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Longitudinal Velocity Control of Autonomous Ground Vehicle using PID and PI Controller

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Abstract: An autonomous vehicle is a portable robot that combines multiple sensory navigation, intelligent decision making and control technology. This paper outlines the design of AGV control system, for controlling the longitudinal speed. In this way, a bicycle model is built to create a tracking problem and how to control the longitudinal speed in state space format. There are frictional forces that are considered while changing the velocity. PI and PID controllers are used for the speed control. By controlling the longitudinal speed of the autonomous car the results of the PI and PID controller are discussed. The relationship of speed and gas pedal position has also been obtained so as to make the journey jerk free.

Keywords: Autonomous vehicle, bicycle model, speed control, PI controller, PID controller, Gas pedal

I. INTRODUCTION

Autonomous vehicles are the future of the emerging automotive industry. An autonomous car is an intelligent robot that integrates sets of field research fields including natural understanding, pattern recognition, navigation and positioning, intelligent decision-making and computer science. We are currently working to achieve Level 5 automation.

Level 0- No Automation	Manual control. The human performs all driving tasks(steering, acceleration, braking)
Level 1- Driver Assistance	The vehicle features a single automated system (i.e. it monitors speed through cruise control)
Level 2 - Partial Automation	ADAS(the vehicle can perform steering and acceleration. The human still monitors all tasks and takes control at any time).
Level 3 - Conditional Automation	Environmental detection capabilities. The vehicle can perform most driving tasks, but human override is still required
Level 4 - High Automation	The vehicle performs all driving tasks under specific circumstances. Geofencing is required. Human override is still an option.
Level 5 - Full Automation	The vehicle performs all driving tasks under all conditions. Zero human attention or interaction is required.

Table 1: Levels of automation

Automatic vehicle tracking control is one of the most difficult automation challenges due to traffic congestion, speeding speeds, high speed performance, complex communication with the environment and a lack of prior knowledge. The car speed controller can be divided into lateral and longitudinal controls. It is basic and important to learn how to control the speed of independent vehicles. The speed and stability of the speed controller directly affect the driving systems and control the coordination of multiple vehicles [1-2]; In addition, the use of autonomous vehicles also contributes to energy savings, resource protection and other vehicle-related features [3].

The speed control of AGV is to calculate the desired speed based on the details of the car and its surroundings, and then to control the electromotor according to the desired speed and position of the car. The performance of the speed controllers should be high as there are many difficulties like the complex driving environment and the variation of the output of various vehicles.

Unlike standard cruise control systems, the AGV speed controller should handle changes between all velocities. The speed controller converts the input gas (%) which adjusts the power to the car, creates torque in the train drive, operates by connecting from a wheelbarrow to the road, and changes the speed of the car.

In this paper we are basically focusing on the variation of movement in the gas pedal or accelerator pedal with respect to velocity change to smoothen the trajectory and making it oscillation free, so that there will not be any jerk felt. The PI and PID controls have been compared. There are many benefits while using a PID controller such as, it has a simple structure, good control effect; it is powerful and easy to use. Some of the advantages of a PI controller are they do not have large overshoots and the oscillations are very small, but it takes time to reach the target as it moves slowly in nature.

II. MATHEMATICAL MODELING OF AUTONOMOUS VEHICLE

External forces and torque operating on a vehicle are of two main types: wheel contact forces and aerodynamic forces. We will introduce the car model and the tire model used in the control and derivation process. The Ackerman [19] bicycle model is a simple and effective car model that has been widely used in vehicle stability control as shown in Fig. 1. To install this model, other simplification should be considered:

1) Wheels of the same axle are mounted on a single wheel located in the center of the front or rear axle.
2) The body weight is evenly distributed on each wheel.
3) The movement of suspension, smoothness, and aerodynamic influences are ignored.

