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Design and Development of Vision Based AVCS

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Abstract

Advanced Vehicle Control System (AVCS) includes both the lateral and longitudinal control of the vehicle. Tracking of lane using the physical model of the vehicle and suitable control system for the vehicle is proposed in this work. 1-D line scanning camera is used as vision system to track the black line from the white background. Lane detection algorithm uses 1-D line scanning camera values to precisely identify the position of the vehicle in the track independent of light intensity variations. The vehicle takes advantage of the adaptive nature of the Kalman filter for line tracking and effective control of the PID control algorithm for precise control over the lateral steer. Active speed control algorithm makes the vehicle to track the path smoothly with optimum speed. The control algorithms are tested in two stages. First, the vehicle is modelled to check the controller's feasibility. Second, the controllers are implemented in the prototype vehicle and their performance is analysed. The visual navigation and control system allow the vehicle to navigate and track through the lane to accomplish autonomous locomotion. Proposed algorithm reduces tracking error and minimizes the computational cost and the control action is soft and smooth.

Keywords: Visual navigation, Kalman filter, PID controller, AVCS

1. Introduction

The concept of the Intelligent Vehicle/Highway System (IVHS) is a direct descendent of earlier work on "roadway automation". Recent advances in a variety of technologies have now made automatic control of the operation of road vehicles a much more realistic proposition than it was even in the recent past. The most "advanced" and hence the most controversial component of IVHS is that group of technologies known as AVCS. These systems extend beyond the function of transferring information among drivers; vehicles and the wayside to the more challenging functions of helping the driver control his car and even relieving the driver, the responsibility for controlling his car[1].

The Mobility 2000 working group on AVCS has divided AVCS into three evolutionary stages [2]**.** The first stage of AVCS systems (AVCS I) are the driver assistance systems, which do not necessarily take control of the vehicle away from the driver. In the second stage of AVCS evolution (AVCS II), control of the vehicle can be transferred by the driver to the automatic system on certain special limited-access facilities such as High-Occupancy Vehicle (HOV) lanes. The third stage of AVCS evolution (AVCS III) extends control of the vehicle operations to the interstate and urban freeway network, using lanes that are continued to be used by conventional, manually-controlled vehicles.

AVCS is the only IVHS function that has the potential to make quantum leaps in the productivity, capacity, speed and safety of road transportation. The best current estimates indicate that the Advanced Traffic Management Systems (ATMS) and Advanced Driver Information Systems (ADIS) functions can produce improvements of no more than 10% to 20% in recurrent congestion [3] and a little more than that in non-recurrent congestion. The AVCS technologies have the potential to increase the capacity of a bridge or freeway by several hundred percent. By taking the driving function over from the driver, these technologies can also eliminate the driver-error caused accidents. AVCS includes of over 20 functions that includes adaptive cruise control, vehicle to vehicle communication, automatic steering control and several others[1].

The European PROMETHEUS program is certainly the most ambitious IVHS program currently active, with the longest-term perspective. The Personal Vehicle System (PVS), formerly referred to as the Intelligent Vehicle System (IVS), program in Japan is a relatively recent MITI-sponsored IVHS project oriented toward development of an intelligent, autonomous road vehicle. Texas A&M University has developed an autonomous road vehicle that uses a computer vision system to supply its information about upcoming road geometry, signing and obstacles [4]. The Program on Advanced Technology for the Highway (PATH) at the University of California, Berkeley is researching a wide range of AVCS technologies and will be incorporating the results of that research in upcoming system engineering activities. Traffic congestion is a world-wide problem. The Advanced Vehicle Control Systems Committee of the Intelligent Vehicle Highway Society of America has identified Research and development activities necessary to improve the performance of the surface transportation system. AVCS represent the application of sensors, computing algorithms and electromechanical actuators to provide drivers with warnings of hazards, assistance in controlling their vehicles, or fully automated control of vehicle motions [5]. The Automatic Vehicle Control System (AVCS) has been suggested to help solving this problem [6, 7, 8].

The central theme of AVCS is to improve the throughput and safety of highway traffic by using automatic control with its precision and fast reaction to replace human drivers. Human drivers have reaction time between 0.25–1.25s, which necessitates an inter-vehicle spacing of around 30 m or more at 60 m/h[5].

The functions of targeted Advanced Vehicle Control and Safety Systems (AVCSS) should be identified first. A selected list of AVCSS functions is given [9]:

- Lane departure warning
- Automated longitudinal control
- Automated lateral control
- Safety impact of coordination layer and network
- Collision warning (frontal, side, rear)
- Collision avoidance in frontal direction layers

Driving in traffic jam conditions is one of the most challenging topics of large city traffic management[10]. The data on Madrid (Spain) indicate that its almost one million workers every day waste more than 30 minutes at rush hours because of traffic jams. The estimated annual cost is more than 800 million Euros[11]. The efficient solution to all these problems is to turn towards the AVCS.

The enabling technologies for AVCS have been subdivided into categories of sensors, communication, computation, electromechanical actuators, software and systems technologies, and special tools and facilities[12].

