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Autonomous Robot Driving Decision Strategy Following Road Signs And Traffic Rules : Simulation Validation

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Abstract: Autonomous robot driving decision strategy following road signs and traffic rules is described using simulation with a Turtlebot [1]. A fully autonomous robot driving strategy is presented, which follows human level logic in decision making. A vision-based autonomous vehicles navigation system for road vehicles includes three main parts: 1) road and traffic signs detection; 2) vehicle movement guidance system; and 3) decision making following human level logic. The first two modules have been studied independently for many years and obtained many good results using different solutions, but there are little research in fully integrated system with high level decision making to achieve fully autonomous robot navigation following road signs. It is valuable to study and apply this concept into a real system. A simulation world is built according to real environment scenario proving the concept of study.

Keywords: Autonomous Robot, Decision Strategy Following Road Signs, Road Navigation.

1. INTRODUCTION

Every year, according to the statistics, 1.2 million people are known to die in road accidents worldwide. [2] Average 2 people die because of vehicle accidents. Millions of others sustain injuries with some suffering permanent disabilities. Most of the time accidents occur because of human error like tiredness and ignorance of traffic rules and regulations. Therefore, replacing the driver with an autonomous robot driving system will be able to reduce these accidents. There are lots of researches focusing in the area of vehicle navigation [3-5] or road signs detection [6-9]. Unfortunately, no research combines both techniques with autonomous decision making skills. Researches in the computer vision areas mostly focus on image processing including detection and identification of traffic signs. There is no future consideration after the traffic signs are detected. On the other hand, research work in the areas of autonomous robot navigation mainly doing localization and object avoidance. They do not interpret traffic signs and follow human logic in decision making. Therefore, this paper is going to present an overview of autonomous robot driving system that uses road and traffic sign detection, lane guidance and a decision making strategy following road signs and traffic rules.

Fig 1. Turtlebot [1]

2. OVERVIEW

In order to replicate the real scenario in simulation, a road map shown in Figure 2 has been built. Figure 3 shows the traffic signs present in the simulation world. The driving rules defined in the robot's control system are shown in Table 1. The autonomous robot will drive along the road from a starting point to an end point while obeying various traffic signs scattered around the map without human intervention.

Fig 2. Road map

Table 1. Driving rules set in the system

TRAFFIC SIGNS	ACTION
Turn Left	Mandatory left turn
Turn Right	Mandatory right turn
Go Straight	Mandatory to go straight
No Left Turn	Prohibits the robot from turning left but it may move to any other directions
No Right Turn	Prohibits the robot from turning right but it may move to any other directions
No Entry	Prohibits the robot from entering the road beside the no entry sign
Stop	The robot will stop before the junction, turn (approximately) 90 degrees to the left or right; the robot may then continue its journey to any direction

Fig 3. Traffic sign in the environment

3. DRIVING STRATEGY

3.1 Road and traffic sign detection

3.1.1 Road edge detection

In order for the robot to move along the road, it needs to detect and differentiate road boundaries, drivable areas and off-road areas use road detection. Scene images taken from the camera are first being processed and the edges are extracted using Canny edge detector [10]. Straight lines are then extracted using Hough transform [11]. In order to differentiate the lines representing the road where the robot is and other lines such as the horizon, junction marks and road marks perpendicular to the current road direction, etc., the lines are filtered depending on its angle calculated using

Eq. (1), Lines representing the road where the robot is will have a steeper angle compared to other lines.

$$\theta = \tan^{-1} \left(\frac{y_2 - y_1}{x_2 - x_1} \right), \quad (1)$$

Where θ is the angle of the filtered line (blue lines show in Figure 4); x_1 is the x coordinate of point 1 of the filtered line; y_1 is the y coordinate of point 1 of the filtered line; x_2 is the x coordinate of point 2 of the filtered line; and y_2 is the y coordinate of point 1 of the filtered line.

As shown in Figure 4, the filtered lines which represent the road boundaries are marked in blue. Eq. (2) is use to determine the robot's heading on the road.

$$S_{fl} = \sum_{i=0}^n \theta_i, \quad (2)$$

Where S_{fl} is the summation of the filtered line angles; n is number of the filtered lines.

On a straight road, when the robot's heading is the same as the road's direction, the filtered line angles will be positive on one side, and negative on the other side on the scene image.

Fig 4. Filtered line represents the road boundaries in robot's camera view

3.1.2 Lane guidance

Situated in a country where vehicles travel on the left side of the road, the robot has to stick to the left lane during navigation as well. In order to achieve this, the robot needs to detect the yellow road markers shown in Figure 2, particularly the one on the left. The scene images are first converted from RGB color space to HSV color space, where it is represented in a more intuitive geometry for color detection and extraction. A threshold image is constructed based on the range of hue, saturation, and value set for yellow color extraction. Moment and center of mass are calculated from the contours in the threshold image using Eq. (3).

$$C = \frac{1}{S} \sum_{i=1}^n M_i I_i, \quad (3)$$

Where C is the center of mass in terms of x and y coordinates; S is the total number of contour pixels; M is the pixel value in the threshold image; and I is the x and y coordinates of the pixel.