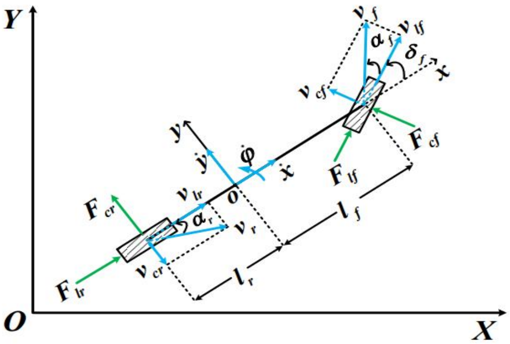


Fig 2: Bicycle model

A momentum balance is the accumulation of momentum for a control volume equal to the sum of forces F acting on the automobile

$$\frac{d(mv)}{dt} = \sum F \qquad (1)$$

with m is mass in vehicle including passengers and v is the velocity of automobile. Assuming the constant mass of the vehicle,

$$\frac{d(mv)}{dt} = Fx + Fy \qquad (2)$$

Where *Fx* is longitudinal force and *Fy* is lateral force. In this paper we are only considering the longitudinal direction movement. Therefore only *Fx* is considered.

The external condition of the vehicle being tracked is complex and has many implications. These effects are reflected in the external environment such as wind, soil and energy of another system operating in the vehicle being tracked. Suppose a tracked vehicle traveling on a long slope at an angle α with a ground plane is subjected to the following strengths: wind resistance, longitudinal slope resistance, grounding resistance, external resistance and direct speed collisions, and gravity

The symbols used in this figure are shown in the table below.

M	Moment
Cm	Centre of mass
F_{yf} / F_{yr}	Frictional force between front and back tyre
Lr/ Lf	Distance between center of mass and front and back tyre
δ	Steering wheel angle
φ	Orientation of the body in space
$\theta vf / \theta vr$	Angle between velocity vector and longitudinal axis
$\gamma f / \gamma r$	Slip angle of front and back tyre
γ	Angular acceleration

Table 2: Definition of variables used

A. Resistance of Tracked Vehicle

There, Fa is air resistance C_s air resistance coefficient, V_r relative speed, μ is ambient atmospheric density, A_r is the driving direction of the driving vehicle, $A_r = C_A B_r H_v$, H_v height of the vehicle to be tracked, Br is the track center distance, and C_A is the tracked vehicle orthographic projection area correction factor 0.8-0.9

$$Fa = \frac{1}{2}\mu C_s V_r^2 A_r$$

B. Traction of Tracked vehIcle

Under the condition that the earth is sufficiently attached, the torque of the engine is converted into traction force on the track, called engine traction force F.

$$F = F_p * u \qquad (4)$$

Where, F_p is the thrust parameter and u is position of gas pedal.

Hence,

$$\sum Fx = F - Fa$$

$$m\frac{d(v)}{dt} = F_p * u - \frac{1}{2}\mu C_s V_r^2 A_r$$

$$\frac{d(v)}{dt} = \frac{1}{m}F_p * u - \frac{1}{2}\mu C_s V_r^2 A_r \qquad (5)$$

Therefore, we have found a balance of the rate of change of speed, which will also be used to control the movement of gas.

Cs	0.24
Ar	5.0
m	700 kg
Fp	50
μ	1.225

Table 3: Values of parameters used

III. MODELING OF CONTROLER

The PID controller adjusts the control parameters, i.e., adjusts the corresponding proportional coefficient of Kp, the integral coefficient Ki and derivative coefficient Kd. The controller detects the speed deviation as an input based on the set speed of the AGV speed compared to the actual speed of the AGV.

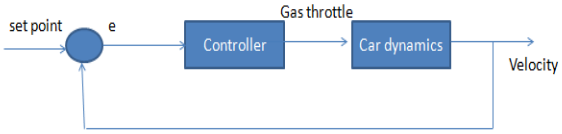


Fig 3: Block diagram of speed change of autonomous vehicle

Error, e = Set point – velocity

The error is applied to the controller and the speed controller converts a gas pedal (%) input to change the velocity of AGV. Gas pedal input changes the current to motor, creates torque on drive train. It applies thrust in the forward direction of the wheel, and tends to change velocity of the vehicle. Regenerative braking allows the gas pedal to adjust from -50% to 100%. Decreases in velocity are also due to resistive forces. Negative velocities (backward driving) are highly undesirable.

A. PID Controller

A key factor in determining the quality of a PID controller is its ability to achieve set point accurately and quickly. For this purpose all modern PID controllers have auto tune function.