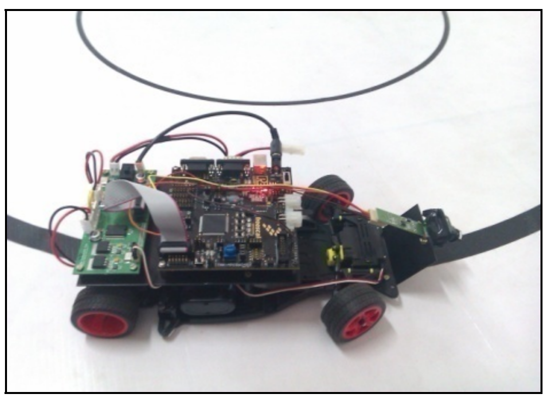
The Intelligent Vehicle/Highway System (IVHS) and Area wide Real-time Traffic Control (ARTC) had been gotten attention twenty years ago ([13], [14]). And automated highway (AHS) or cooperative vehicle highway systems (CVHS) are under development to enhance utilization, reduce journey times and improve usage of energy ([15] and the references therein). At the same time, the effectiveness of all these systems also depends on the satisfactory functions of control layer according to [13]. It is required that the performance of the vehicle control system should be safety, accuracy and effectiveness [16]. There have been many methods proposed ([17] and the references therein), including linearization plus proportional-integral-derivative (PID) [18, 19], adaptive control [20, 21], and sliding mode [22], etc. Recently, there are still a lot of works on the control of vehicles, for example, the work on how to maintain the same relative velocity and keep a certain safe distance between adjacent vehicles [23], a decentralized bidirectional control of a platoon of *n* identical vehicles moving in a straight line [24], vehicle platoons through ring coupling [25]. From the viewpoint of method, there are sliding mode to guarantee robust stability in front of disturbances and model uncertainties [26], a novel safety and efficient driving control scheme based on the regenerative braking system [27], PI-type speed controller to anti windup strategy [28]. But there is still little work on the safety and comfort control of vehicles [29]. The current work focuses on the combined lateral and longitudinal control with adaptive algorithm that works on real time feedback obtained from the operating environment.

The paper is organized as follows. Section II describes the physical model of the vehicle and the line tracking system. Section III discusses the visual navigation system, the algorithm and the simulation outcomes. Section IV provides the results on experimenting the proposed algorithm and performance comparison with other existing techniques.

2. Vehicle and System Model

The model of the intelligent vehicle is shown in figure 1. It is driven by two dc motors each of which has a gear reduction ratio of 4:1.

Figure 1: Autonomous Vehicle



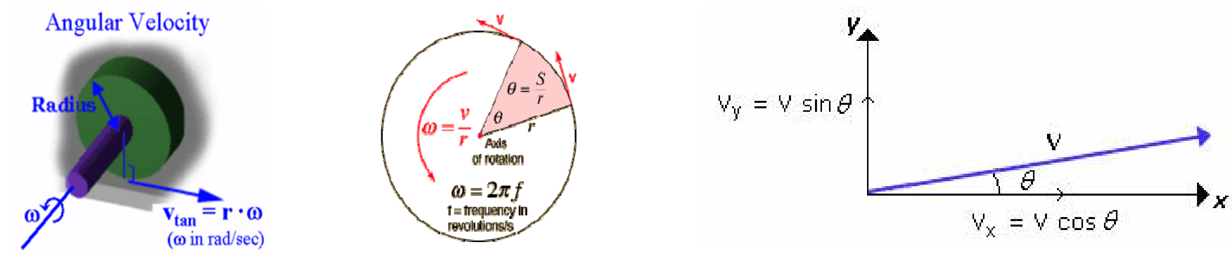
The steer of the vehicle is controlled by high precision servo motor. According to basic physics, the relation between the linear and angular velocity is given as,

$$v = r\omega \tag{1}$$

Where 'v' is the linear velocity of the vehicle, 'ω' the angular velocity.

From the values of the current velocity and the angular position of the vehicle, the position of the vehicle at any point of the track can be accurately given by the fundamental relationship between the parameters. Let 'v' be the linear velocity of the vehicle, then the relation between the linear and the angular velocity is shown in figure 2. The horizontal and vertical components of the velocity can be decomposed as shown in figure 2(c).

Figure 2: (a) (b) (c) Angular Velocity, Linear Velocity and Velocity Components



(a) (b) (c)

The horizontal and vertical component of velocity is related to their corresponding displacements as given in equations 2 and 3.

$$v_x = {dx}/{dt} \tag{2}$$

$$v_y = {dy}/{dt} \tag{3}$$

where x and y are the displacements in horizontal and vertical direction respectively. The position of the vehicle can be given by equations 4, 5 and 6.

$$x = \int_0^t v_x(t)\,dt \tag{4}$$

$$x = \int_0^t v(t) cos\theta(t)\,dt \tag{5}$$

Similarly for y co-ordinate,

$$y = \int_0^t v(t) sin\theta(t)\,dt \tag{6}$$

In differential form, it can be given in equations 7 and 8.

$$\dot{x} = cos\theta(t).v(t) \tag{7}$$

$$\dot{y} = sin\theta(t).v(t) \tag{8}$$

From equation (1), $v = r\omega$, rewriting the equation,

$$\omega = \frac{1}{r}v \text{ and } \dot{\theta} = \omega(t) = \frac{1}{r}v(t) \tag{9}$$

The vehicle model of the intelligent vehicle can be thus given as in equation 10,

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta \\ \sin\theta \\ 1/r \end{bmatrix} [v] = \begin{bmatrix} \cos\theta \\ \sin\theta \\ 0 \end{bmatrix} v + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \omega \tag{10}$$

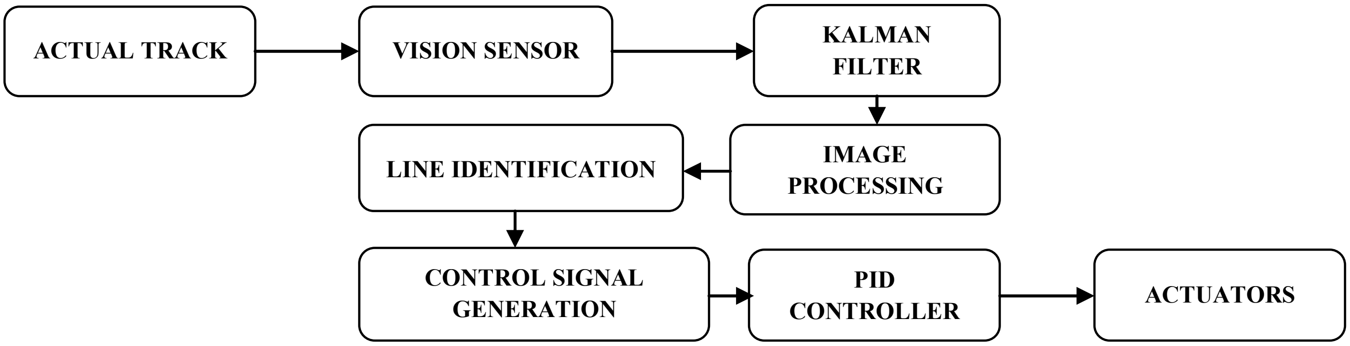
The modelled vehicle is expected to track a black line on white background. Let, x_t be the present state of the vehicle and x_{t+1} the next state of the vehicle. The vehicle is supposed to track the line without any error, thus the system is modelled as given in equation 11,

