International Journal of Computing and Network Technology
ISSN (2210-1519)
Int. J. Com. Net. Tech. 6, No. 3 (Sept.-2018)

http://dx-doi.org/10.12785/ijcnt/060303

Development of Lane keeping Controller Using Image processing

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Received: 12 July 2018, Revised: 22 Aug. 2018, Accepted: 26 Aug. 2018, Published: (1 Sept. 2018)

Abstract: Motivated by the need to overcome dynamic traffic congestion problems and driving safety issues, lane keeping control of vehicles has become a very active research area and is a driver-assistance vehicle feature that automatically controls a vehicle's lateral direction at a certain look-ahead distance. This study presents the development of autonomous lane keeping controller using image processing in simulation environment and experimental setup. In the simulation study, a single tracked bicycle model was adopted as vehicle model. All simulation study of controller was based on the developed model in MATLAB environment while for experimental study; a scale vehicle was developed and used as a platform to test the lane keeping algorithm in a closed environmental setting. The lane keeping algorithm development comprises of two major parts. They are lane detection using image processing and lane keeping control. The lane detection provide important data like the lane boundaries and position of the vehicle with respect to the road and feed these data to the lane keeping controller for steering control. Proportional derivative controller (PD controller) control was developed to steer the vehicle and keep it on its lane at varying longitudinal speeds. Results in terms of stability of vehicle and maneuverability indicated that the range of values of both proportional and derivative gain altered the performance as can be seen in the simulation result and also suggested the inclusion of an Integral term I in an uncontrolled environment. The lane keeping algorithm was then implemented on the scaled vehicle and tested in a controlled environment and results indicated that the mobile robot was able to follow the desired reference trajectory by correcting the cross track error to the barest minimum. Experimental results also showed a similarity with simulations results of the mobile robot steering control

Keywords: Lane Keeping Algorithm, Lane Detection, Lane Keeping Controller, Lane Model, Image Processing Simulation.

1. Introduction

Autonomous vehicle is a self-driven vehicle that drive itself with necessary sensors, such as GPS, IMU, cameras, sensors etc. as can be seen in [1], [2]. They have been said to be the next big disruptive innovation in the years to come [3]. They have been in development for over 65 years—infact, the first cruise control systems were introduced in 1948. With the current rate at which civilization and technological advancement is growing at a rapid rate, especially in the automotive sector especially in self-driven vehicle. Active vehicular safety has been one of the most researched topic. Vehicle safety has attracted more attention in recent years especially in the automotive industry. The automotive industry worldwide is enthusiastic about developing advanced driver assistance systems (ADAS) and various car manufacturers are now focusing on developing (ADAS) for drivers, improve safety and provide comfort. With sensors technology and control algorithm, ADAS system help to increase safety, adapt to surrounding and automate the car. The ADAS system have come a long way in a relatively short period at least by the standards of the auto industry. It is no doubt that technology arguably has its roots in features that started showing up more than a decade ago, features like adaptive cruise control, or perhaps even further back to the introduction of simple driver warning systems, such as emergency brake lights. The term ADAS didn't really enter the lexicon until a few years ago, about the time that forward collision and lane departure warning emerged in higher-end cars.

Today ADAS is nearly mainstream. More brands and models, including compact economy cars, offer an expanding array of features to boost driver safety, from adaptive or glare-free high beams to driver drowsiness detection to wrong-way driving warning. Even the subcompact Kia Rio, with an MSRP that starts less than $15,000, comes with a backup camera and Kia's UVO

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telematics services. Other common ADAS systems include Collision avoidance system, Adaptive cruise control, automate braking, and automate lighting, parking assist system, lane departure warning system and lane keeping system.

This study addresses the development of an autonomous vehicle using image processing. The proposed system involve two basic procedures: lane detection and lane keeping. That is keeping safe distance in between vehicles, controlling speed of a vehicle according to traffic situation and road characteristics, lane change maneuvers for overtaking vehicles, obstacle avoidance as explain by [4]. The goal of the lane detection algorithm is to detect the lane boundaries and centerline and then this data is sent to the lane keeping vision dynamic algorithm, which will help to determine the desired position and direction of vehicle and then try to maintain the vehicle desired position on the road by controlling steering angle of the vehicle. A robust and good performance controller is needed for controlling the vehicle.