The control algorithm is a continuous proportional-integrated-derivative (PID) algorithm that cannot be used directly as a controller and needs to be discretized. The PID control algorithm is presented as

$$u(k) = kp(error(k) + \frac{T}{TL}\sum_{j=0}^{k} error(j) + \frac{TD}{T} error(k) - error(k-1))$$

$$= kp(error(k) + ki\sum_{j=0}^{k} error(j) + kd(error(k) - error(k-1)) \qquad (8)$$

When ki = k_p * T / TL, kd = kp*TD / T, where T, TL, TD are sample time, integrator time and differentiator time, respectively. k = 1,2,3… sampling number, error (K-1) and error (k) are derivative signals obtained at the time of k-1 and k.

According to the recurring principle,

$$u(k-1) = kp(error(k-1) + ki\sum_{j=0}^{k-1} error(j) + kd(error(k-1) - error(k-2)) \qquad (9)$$

After subtracting eq. (9) and (8)

$\Delta u(k) = kp(error(k) - error(k-1)) + ki(error(k) + kd(error(k) - error(k-2))$ Therefore, the equation becomes

u (k) = u (k-1) + Δu (k)

B. PI Controller

To get the pi controller equation, set the value of kd = 0,

According to the recurring principle:

$$u(k-1) = kp(error(k-1)) + ki\sum_{j=0}^{k-1} error(j) \qquad (10)$$

Subtract eq. (10) with eq.(11)

$$\Delta u(k) = kp(error(k) - error(k-1)) + ki(error(k)) \qquad (11)$$

Therefore, the equation become

u(k) = u(k-1) + Δu(k)

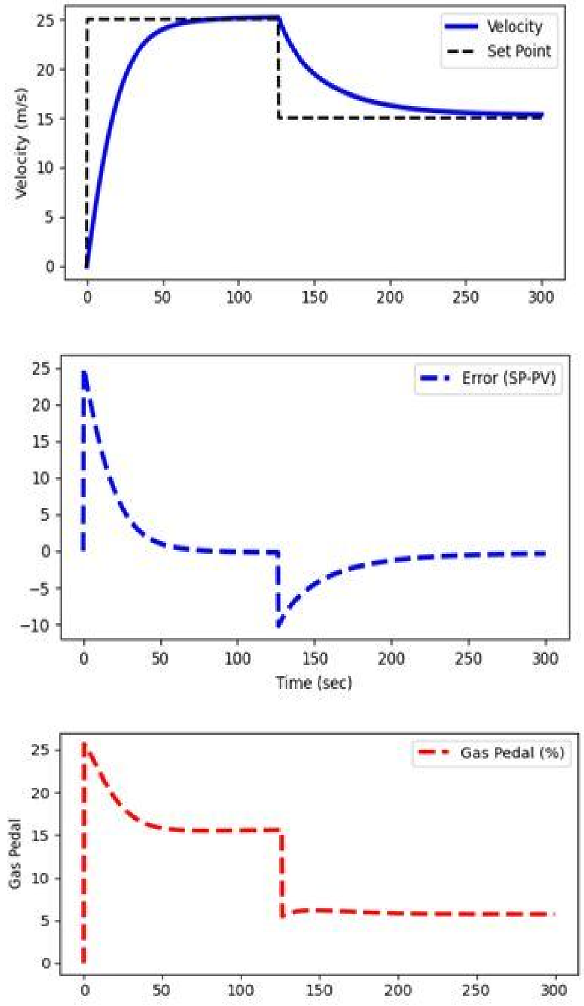
IV. SIMULATION

There are 4 graphs velocity, gas pedal position, error and integration of error with respect to time. Our main aim is to have a stable gas pedal position and reach the set point value of velocity as soon as possible. The error should also be minimum, and eventually turning to be zero. We are comparing the results obtained from the PI and PID controller.

A. PI Controller

Sampling time taken is 300, k is the system gain = 0.416, integration time constant is 40.

From the below graph, firstly velocity-time graph we can see that from 0 to 125 sec the set point is 25, and from 125 sec to 300 sec the set point is 15. As, we know the characteristic of a PI controller is that it is slow in nature. Hence, to reach the set point value 25, it takes 50 sec and then again to reach 15, it takes 40 sec. In error graph as well, we can say from that is, the error becomes zero, and the vehicle follows it trajectory without oscillations is from 175 sec.