$$x_{t+1} = x_t \tag{11}$$

3. Visual Navigation System

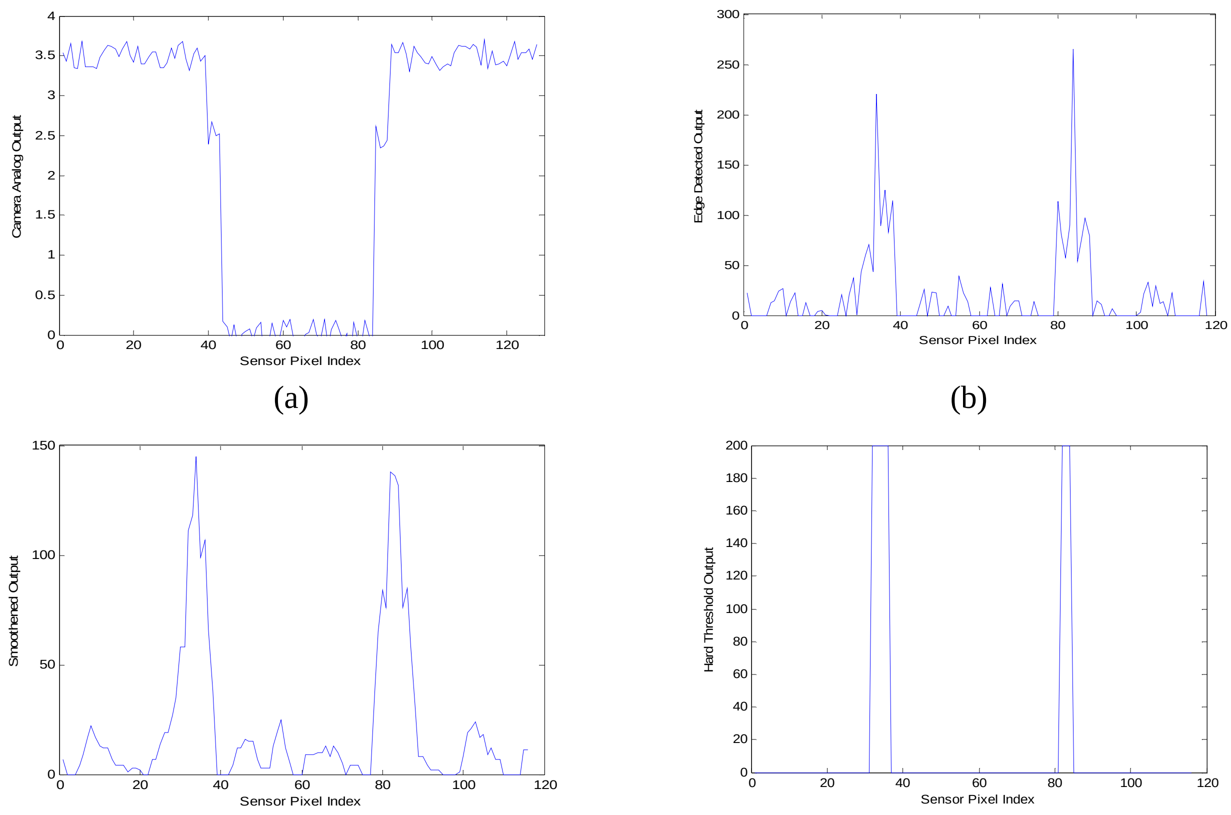
The visual navigation system has two major parts. They are (i) Active Steering Control System and (ii) Cruise Control System. The structure of the proposed active steering control system is illustrated in the figure 3. It consists of a single line scanning camera, Region Of Interest (ROI) based image processing with Kalman filter and PID controller. A single camera acquires road scenes into a one dimensional array of values. The ROI is selected such that the line identification is achieved in real time at low cost.

Figure 3: Active Steering Control System



The ROI is identified from the pixel values, which is the position of the starting and the end point of the line. From the ROI, the centre of the black line is identified and the control signal required to steer the vehicle is generated which is given to Kalman filter for noise elimination and is given to PID controller which in turn is used to steer the vehicle as shown in figure 4.

Figure 4: Processing Steps



(a) (b) (c) (d)

The figure 4(a) shows the values obtained from the sensor which is then pre processed to obtain the Region of Interest (ROI). The sensor values are subjected to various image processing techniques such as edge detection, smoothening, hard thresholding and finally the start and end position of the black line is obtained as shown in figure 4(d). From the index value of the position of the line, suitable steer value is computed by the Kalman filter and is given to the PID controller which in turn controls the servo motor based steering mechanism.

The speed of the vehicle is to be actively varied during the run time based upon the track conditions. Speed of the vehicle during the turn in inversely proportional to the sharpness of the curve. Thus the speed limit identification is the first critical requirement of the cruise control of the vehicle which assures the stability of the vehicle during steering.