2. SINGLE TRACKED (BICYCLE) MODEL

To describe the lateral dynamics of a vehicle, a single tracked bicycle model with the following parameters in table 1 were used for the simulation analysis.

Table 1: List of parameters for vehicle dynamic

S/N	Parameter	Symbol
1	front tire cornering stiffness	C_{af}
2	rear tire cornering stiffness	C_{ar}
3	vehicle longitudinal velocity	V_x
4	front tire distance	l_f
5	rear tire distance	l_r
6	motor inertia	I_z
7	mass of the vehicle	m
8	front and rear side slip angle	α_f, α_r

Considering the developed bicycle model vehicle dynamics with the following state space representation as seen below

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \quad (1)$$

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} -\frac{2C_{af}+2C_{ar}}{mv_x} & -\frac{2C_{af}l_f-2C_{ar}l_r}{mv_x^{2}}-1 \\ -\frac{2C_{af}l_f-2C_{ar}l_r}{I_z} & -\frac{2C_{af}l_f^{2}+2C_{ar}l_r^{2}}{I_zv_x} \end{bmatrix}; \quad (2)$$

$$B = \begin{bmatrix} b_{11} \\ b_{21} \end{bmatrix} = \begin{bmatrix} \frac{2C_{af}}{mv_x} \\ \frac{2C_{af}l_f}{I_z} \end{bmatrix}; \qquad C = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad (3)$$

It should be noted that the lateral vehicle dynamics was represented using a linear time-invariant (LTI) system with shown state, input, and output variables [5]. The initial conditions for the state variables was assumed to be zero, with the state variables being Lateral Deviation and Relative yaw angle rate. The Input variable is Front steering angle and Output variables are same as state variables. It should also be known that the longitudinal vehicle dynamics was separated from the lateral vehicle dynamics. Hence, the longitudinal velocity was assumed to be constant at the beginning. With the following assumptions and state, input-output variable, the simulation of a PD controller and its performances as the longitudinal speed changes was carried out to show what happens in an actual real vehicle scenario as the vehicle travels along the reference centerline of the lane.

3. METHODOLOGY

Fig 1 illustrates the methodology adopted for the development of the lane keeping algorithm using image processing. It shows the complete block diagram for lane keeping functions using image processing which consist of two major part which are lane detection using image processing and lane keeping algorithm

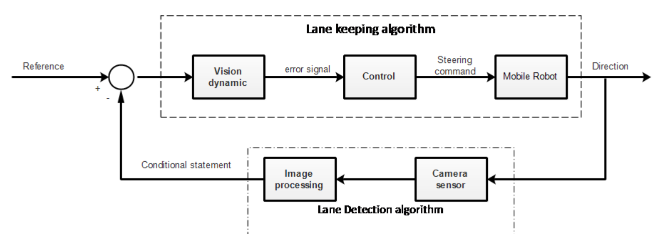

Figure 1: Block diagram of lane keeping Algorithm Using Image Processing

The study started with the lane detection algorithm where a camera was used to detect the road lane using image processing method. Edge detection technique was the image processing method used for detecting the lane boundaries as seen in [6], [7]. It involved three basic steps: Image smoothing for noise reduction; this step involves filtering the original RGB image to improve the performance of edge detector. The next step was the detection, where extraction of all edge points that are possible candidates to become edge point are carried out as seen in [8].

