International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Vehicle Speed Control for Autonomous Vehicle using PID Controller

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Abstract: This project presents a real time reading of Proportional Integral Derivative (PID) controller tuning. The system will control the output speed of the vehicle based on the given input speed by implementing the PID controller. The controller helps in ensuring that the output speed achieves the same as the input speed given and does not depart. The speed of car is controlled by controlling a linear motor that is attached to a current sensor and an incremental encoder as a feedback to calculate speed. The output reading of speed is in km/h. Raspberry Pi 3B+ is used as microcontroller and python language is used in order to program the vehicle speed. The vehicle is tested and PID parameter are calculated. The system is then run by using PID parameter and it shows that expected PID controller is stable and able to control the car's speed.

Keywords: Autonomous vehicle, incremental encoder, speed control system, PID

I. INTRODUCTION

Autonomous vehicle (AV) is also known as a self-driving vehicle which can be defined as a vehicle that can move independently without human input or control and capable sensing its surrounding. This driverless car would be benefit to people and the environment as it implementing artificial intelligence and an electric vehicle would help to reduce harmful gas emission to the surrounding [1]. Besides, this self-driving car help people with disabilities or even elderly people who often choose public transport or seek help of others to reach a destination [2]. In this era, intelligent vehicles are becoming more crucial due to the famous technology integrated system. Hence, speed of an autonomous vehicle system is important in order to control the brake and measured current reading of motor. The speed control is needed in every AV. In the process system, there are many variables that can change that will be causing the output reading do not achieve its desired value. The output speed must have the equal speed as the desired speed. Under other conditions, if the output speed is higher than input speed given into the program, the error signal considered negative and the motor speed will be decrease.

In nowadays technology, majority of control systems in the most industries are operated by using PID controllers. PID controller is usually used widely because of it is works precisely, easy to tuning and easy to implement in many processes. The PID controller helps to maintain and reduce error in the system [3]. Moreover, DC motor is a nonlinear device. Thus, speed can be varying because of load demand and disturbances that changing throughout time [4]. By tuning all parameters of PID, the error can be improvised in order to achieve the desired output. PID controller can regulate the input value based on historical data and it improve the error produce and make the system more precise and reach a stable system. In order to achieve required output, the parameter of PID gain values is adjusted to operate the changing process variable. The process reaction result is test without PID control; after that it will inserted to the program for its tuning process. A study by researchers [5] analyze the result of implementation of proportional (P) and proportional and integral (PI) controller for speed control. The control system parameters such as peak time, peak overshoot, settling time, rise time, steady-state error, are used to measure the speed response of PI controller and P controller. For the result, PI controller has preferred control performance than P controller for all three desired speeds that have been set. Through observation, P controller has less settling time but steady-state error arise and higher reading of overshoot in the response [6]. Thus, a PI controller is used to lessen the overshoot and steady-state error. Based on previous researcher [7], there is problem arise with servo motor which is used in order to push a rod into speed movement mechanism. The use of servo motor has an advantage on controlling the angle but servos have a bad thermal performance. The temperature of servo is easily rising and it may affect the servo's lifespan. In addition, problem is arisen as the motor's rotor in the servo is continuous moving back and forth even when it stop. It creates vibration that may affect the movement of rod into the speed mechanism. Although the reading of speed can be maintained but it can be difficult to maintain them in hazardous environments. Hence, it makes the level of robustness is lower compare to linear motor. Therefore, the aims of this project is to design a speed control of autonomous car system that able to maintain the input speed given by the controller by using Raspberry Pi controller as well as PID controller.

Manuscript published on November 30, 2019.
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II. METHODOLOGY

A. Conceptual Design

Fig. 1 shows a block diagram of speed control system. An input speed is set in the program and known as a desired input. A controller, Raspberry Pi 3B+ will process the given input and control movement of linear motor. By using pulse width modulation, the linear motor can be controlled. Linear motor is attached to the speed control mechanism. The value of voltage is sent to the motor controller and it manipulate the speed of the motor according to value of given set input. An incremental encoder is used and it is attached on the inner part of the rear wheel. The incremental encoder will give value of pulse per rotation which is then will be converted into speed on the program.