From the basic laws of physics, the centripetal force is given by,

$$F = m\frac{v^2}{r} \tag{12}$$

The frictional force acting on the vehicle is given as,

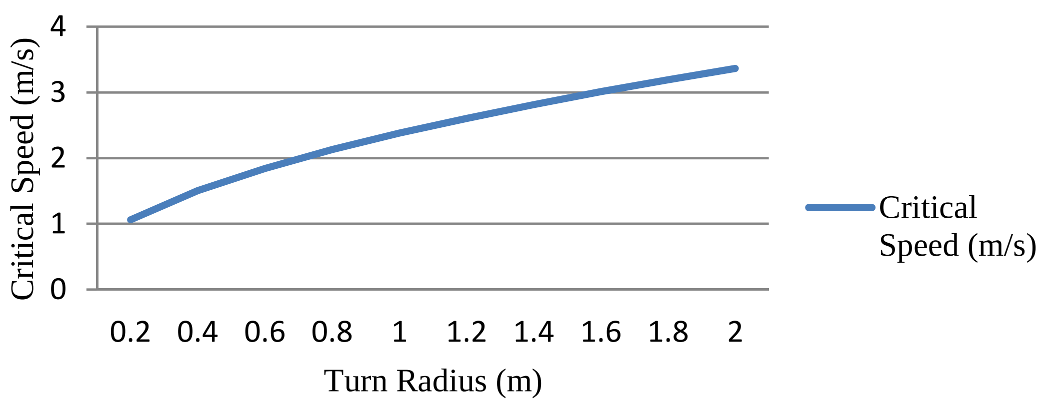
$$F = \mu m g \tag{13}$$

From the equations we obtain the result to be

$$v = \sqrt{\mu g r} \tag{14}$$

where ‘μ’ is the static coefficient of friction, ‘g’ is acceleration due to gravity and ‘r’ is the radius of the turn. The static co efficient of friction for KT board is obtained to be equal to 0.577. The relationship between the critical speed and the radius of the curve are plotted and is shown in figure 5.

Figure 5: Critical Speed vs. Turn Radius



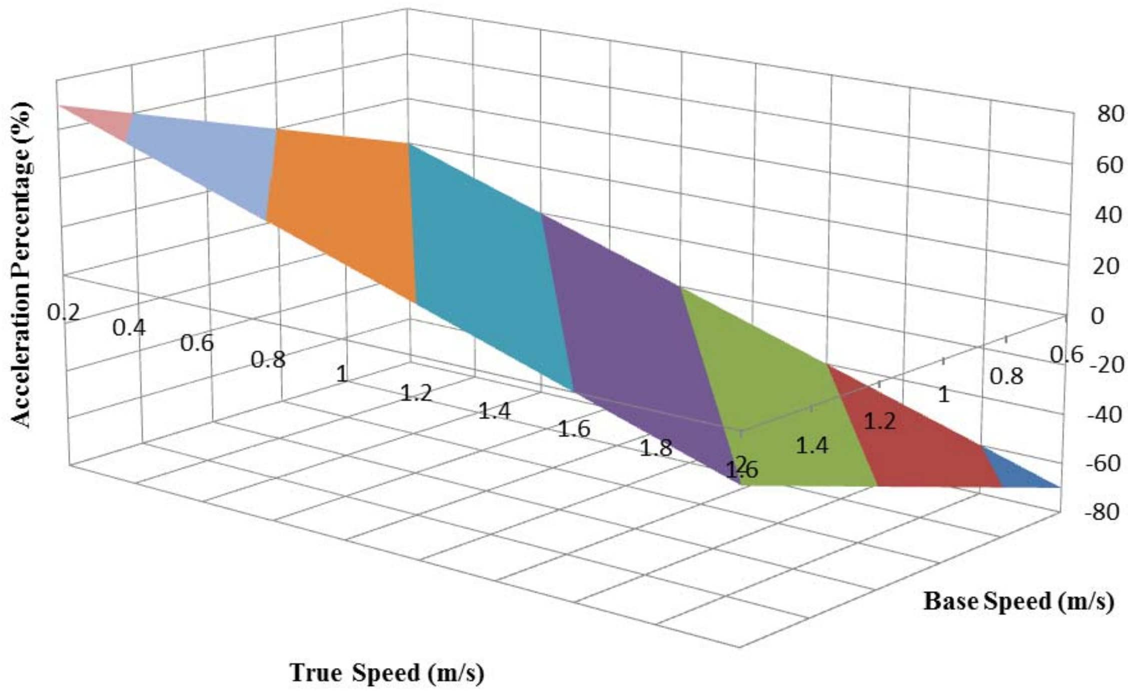
The second major constraint to be considered in cruise control is to maintain the speed of the vehicle. The speed of the vehicle varies due to various external factors such as friction during turns, variations in the track. Thus a suitable speed control algorithm is mandatory in cruise control. In the proposed method, the true speed of the vehicle is obtained as feedback current from the motors and an appropriate control algorithm alters the PWM of the motor in order to achieve the desired speed.

$$\Delta v = \mu * (Base\,speed - True\,Speed) \tag{15}$$

where ‘Δv’ is the change in velocity and ‘μ’ is the speed control parameter used for maintaining the speed of the vehicle.

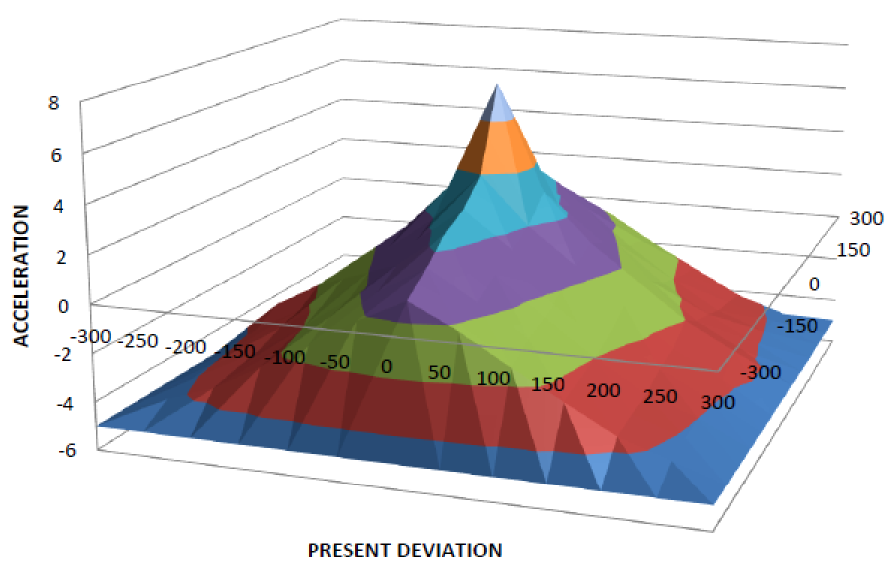
The reference speed is the ‘base speed’ and the current speed is the ‘true speed’. The difference between the two is used for speed control. If the true speed is too high than the base speed, then the vehicle is decelerated and vice versa. The possible range of acceleration (in %) with respect the true speed and base speed is plotted in figure 6.

