conducted in [6] is focused on lateral control of automobiles in an automatic highway system and primarily on lane change maneuvers. The optimal path for lane change maneuvers is called virtual desired trajectory or VDT, which must be designed with respect to passenger comfort and the time of maneuver. In [6], a self-adjusting fuzzy logic control is used as a path controller and forces the vehicle to follow the VDT. For better evaluation of performance of closed-loop system, a series simulations have been performed under different driving conditions. The evaluation results show the feasibility of using this self-adjusting fuzzy logic control for lane change maneuvers.

Authors of [10] have followed a GPS-based navigation approach. In this work, a GPS component receives the location signals from satellites and then sends them to an algorithm for ground level processing. Other parameters such as direction and distance have also been incorporated into this autonomous navigation scheme.

GPS-based autonomous navigation is a rapidly growing technology, and researchers have already developed several techniques for navigation in a variety of outdoor environments. [7-12].

The Global Positioning System (GPS) is a system originally consisting of 24 satellites orbiting the earth, with small rockets keeping the satellites in their designated orbit. These satellites are called NAVSTAR, and allow geographical positioning with accuracy of 10 to 100 meters. The satellites broadcast signals which once received and lightly processed by ground receivers can be decoded into longitude, latitude and altitude data [14].

In [13], continuous identification of vehicle location and direction is carried out using the signals provided by global positioning system (GPS) and global system for mobile communication (GSM).

In the present paper, first the proposed flowchart is presented, then principles of the use of stereo camera, GPS and Mamdani fuzzy logic are discussed, and in the end, the outputs and results are presented.