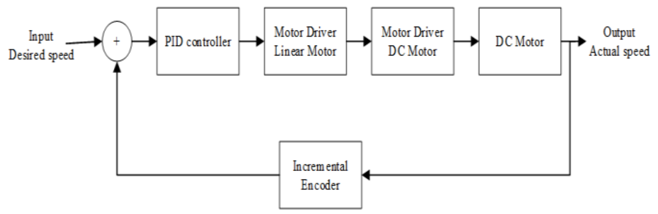

Fig. 1. Block diagram of the speed control

Hardware

Fig. 2 illustrates the hardware connection used in this project. The Raspberry Pi is supplied through an Uninterruptable Power Source (UPS). A motor driver is connected to a 36V of direct current (DC) battery and GPIO pin of Raspberry Pi. Furthermore, a 10A DC motor driver is used to moves a linear motor and it is supplied with 5V. Besides, an incremental encoder is supplied with 5V. In order to protect overflowing current, the UPS flows through a Miniature Circuit Breaker (MCB) before supply to the system. In order to step down power from MCB, a 12V switching power supply is used. Next, 12V is converted to 5V by using an adjustable step-down voltage. The DC motor is operated with 36V battery by using six 6V lead acid batteries. For the incremental encoder, two pins signal connection is used for channel A and B which is connected to pin 38 and 40 through 220ohm resistor.

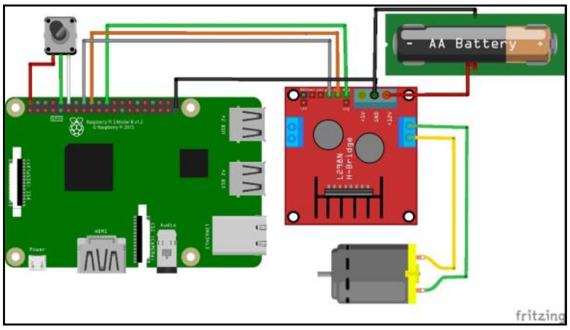

Fig. 2. Connection wires of Rasberry Pi

In this project, an incremental encoder is used as feedback speed. Incremental encoder is a device that produce a digital signal output of two squares of 90 ° out of phase. For speed and distance reading, incremental encoder is an ideal choice because it consists of rotating disk, a light source and a photodetector or also known as light sensor. It works fine as its initial counter become to zero every time the program starts. Hence, the speed can be calculated based on pulses per rotation. Fig. 3 shows a 3mm thick iron is used to attach the encoder to the vehicle's body. There are steps are being taken as to ensure the encoder is mounted neatly into the inner tire and being able to rotate smoothly.

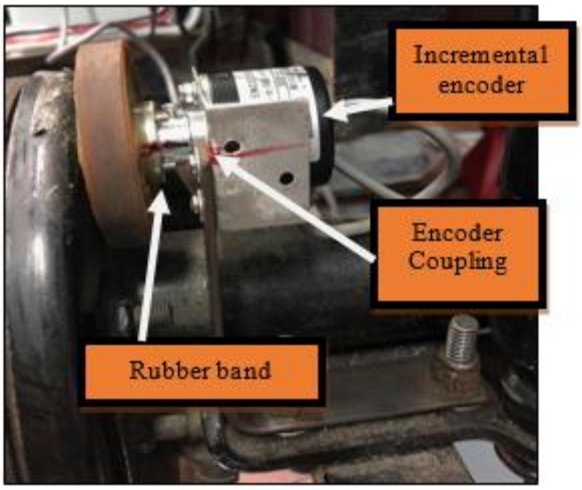

Fig. 3. Encoder and coupling mounted AV

B. Proportional Integral Derivative Controller

The main technique used in this speed control system is by applying PID controller to the system. This technique provides faster response and more control actions compared to P and PI controller techniques. PID reduces time taken to archive the set point and control reduces the effect of the disturbance. The value of gain Kp, Ki and Kd need to be calculate before implementing a tuning process for the system. For tuning process, Ziegler Nichols is used as it helps to improve response of PID curve. All the parameters are calculated by using equation in Table II. Table below shows the Ziegler-Nichols calculation on getting values of Proportional Gain, (Kc), Integral Time (T_I) and Derivative Time (T_D) for each controller type.

Majority of control systems in the most industries are operated by using PID controllers [8]. Proportional mode will speed up the process, dynamic response and makes an accelerate improvement of the manipulating variable in order to lessen error. Integral mode achieves zero offset, where there will be no steady state error. Derivatives mode contribute a speed alteration refer on the rate of change of controlled variable. Another researcher stated that overall system including P term, I term and D term commit in carry out a minimum overshoot, rapid rise time increase in stability lessen steady state error [9]. Table I shows the characteristic changes for each controller.

Table- I: Characteristic changes for each controller

Term	Rise Time	Overshoot	Setting Time	Steady State Error
Proportional	Decrease	Increase	Small changes	Decrease
Integral	Decrease	Increase	Increase	eliminate

Derivative	Decrease	Decrease	Decrease	No changes

In a research [10], the speed of DC motor is controlled by PID auto tuning method. The control system is pictured by an approximate mathematical model through system description when output is measured by precise input signal. PID controller is implemented and the P, I and D parameters are gain through auto-tuning method that normally done through MATLAB. A Simulink model is built to run a PID closed-loop control for identification system. The PID parameters are tuned automatically. As a result, PID algorithm produce a tolerable stabilize between achievement and robustness.