Figure 6: Active Speed Control



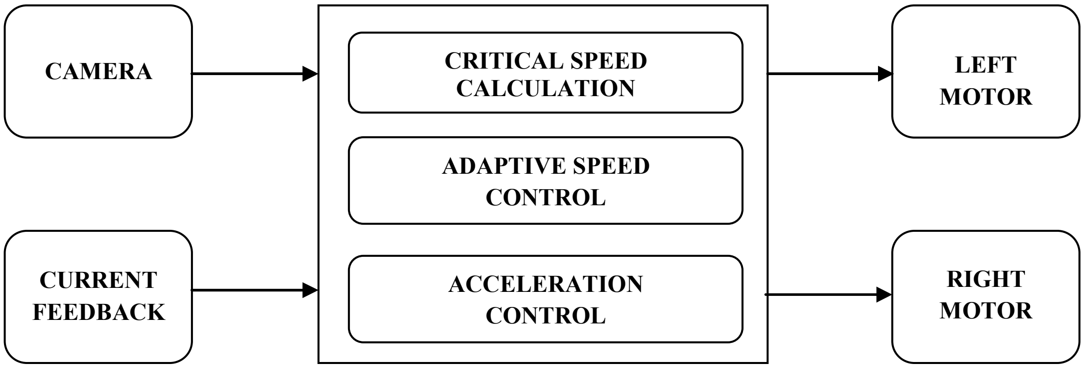
Optimization of speed in straight line is another major consideration in cruise control of the vehicle. The speed of the vehicle has to be maximised during straight line and appropriately reduced during the turns in order to achieve the optimised performance. Thus an algorithm has to be adopted for achieving this optimisation. The result obtained by the speed optimization is shown in figure 7.

Figure 7: Active Acceleration Control



The critical speed, acceleration control and the speed control together form the cruise control of the vehicle. The overall longitudinal control block of the vehicle is given in figure 8.

Figure 8: Longitudinal Control Block



4. Experimentation and Results

The active steer control and the cruise control systems are implemented in 5604B microcontroller based hardware. Upon execution, the code takes an average amount of 0.01 seconds for completing iteration, thus making it a total of 100 iterations per second.

Execution Rate: 100 iterations / sec. This high execution rate is the direct consequence of the reduced complexity of the control algorithm and it favours smooth tracking over the track as the number of samples taken is increased.

Various tracking methods such as Kalman filter, PID controller and the proposed cascaded paradigm of Kalman filter and PID controller method are implemented and their results are compared in table 1.

Table 1: Comparison of Overshoot and Undershoot among Various Methods

	PID	**Image Processing**	**Kalman filter**	**Proposed Method**
Overshoot	Present	Minimally present	Absent	Absent
Undershoot	Present	Minimally present	Absent	Absent

From the experimental results it has been seen that the proposed method is more stable than other algorithms and it works well even at high speeds where all the other algorithms failed. The '*' in figure 9 indicates the point at which the algorithm fails. The lap completion time and the tracking accuracy of various algorithms has been compared and shown in figures 9 and 10.

Figure 9: Comparison of Lap Completion Time of Various Algorithms

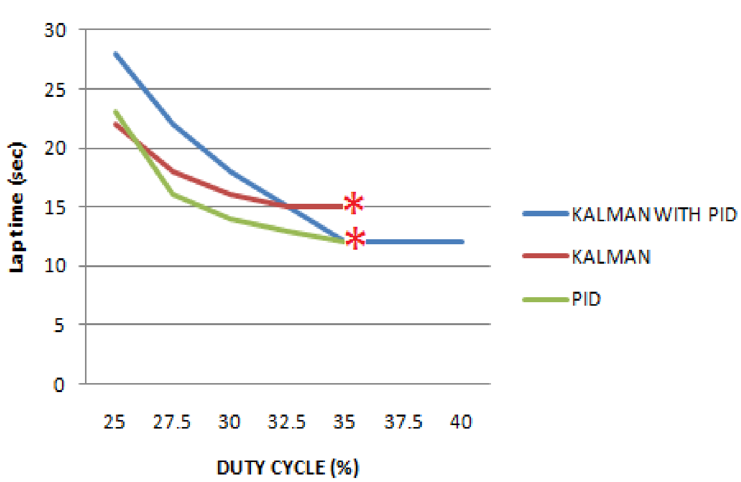
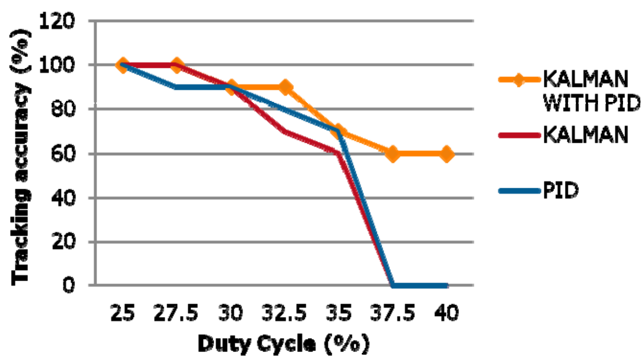


Figure 10: Comparison of Tracking Accuracy of Various Algorithms



A comparison is also made between the existing Kalman filter model and the proposed model. In Kalman filter based design, the parameter P plays a vital role as it gives the error in the estimation of the state. The value of P should be maintained as low as possible towards 0. Lower the P value towards 0, more accurate the estimated state of the system is. Thus a comparison is made among the P values of the Oscar's Method [30] and the proposed model and the result is shown in Table 2.

Table 2: Comparison of 'P' Value

OSCAR'S Method	Proposed Method
P = 0.07	P = 0.0031

Thus from table it is evident that the estimated state of the proposed model is more reliable than that of the Oscar's Method. Comparison is made between the proposed method and the already existing image based line tracking by A.H.Ismail et. al [31] and the results are tabulated in table 3.