Last is the edge localization, involving the candidate edge points only that are true members of set of points comprising an edge. The output of the lane detection is expected to provide important information to the lane keeping controller, telling it which is the left/right lane boundary and obtaining the position of the vehicle with respect to the road. Therefore, it is important to develop fast and accurate lane detection algorithm so that the direction and position of the vehicle can be determine correctly. The lane keeping algorithm consist of dynamic vision which processes the information gotten from the lane detection algorithm and feeds this information as steering input command to the controller. The study was done in Matlab simulation environment and tested using experimental setup. In simulation study, a single tracked bicycle model was adopted as vehicle model. All simulation study of controllers was also based on the developed model in Matlab environment while for experimental study, a scale vehicle is developed and used as a platform to test the lane keeping algorithm.

4. Discussion of Results

The pre-processing steps involves Video/Image conversion and smoothing. This was where the images/videos were converted from the original Red Green Blue (RGB) format to grey scale format for further processing. The conversion was necessary to help recognize and locate sharp discontinuities in the road image/video. Image/video smoothing was then carried out in order to improve the performance of edge detector and remove noise. The next step was the edge detection part, where Extraction process to identify the possible candidates to become edge point was done. A suitable edge detector was applied to produce an edge image with automatic thresholding to obtain the edges. These edged image/video was then sent to the line detector after detecting the edges which in turn produced the right and left lane boundary segment. The lane boundary scan uses the information in the edge image detected by the application of Hough lines (Hough transform) to perform the scan. The scan returns a series of points on the right and left side. Finally, pair of hyperbolas is fitted to these data points to represent the lane boundaries as seen in fig 2.

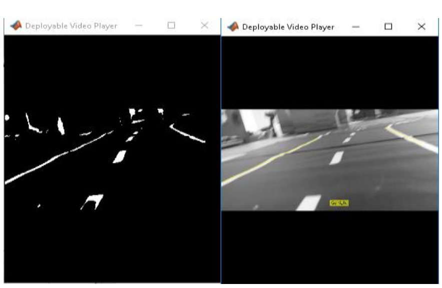

Figure 2: image processing output for PID lane keeping control

In the Simulation of lane keeping control using a PD controller and some very interesting points were revealed. It showed that controlling a car on a given lane can yield a jerky response. Hence, the introduction of PD controller was necessary to try and reduce this jerky response. The simulation was of a typical scenario where a vehicle was moving on a given lane at a constant velocity. But upon a sudden lane departure from the desired reference, the velocity is expected to change during the lane keeping maneuver. Looking at fig 3 the jerky response of the vehicle can be observed as the vehicle move further away from the desired reference, creating a very large cross track error as seen in [9], [10]. Now the goal of the controller is to reduce this cross-track error. Hence the introduction of the proportional gain P