A comparative study has been done by using induction engine speed control for proportional P, PI, PID [11]. The operating principle is three-phase induction engine and it was precisely combined with the supply frequency which it drives to identical inverter-fed induction engine in industrial application that approve for a reliable and better equivalent study. In this research, it can be shown that benefit of P is to let 1st order equilibrium of the unstable system. Furthermore, PI help to lessen large interruption in the process and reduce noises. Last but not least, PID proves that it is the most suitable for higher order capacitive process and the suitable result related to P and PI controller to control induction motor speed.

In contrast, starting with the design of the smart car system, the conflict of PID controller itself cannot overcome. Normally, traditional control method is PID algorithm [12]. Common PID cannot adapt the changing operation conditions controller with fixed parameters even though it has simple structure and strong robustness.

C. Software

The main technique used in this speed control system is by applying PID controller to the system. This technique provides faster response and more control actions compared to P and PI controller techniques. PID reduces time taken to archive the set point and control reduces the effect of the disturbance. The value of gain Kp, Ki and Kd need to be calculate before implementing a tuning process for the system. For tuning process, Ziegler-Nichols (ZN) is used as it helps to improve response of PID curve.

Table- II: Formulation for PID tuning method

Controller type	Propotional Gain (K_C)	Integral Time (T_I)	Derivative Time (T_D)
P-only	$(1/K_P)(\tau_P/t_0)$	-	-
PI	$(0.9/K_P)(\tau_P/t_0)$	$3.33t_0$	-
PID	$(1.2/K_P)(\tau_P/t_0)$	$2t_0$	$0.5t_0$

All the parameters are calculated by using equation in Table II which shows the Ziegler-Nichols calculation on getting values of Proportional Gain, (Kc), Integral Time (T_I) and Derivative Time (T_D) for each controller type.

Magnitude of the input change, δ, magnitude if the steady state change in output, Δ, and the maximum slope of the output-versus-time plot, S, are managed to gain from process reaction curve. Hence, the parameter calculated can be implement in Equation (1).

$$G(s)=\frac{Kp}{\tau s+1}\, e^{-\theta s} \qquad (1)$$

The value of incremental encoder is in pulses. Hence, equation below is formula for converting pulses of encoder into actual speed.

$$encoder = ((counter - pulse)/500) \qquad (2)$$

$$speed = \frac{encoder \times 0.2}{0.65} \times 1.45 \qquad (3)$$

$$km/h = (distance*3.6) \qquad (4)$$

As motor rotates, the encoder will produce pulses. In order to get number of encoder pulses in one second, current pulse is subtracted with the previous reading. The number of pulses is then divided by 500 which is the encoder's pulses per rotation. Hence by using Equation 2, reading of encoder pulses per second can be obtained. Next, after getting reading from encoder, the diameter of the outer and inner wheel is calculated in order to know the distance travel and speed of car in kilometer as stated in Equation 3. Equation 4 is used in order to convert the speed from meter per second to kilometer per hour.

D. Intelligent PID

Another researcher implements an advance PID controller and named as intelligent PID controller in sequence to analyzed and control speed of BLDC motor [13]. A classical PID controller does not provides a robust performance, hence, it not suitable to work with BLDC motor dynamic model as it includes uncertainties and nonlinearities. Thus, an intelligent PID controller is implement refer on the system complexion and understanding of experts. As a result, it shows intelligent PID simulate a better result in terms of reference capture and toughness even in existence of disturbances. The intelligent PID controller eliminates the disturbances wonderfully as compared to conventional PID controller. It works when the absolute error moves towards becoming constant or smaller value, an input is appointed to control its value. Whenever absolute error values more afterwards an extensively small, the PID controller is then divert to PI controller. Thus, the static error can be reduced. In such a way, the implementation of intelligent PID Controller help to minimize error response for BLDC motor for speed control system.

III. RESULT AND DISCUSSION

Fig. 4 shows that the reaction curve of the speed of vehicle when given an input speed of 6 km/h. The system has a medium response at the beginning as speed increasing at the first 11 seconds. The speed has overshoot and poor stability. It can be observed from reading of speed in Fig. 4 where it increasing until 7.76 km/h. Overshoot of this experiment is 1.76 km/h or 29% of input speed given.

The speed is started to decrease after overshoot but it still does not show any balance input speed but it finally stables at the 7.6 km/h. After getting the process reaction curve, the PID parameters is calculated and a transfer function is obtained. Table III shows the result obtained when the speed is not controlled by PID controller.