Table 3: Comparison between Ismail's Method and Proposed Method

A. H. Ismail's Model	Proposed Model
160 X 120 camera	128 X 1 camera
NIDAQ required	-
On-board laptop	Onboard Microcontroller
1.66 GHz processor	64 MHz controller
80 GB hard disk	On-chip RAM, flash
MATLAB and LABVIEW	-
30 images per second	100 images per second
Tracking not much accurate (8 deviations)	Relatively accurate tracking (2 deviations)

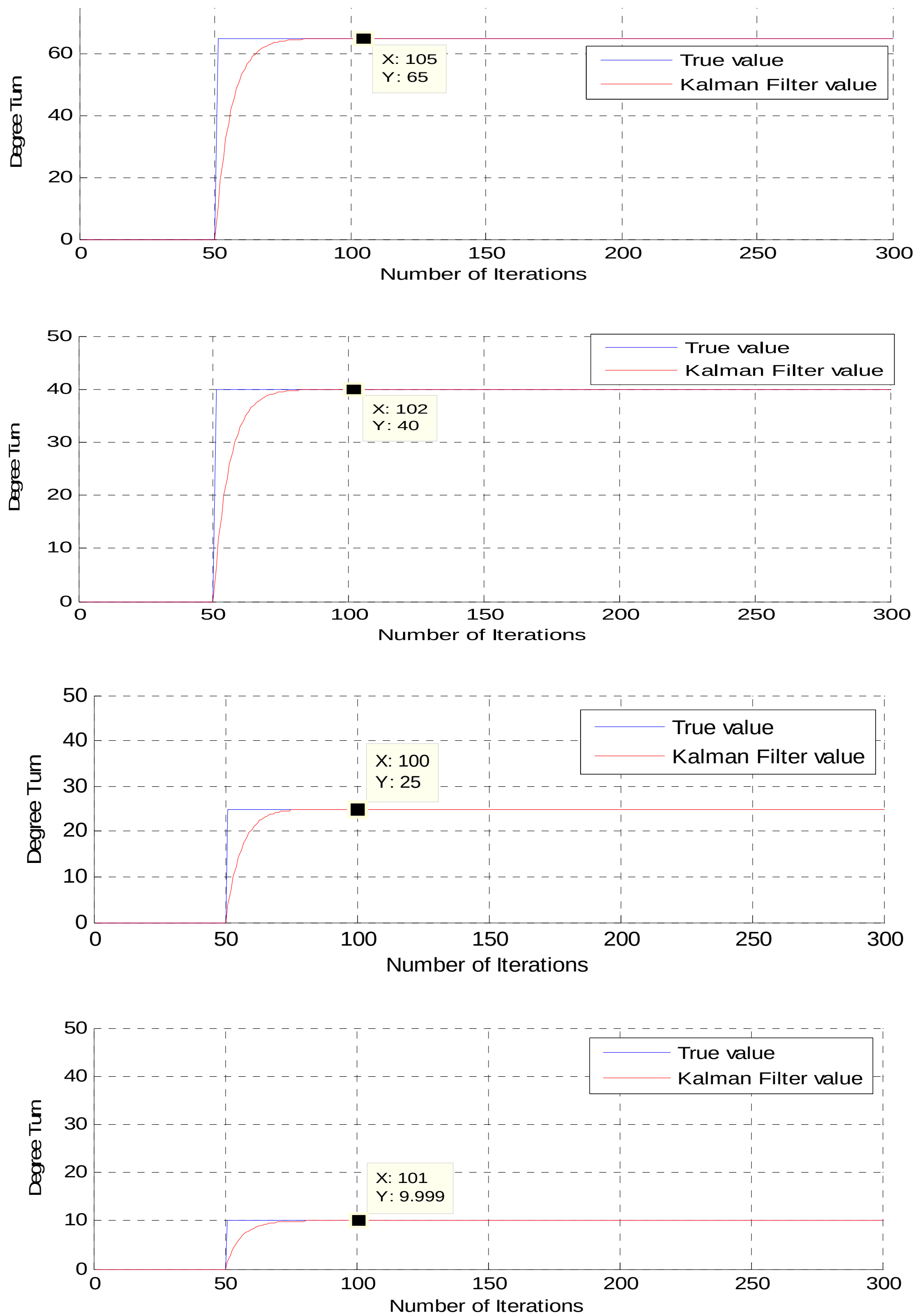
When compared to the method of Julio E. Normey-Rico et. al, [32] the proposed algorithm proves to be more efficient in terms of execution speed and the vehicle speed. The comparison is made on table 4.

Table 4: Comparison Between Julio E. Normey's Method and Proposed Method

Julio E. Normey's Method	Proposed Method
Speed = 0.4 m/s	Speed = 0.83 m/s
Sampling time = 0.2s	Sampling time = 0.01s

An analysis is made on the time taken by the autonomous vehicle to align itself with the track during a turn and from the MATLAB simulations it is clear that the vehicle consistently takes a constant time despite the turn degree.

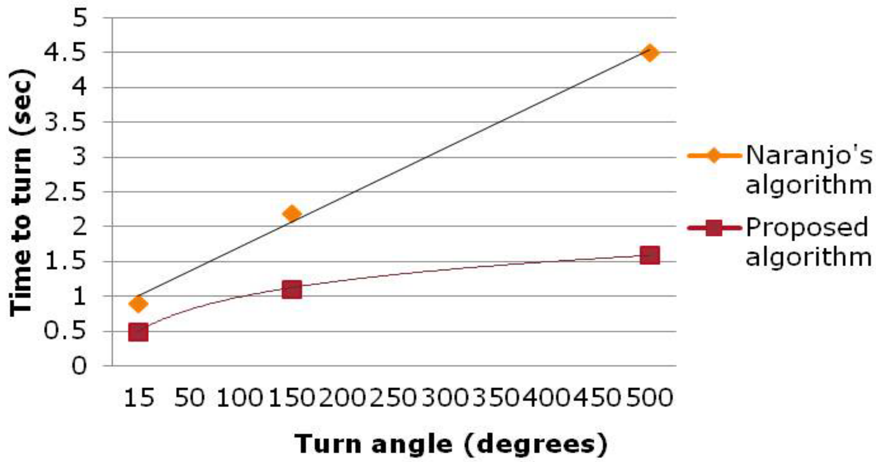
Figure 11: Number of Iterations to Settle Vs. Degree Turn



Unlike the Jose E. Naranjo et. al's method [33], where the turning time varies with respect to the turn angle, the proposed algorithm maintains almost constant time to turn all kinds of curves however sharp or blunt they might be as shown from figure 11 and the time required to turn is given by the number of iterations required to settle multiplied by the time taken for one iteration and in this case the time taken to align with any kind of curve is always nearly 0.5 seconds. This proves that, the proposed method will be of great advantage when a track with multiple sharp curves is encountered.