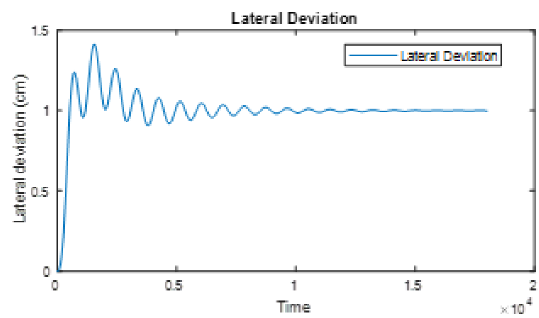

Figure 3: Initial lateral deviation showing cross track error

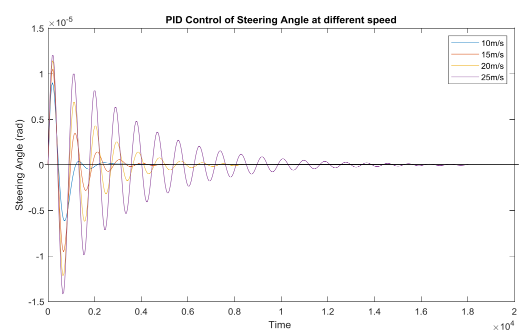

Figure 4: PD steering control performance analysis

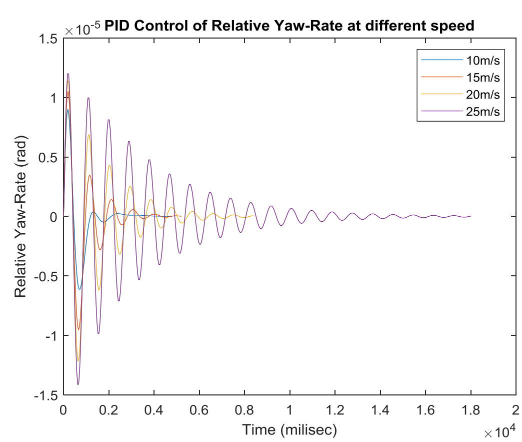

Figure 5: PD Relative yaw rate control analysis

Fig 4 and 5 shows what happens when the proportional term is introduced, the proportional control tries to steer the vehicle towards the desired reference trajectory, by reducing the cross-tract error.

The cross-track error here is defined as the measurement of how far away the front wheel is to the desired reference trajectory. It was observed that the controller tried to reduce the cross-track error as the proportional gains increased, but as a result the system spin out of control when it reached the desired reference centerline as can be seen in the figures. There was a repeated overshot, rather than follow the desired reference. To correct this overshot an update of the new cross track error was sent to the steering command, by checking how fast the vehicle is moving in the perpendicular direction to the desired reference. This was achieved by the introduction of a derivative D term to the steering command. Both the proportional and derivative gains must be tuned simultaneously. When the D term was tuned it was observed that at a low gain the overshot and oscillations recorded remained, thereby making the system underdamped. As when the gains were increased higher the same thing oscillations making the system overdamped taking longer time to correct the offsets. But a suitable derivative gain was reached as could be seen in figure 4? making the vehicle to travel closer to the desired reference but at a much lower speed. Hence, the cross-track error was greatly reduced toward zero making the system critically damped. But all these were possible at a lover longitudinal speed as seen. It can be seen also that at much higher speed the controller behavior was erratic causing overshoots. All these were done in a controlled environmental settling. But in an actual situation where certain environmental factors such as rain, road bumps wind etc. are experienced an integral term I must be introduced as to take care of all this.

During the experimentation the data of both left and right lane with respect to a look ahead distance gotten from the lane detection algorithm was sent as a control input to control the steering angle of the vehicle. Fig 6 shows the control command that was sent to the steering control. It shows the functioning of the controller based on the data/command received from the MATLAB. First of all, the data/command received from the MATLAB goes under the loop of the conditional statements that generates the control signal for the servo to control the steering based on finding a match in the sequence of conditional statements. The output of these command can be seen in fig 7 as the vehicle tries to steer itself towards the desired reference trajectory

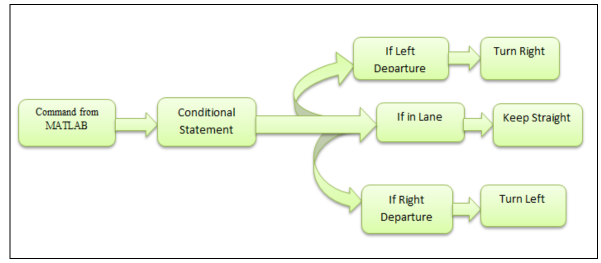

Figure 6: Lane keeping control algorithm

Figure 7: experimental cross track error result of scaled vehicle following the desired reference

5. Conclusion

The goal of this study was to understand the fundamental in the development of autonomous vehicle's lateral control dynamics using basic PI, PD or PID control for begineers and educational purposes. An understanding of these basic principles will help self driving car enthusiast build more ideas on further ways of improving lateral controllers for autonomous car. Therefore, this study was concerned with the development of a simple and basic control for lane keeping. The result of the study proved that the PD controller was able to control the steering angle of the scaled vehicle close enough to the desired reference in a closed controlled enviromental setting. But in an uncontrolled setting where certain enviromental factors come into play, an integral term I must be incoporated into the controller for proper stability of the system. The basic principles highlighted in this study can now be improved on other advanced controllers like adaptive PID, MPC, adaptive MPC controls for lane keeping purposes and other autonomous features.

Acknowledgment

I would like to acknowledge my supervisory team for their unending support in the course of my studies so far.

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