2. The Proposed Flowchart

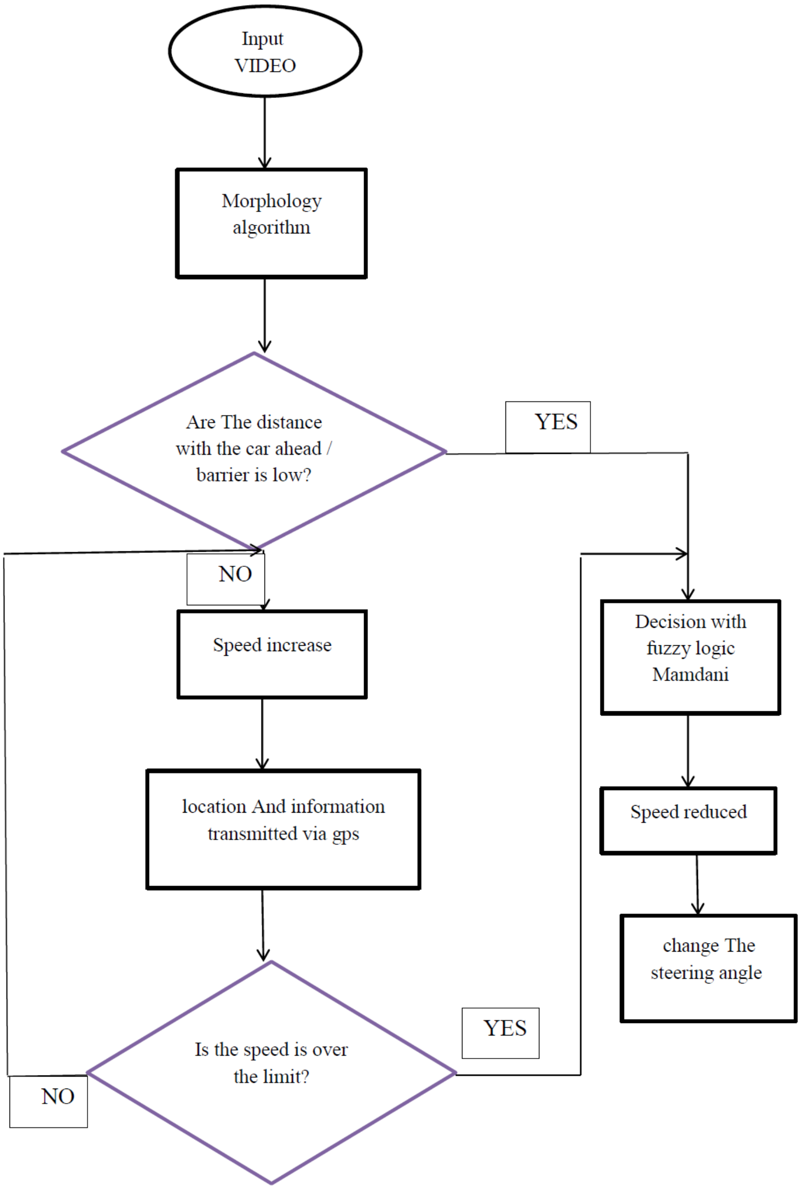

Figure1. *Illustrates the outlines the proposed method.*

3. STEREO CAMERA

In this paper we used a stereo camera to record images. This camera plays a central role in the process, so morphological operators are used as low-level processes to reduce the noise and increase the contrast and resolution.

The hole-filling algorithms are a type of morphological operators widely used for image processing. Morphological operators include a wide range of algorithms that process the images based on their morphology without any image resizing. Morphological operators determine the value of each pixel in the output image based on the value of its neighboring pixels in the input image. Many morphological operations use a combination of basic operators like erosion or dilation or other simple rules.

The processing procedure of a binary image is shown in Figure ().

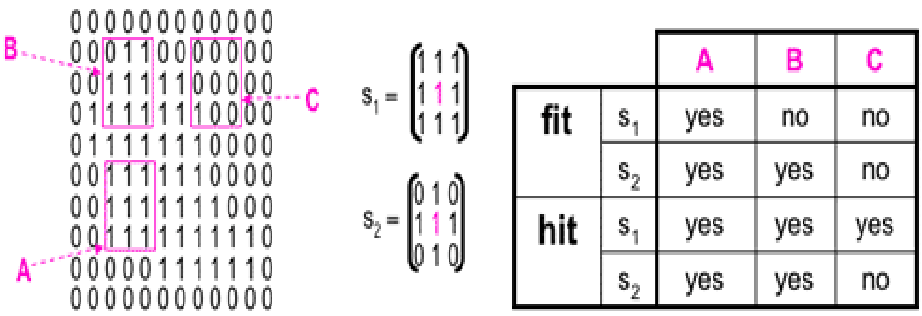

Figure2. *The processing procedure of a binary image*

$f^c(x,y) = 1 \; if \; f(x,y) = 0 \; and \; f^c(x,y) = 0 \; if \; f(x,y) = 1$
$h(x,y) = 1 \; if \; f(x,y) = 1 \; and \; g(x,y) = 0$

f and g are both binary images and $h = f \cap g$

The morphological algorithm is used to separate the vehicle from the background, then distance front vehicle is measured by the use of ratio of its height to height of original image. Whenever this distance gets lower than a minimum threshold (here this threshold is 1 meter) controller will be commanded to make and apply necessary decisions.

4. GPS

Assuming that initial location of the receiver is (x_0, y_0, z_0), the actual location of the receiver can be expressed by equation (1) [7]:

$$x_i = x_0 + \Delta x_i, y_i = y_0 + \Delta y_i, z_i = z_0 + \Delta z_i \tag{1}$$

where $(\Delta x_i, \Delta y_i, \Delta z_i)$ are new unknowns. (x_i, y_i, z_i) can be written in form of equation (2):

$$g(x_i, y_i, z_i) = g(x_0 + \Delta x_i, y_0 + \Delta y_i, z_0 + \Delta z_i) \tag{2}$$