Based on where the center of mass is located in the scene image, the robot would rotate left or right in order to keep itself moving near the left yellow road marker. A lower x coordinate value in the center of mass means the yellow road marker is further away to the left with respect to the robot.

3.1.3 Junction detection

The robot needs to decide its next movement when it reaches a junction. Junction detection uses the same threshold image constructed for lane guidance. The number of pixels that formed the contours in the threshold image is added. To avoid false detection, only the lower one-third of the threshold image is considered during calculation. This is because the upper two-third of the threshold image might represent the yellow road markers from the opposite road or those perpendicular to the current road direction. The number of pixels at the lower one-third of the threshold image should be close to zero when the robot approaches a junction.

3.1.4 Traffic sign detection and identification

It is important for the robot to understand the environment and obey the traffic rules and regulations in order to prevent accidents. At the beginning, every traffic signs (objects) are scanned and pre-processed to extract the keypoints with Scale Invariant Feature Transform (SIFT) [10]. Keypoints of each object are saved in the database for future comparisons.

Every 0.01 seconds, a scene image is taken from the camera and processed with SIFT to extract the keypoints. After that, the extracted keypoints are compared with the saved object's keypoints. Keypoints between two images are matched by identifying their nearest neighbors. But in some cases, the second closest-match may be very near to the first. This may happen due to noise or other reasons. In that case, ratio of closest-distance to second-closest distance is taken. If it is greater than Nearest Neighbor Distance Ratio (λ) they are rejected. Nearest Neighbor Distance Ratio (λ) is a constant number set as a threshold. Value of λ is set as 0.8 in the current system. Figure 5 illustrates the overview of the road detection and identification system. Figure 6 shows the result of the system. Detected object will be shown on the left top corner with the scene view.

Fig. 5 Overview of traffic sign detection and identification system

Fig. 6 Traffic sign detection and identification result

3.2 Decision strategy following road signs and traffic rules

Decision strategy is the most important technique developed and present in this system. It represents the brain of the robot. After gathering all the information from the sensor (camera), it will decide how and where the robot should move. The strategy developed here follows human logic in decision making. In Figure 7, we have a very clear decision tree that is made for the robot system. It follows the current road path until a junction is reached. It can also make a random decision about the next direction to follow when there is more than one available option. The robot uses Eq. (4) to decide which direction to move when there is more than one available entrance:

$$d = \text{int}(r \times n), \quad (4)$$

Where d is the output value which represents selected road entry. It is an integer number from 0 to infinity; int is a function that rounds a number down to the nearest integer number; r is a system generated random number between 0 to 0.999999; and n is the total number of available entrance.

Fig. 7 Flow chart for the decision strategy

4. RESULTS

4.1 Robot Path

A simulation video of Turtlebot driving around the world while obeying the various traffic sign scattered has been recorded (YouTube link : <https://youtu.be/XLFu6K18dKE?list=PLitQvOV-dwu3m-kGP2JsHyo1qCv2Q6-bS>). Figure 8 shows the robot's moving path in the world. The robot successfully drives without human intervention by following road signs and traffic rules.

Fig. 8 Robot moving path in 2D map

In the simulation, the robot's movement speed has been limited to avoid overshoot during movement control. The values used in the simulation are 0.3 m/s for linear movement and 0.2 rad/s for rotational movement. During the simulation, the robot constantly slips due the low coefficient of friction between the robot's wheel and the ground. To overcome this issue, the system focused on using vision guidance instead of dead reckoning while the robot moves across a junction. There is an assumption made for junction detection where there is no yellow road markers present at the junction. Therefore, if the robot encounters a box

junction, where the road area at a junction is marked with yellow grid, the robot will not stop or made any decision for the next movement, as there is still large number of pixels present at the lower one-third of the threshold image.

Road edge detection and lane guidance are designed to work together during the robot's movement along the road. This is because when the robot is at some off-road areas, it might still detect either left or right road edges or the yellow road markers. Road edge detection keeps the robot moving between the left and right road edges and lane guidance controls the robot's distance with respect to the left yellow road markers.

5. CONCLUSIONS

An autonomous robot driving decision strategy following traffic signs and rules have been developed in the simulation environment. The entire system has 3 main parts: road detection & line guidance, traffic sign detection & identification and decision making strategy following road signs & traffic rules. It was successfully integrated together and tested well in the simulation environment. Further improvements will be made to the system with additional sensors and information inputs and it will be put into test using real hardware and environment. Navigation systems including Global Positioning System (GPS) and preloaded map will also be considered in the new system. Navigation using GPS and map is useful for global path planning whereas traffic sign navigation system is useful for local path planning, particularly for unexpected changes due to road construction, diversion or other reasons. Since the system is designed to be general, it can be easily implemented to any mobile platforms or autonomous vehicles available in the market.

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