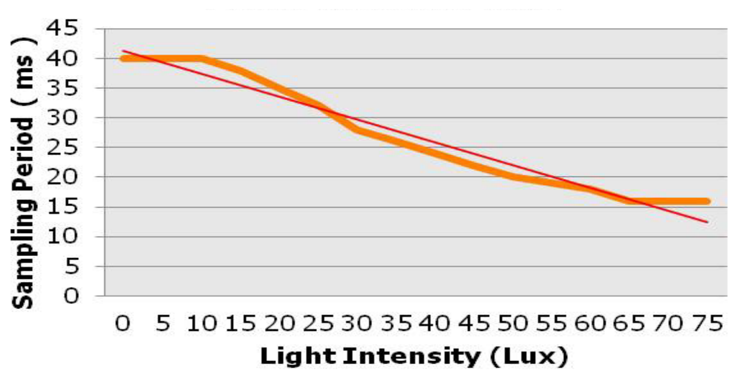
The graph in figure 12 shows that the proposed method results in faster turning compared with Naranjo's method [33] by nearly maintaining constant turning duration for a wide range of turn angle.

Figure 12: Turn Angle vs. Turning Time



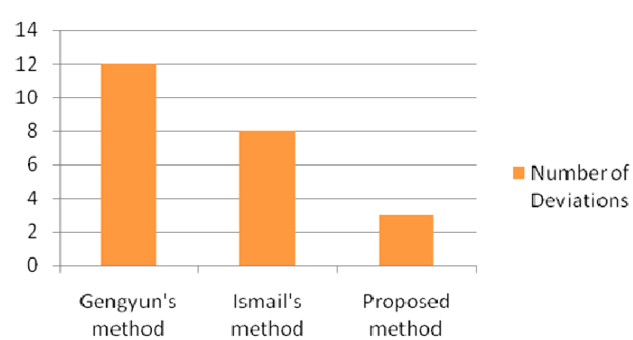
The graph in figure 13 shows the dynamic variation of integration time which is essential for adaptation of the line scan camera for the ambient lighting conditions. The integration time inversely corresponds to the brightness of the surroundings is altered based on the light intensity values.

Figure 13: Dynamic Variation of Integration Time



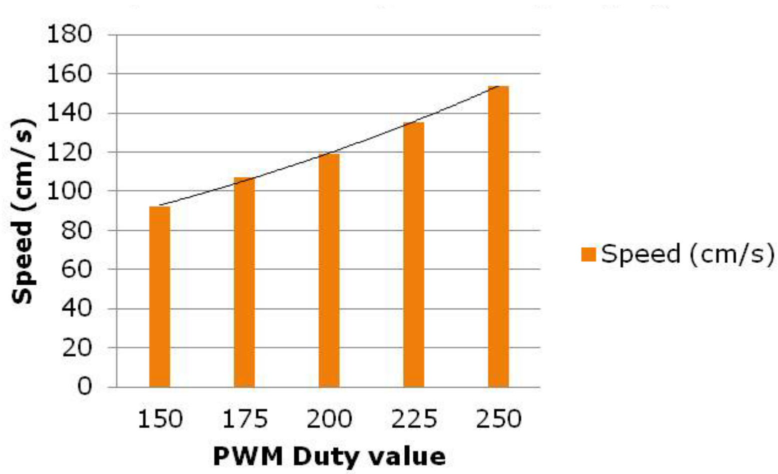
The tracking accuracy of the proposed method is compared with existing methods proposed by Gengyun et. al [34] and Ismail et. al [35]. The tracking accuracy is inversely related to the number of deviations made by the vehicle from the track during the run. The comparison results are shown in figure 14.

Figure 14: Tracking Accuracy



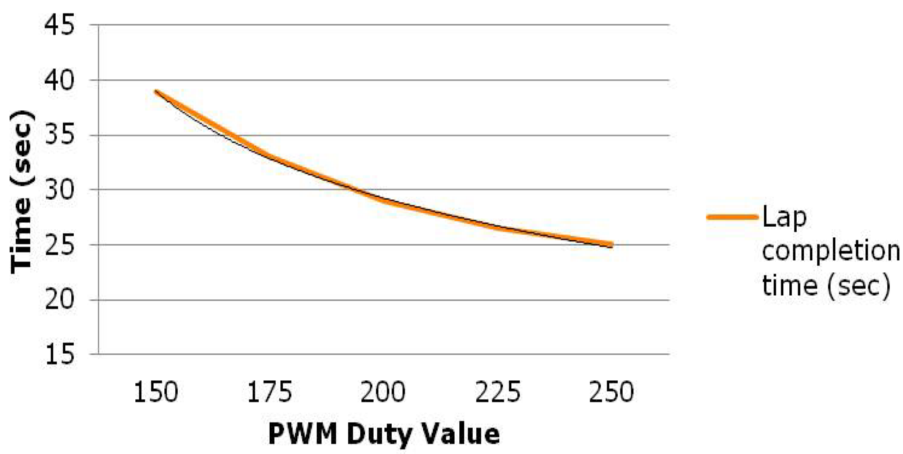
The speed of the dc motor is directly proportional to the duty cycle. The speed of the vehicle and the duty value are plotted and the result is obtained as shown in figure 15. The trend follows a linear fashion.