Writing the Taylor expansion for the point (x_0, y_0, z_0) gives the coefficients of linear terms in form of equation (3):

$$\frac{\partial g\,(x_0,y_0,z_0)}{\partial x_0} = -\frac{x_j - x_0}{p_0^j}, \frac{\partial g\,(x_0,y_0,z_0)}{\partial y_0} = -\frac{y_j - y_0}{p_0^j}, \frac{\partial g\,(x_0,y_0,z_0)}{\partial z_0} = -\frac{z_j - z_0}{p_0^j} \tag{3}$$

Without considering the un-modelable errors, the pseudorange equation can be rewritten as equation (4):

$$p^j = p_0^j - \frac{x_j - x_0}{p_0^j}\Delta x_i - \frac{y_j - y_0}{p_0^j}\Delta y_i - \frac{z_j - z_0}{p_0^j}\Delta z_i + c\Delta_i \tag{4}$$

Equation (4) can be simplified to equation (5):

$$l^j = a_{xi}^j \Delta x_i + a_{yi}^j \Delta y_i + a_{zi}^j \Delta z_i + c\Delta t_i \tag{5}$$

Where:

$$l^j = p^j - p_0^j, a_{xi}^j = -\frac{x_j - x_0}{p_0^j}, -a_{yi}^j = -\frac{y_j - y_0}{p_0^j}, a_{zi}^j = -\frac{z_j - z_0}{p_0^j} \tag{6}$$

OR:

$$\begin{bmatrix} l^1 \\ l^2 \\ l^3 \\ \vdots \\ l^J \end{bmatrix} = \begin{bmatrix} a_{x_i}^1 & a_{y_i}^1 & a_{z_i}^1 & c \\ a_{x_i}^2 & a_{y_i}^2 & a_{z_i}^2 & c \\ a_{x_i}^3 & a_{y_i}^3 & a_{z_i}^3 & c \\ \vdots & \vdots & \vdots & \vdots \\ a_{x_i}^J & a_{y_i}^J & a_{z_i}^J & c \end{bmatrix} \begin{bmatrix} \Delta x_i \\ \Delta y_i \\ \Delta z_i \\ \Delta t_i \end{bmatrix}$$

Where $\vec{L}$ is the vector of n observations (at least 4 satellites need to be accessible), $\vec{X}$ is the vector of 4 unknowns, and A is the 4-dimensional design matrix. Solution of equation (8) is obtained using least square error method, and is expressed as equation (8) [16-18]:

$$\vec{X} = (A^T A)^{-1} A^T \vec{L} \quad (8)$$

The above equation are used to acquire information regarding vehicle location, speed, etc., then this information is compared with current position and speed of vehicle to realize automatic control.

5. Mamdani Fuzzy Logic

This scheme is tasked with controlling the speed and angle of vehicle. This task is accomplished by using two independent Mamdani fuzzy systems to adjust the speed and steering angle [12]. Depending on the amount of input (error or error dot), one or two rules will be triggered. The operator used in the system is the AND operator, which in Mamdani fuzzy logic means determining the minimum input. The output of each rule is one of 13 states, and its membership degree is the minimum of membership degrees of inputs (a number between 0 and 1). The value of output membership degree will be intersected with its corresponding Gaussian graph in each rule and the area under the curve will be determined [15], and the number of areas that must be determined depends on the number of triggered rules. The center of gravity of areas under the curves will be the output [19].

So ultimately, the fuzzy logic makes a final decision to alter the speed or change the steering angle.

6. Results

The data used for the test of automatic control consists of 10 video in 4 scenarios listed in Table (1).

Table1. *Scenarios of vehicle movement*

movement	scenarios
Move in a direction generally (including overtaking and right turn and left turn)	**1**
Move the track and turn left	**2**
The path and turn right	**3**
Move on track and getting ahead	**4**

The steering control system is tasked with following the trajectory, and the lateral and angular deviation tracking model emulates human driver perception by the use of two fuzzy variables of angular error and lateral error. The above system should also track obstacles or other vehicles in the car's path and devise the necessary lane change maneuvers. Vehicle location will be determined through GPS, and cameras will be used to manage complex and difficult traffic situations, enabling the vehicle's automatic control to work properly in any position and situations. Finally, fuzzy logic inference will contribute to better control of vehicle. In the following, the results of speed and steering angle controls are presented.