The gas pedal position becomes stable at 125 sec. Although we have error till 175 sec, but it does not have any impact on gas pedal position and it becomes jerk free

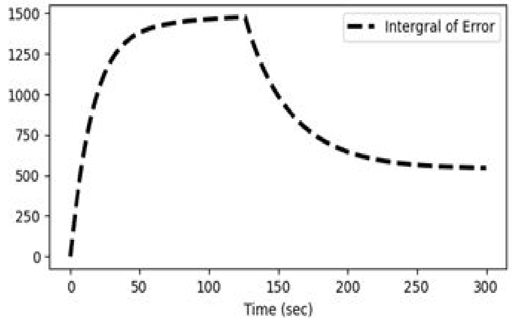


Fig 4: Velocity-time, error time, gas pedal position–time, integration of error-time graph respectively for PI controller

B. PID Controller

K = 0.416, integration time = 40.0, differentiation time=0.8,

From the velocity time graph we can see that the maximum overshoot is 35m/s , but the set point is 25m/s. The vehicle comes back to set point initially at 75 sec and then again when set point is 15, it has some oscillations and reaches the stable point after 200sec. The error is also zero after 220 sec. The variation of speed and the oscillations are very large as compared to PI controller.

We can also infer from gas pedal position graph, that it is never stable or in constant position. It becomes stable after 200 secs. That means till 200 sec there is jerk in the vehicle and also there is huge oscillation in the position as there is overshoot, which means sudden acceleration and deceleration.

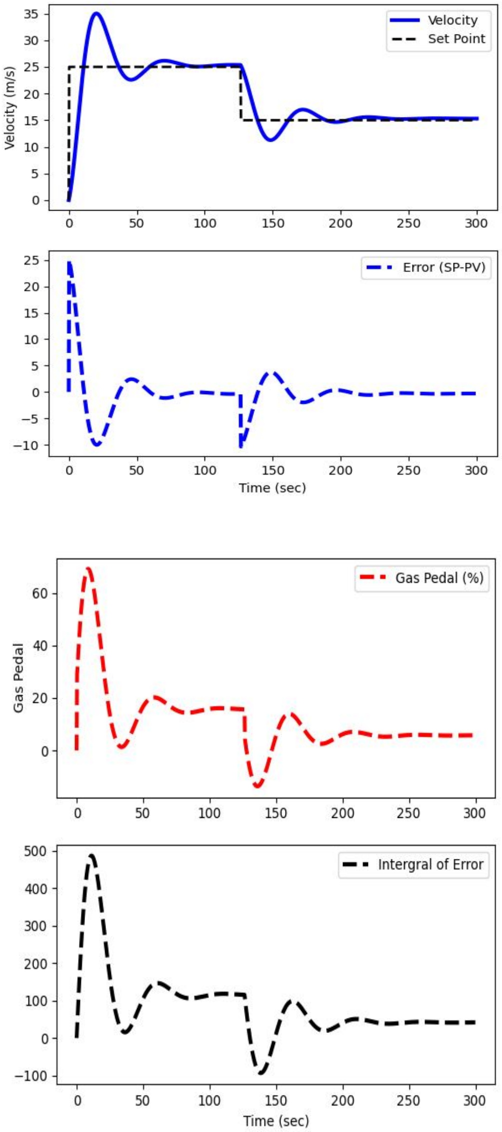


Fig 5: Velocity-time, error time, gas pedal position –time, integration of error- time graph respectively for PID controller.

V. CONCLUSION

In order to control the longitudinal speed of the autonomous vehicle, the control algorithm for both PI and PID has been given. According to the characteristics of tracked vehicle during acceleration and deceleration, the throttle brake switching rules are designed to avoid frequent switching between throttle and brake. in this paper there is a comparison between the results obtained from the PI controller and the PID controller. The graphs plotted here are velocity - time graph, error-time graph and the gas pedal position - time graph. Clearly, we can see that the results obtained from the PI controller were slow in nature. But the result obtained from PID controller had huge overshoots and also there were oscillations. The vehicle was also taking a long time to reach its final set point, and till then damping was there in the system. The set point value changes continuously with the help of lidar sensor, the time taken by the light to transmit and then to return back, tells the distance between the objects. After that set point of velocity is decided and both PI and PID controller helps to vary speed, The PI controller had a better response with respect to PID ,as the aim was to have a jerk free and stable ride. Although PI was a bit slow in nature and can be improved in future works.

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