Figure 15: Speed Vs. Duty Value



The lap completion time of the vehicle is plotted with respect to the duty value of the vehicle and the result is obtained as shown in figure 16. As the speed is increased the lap completion time naturally increase but not in a linear manner. This non linearity is due to the cruise control algorithm which tries to maintain the vehicle in the optimum speed so as to achieve maximum stability though the base speed is increased.

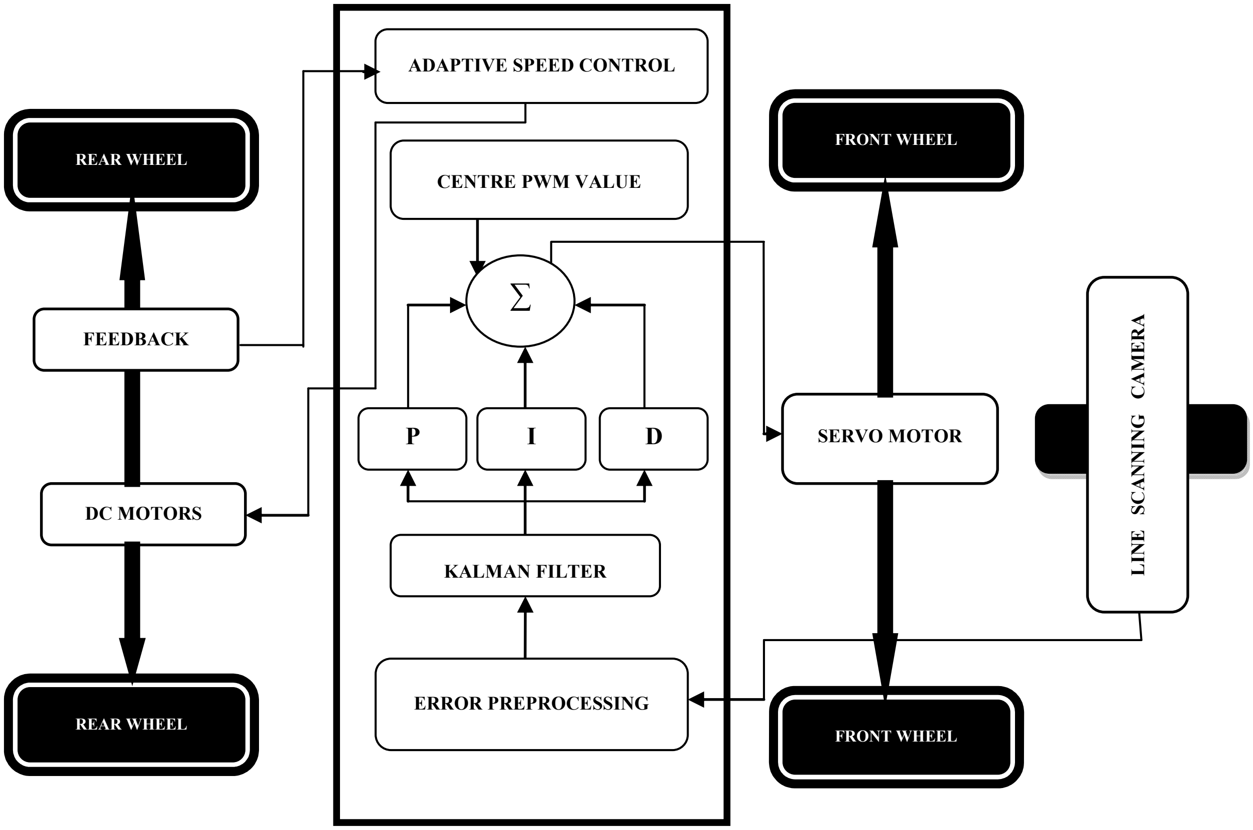
Figure 16: Lap Completion Time Vs. Duty Value



From the analysis of the results it is evident that the proposed algorithm performs better than the existing methods in terms of complexity, efficiency and the performance.

The overall block diagram of the autonomous self guided vehicle is shown in figure 17.

Figure 17: Overall Self Guided Vehicle Block

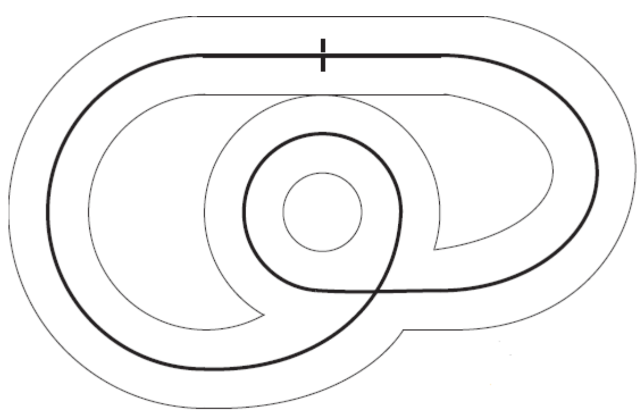


The specification of the test bed track in which the self guided vehicle has been tested in the proposed model is shown in table 5 and the test bed track in which the autonomous self guided vehicle has been experimented and tested is shown in figure 18. It is to be noted that the radius of all the curves are greater than the hardware limitation of minimum turn radius of the vehicle.

Table 5: Track Specifications

Track Length	1510 cm
Line Width	2.6 cm
Track Width	65 cm

Figure 18: Test Track



5. Summary and Concluding Remarks

The proposed method uses 32-bit 5604B microcontroller based self guided vehicle as a test bed and the performance comparison of various algorithms are made by implementing them in the vehicle on the test track. From the experimental results, it is observed that the proposed lane detection algorithm with sensor calibration techniques gives better solution for lane detection and position identification with minimal hardware complexity. The cascade algorithm of Kalman filter with PID provides more accurate steer control than the existing techniques. The proposed adaptive speed control algorithm tends to optimize the speed of the vehicle during the entire navigation. Experimental results prove that the combined lateral and longitudinal control algorithms make the autonomous vehicle to track the path smoothly with greater speed thus providing minimum lap completion time. The proposed model will be a better alternate for the existing techniques.

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