The changes of car speed are illustrated as the graph shown in Figure (2).

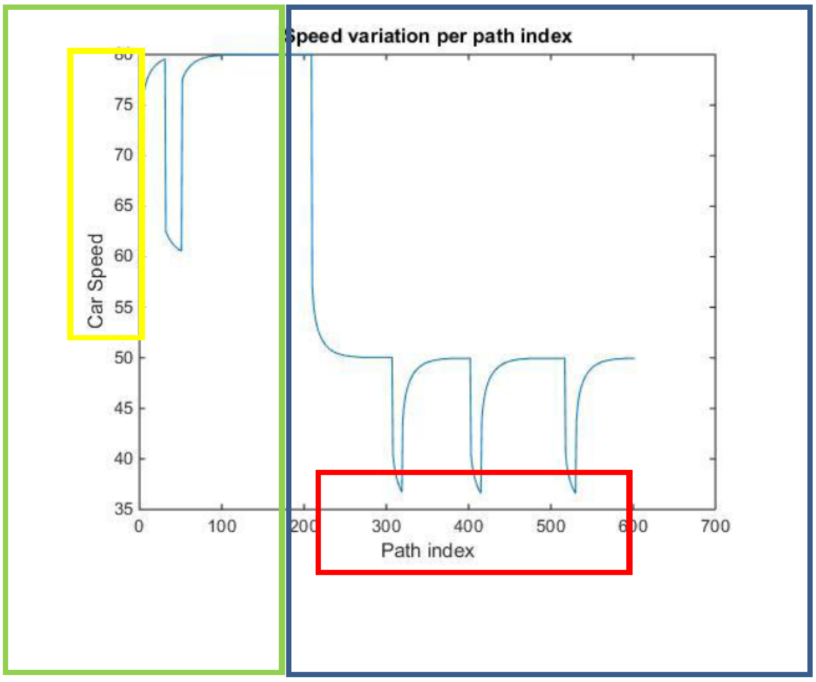

Figure3. *Changes of car speed*

The above graph pertains to speed changes in scenario 1. The horizontal axis is the path index that represents the car movement on the road. As can be seen, car speed first reaches to 80 km/h which is the speed limit in Area 1 (green box). Then car approaches the obstacle (the car in front) and reduces its speed to 60 km/h (yellow box). To overtake the obstacle, car again increases it speed to 80 km/h. Next, car enters Area 2 with speed limit of 50 km/h (blue box). For every turn, speed is reduced to 35 km/h (red box).

The changes of car's steering angle are illustrated in Figure (4).

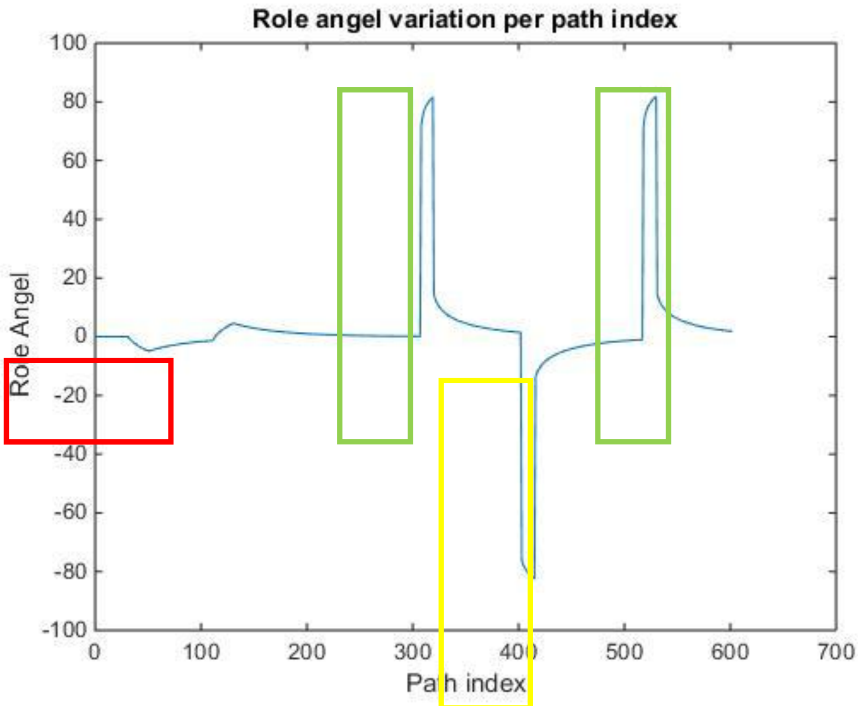

Figure4. *Changes of car's steering angle*

In this figure, car's steering angle is plotted against car movement. In the red box, which shows the process of overtaking the car in front, steering angle first gradually changes to -10 ° (steering to the left), gradually moves toward zero (to center or straight-ahead position) and then smoothly changes to +10 ° (steering to the right). In the green box, which shows the process of turning to the right, steering angle changes to 80 degrees to the right and then return to its original position. The same procedures is also followed for turn left action (yellow box) with only difference being the sign of steering angle.

Given that the above-mentioned inputs have 5 states, a total of 25 fuzzy rules are considered for the system. There are 13 output states, of which those related to speed alterations are in form of Figure (5). The output states related to the control of steering angle are also in the same form.

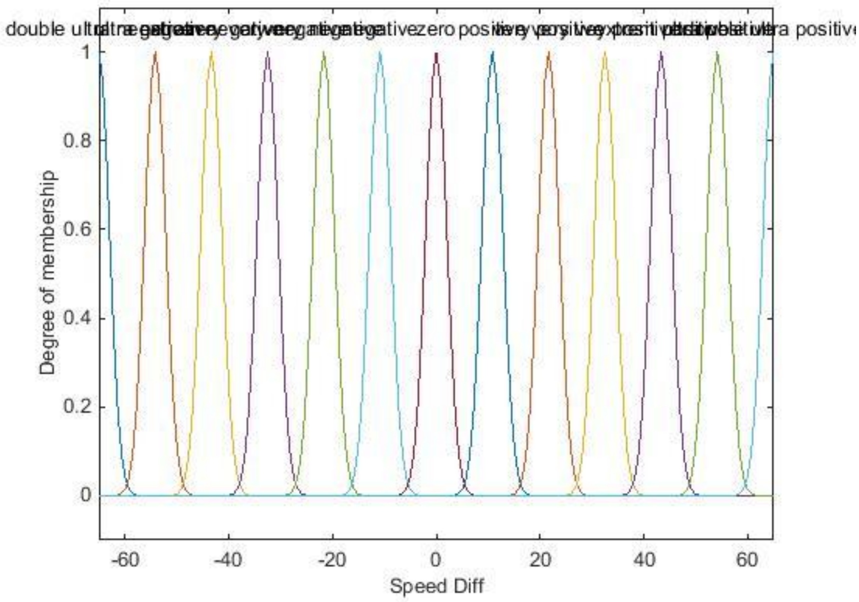

Figure5. *The increase or decrease in the speed with fuzzy logic*

7. Conclusion

The proposed algorithm employs three parameters of speed, movement, and steering for automatic control of vehicle. This algorithm is based on a Mamdani fuzzy inference system controlling the speed and speed limit, wheels and pedals, which along with the used GPS system contribute to better control of vehicle. Overall and with all discussed variables taken into account, the proposed approach allows a better automatic control and decision-making than similar cases.

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