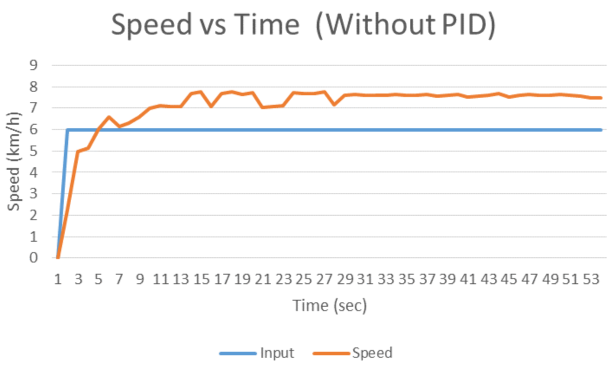

Fig. 4. Reaction curve without PID controller

Table- III: Result speed without PID-ZN

Parameter	Result
Input speed (km/h)	6
Peak speed (km/h)	7.76
Settling time (sec)	27
Percentage of overshoot	29
Steady state error (km/h)	1.5

The output speed in km/h with an approach of PID is illustrated in Fig. 5. The input given into the system is 6 km/h and being tested on vehicle. The speed fluctuated at first but increase slowly after five seconds. There is small overshoot occurs at the beginning but it becomes better at stability as the speed reach steady state around the set point at 6 km/h. This response has a small value of overshoot which is 0.27 km/h is 4.5% of the input speed.

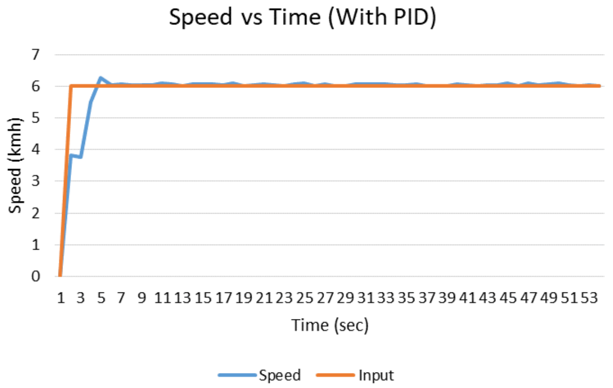

Fig. 5. Reaction curve with PID controller

As can be seen in Fig. 6, it shows the difference before and after implementing PID where it is clearly stable and able to achieve the target speed that have been programmed into the system. The overshoot of the system is lowered to 0.27 km/h and the system reaches steady state earlier compared to system of without PID. The stability of the system is gain faster compared to without PID. Thus, PID is choses for analysis because it helps to avoid excessive control action and it also can be operated within safe constrain. The proportional controller does helps to reduce the rise time. Furthermore, integral gain helps to eliminate the offset value that exists by proportional controller and last but not least, the derivatives help to correct value when there are slightly errors during steady state in the system.

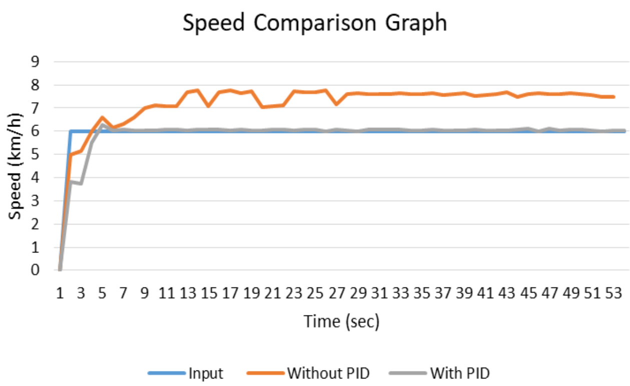

Fig. 6. Reaction curve with PID controller

By referring to Table IV, the overshoot of the system is lowered by 24.1%. The system also produces a better settling time which is at 6 seconds of the process compared to system without PID where it reaches steady value at 27 seconds. The system successfully reaches steady state at 6 km/h with tolerance of 0.02. Last but not least, the stability of the system is gain faster compared to without PID-ZN. Thus, PID-ZN is choses for this analysis because it helps to avoid excessive control action and it also can be operated within safe constrain. The proportional controller does help to lessen the rise time. Furthermore, integral gain helps to eliminate the offset value that exists by proportional controller, and last but not least, the derivatives helps to correct value when there are slightly errors during steady state in the system.

Table- IV: The comparison of speed vs controller

Characteristic	With PID	Without PID
Input speed (km/h)	6	6
Peak speed (km/h)	6.27	7.76
Settling time (sec)	6	27
Percentage of overshoot	4.9	29
Steady state error (km/h)	0.02	1.5

IV. CONCLUSION

In conclusion, proportional controller, P, helps to generate a corrective action to the error. The integral term, I, produce an improvement proportional to the integral of the error. Integral help to reduced tracking error to zero with application of a sufficient control effort while the derivative controller, D, produce a control action corresponding to the error range change. It helps to maintain the speed based on the input given in the system. The process of system with implementation of PID gain stability faster compared to without PID.

Besides, the overshoot of the system is decreases and the given input can be reach using PID system overall system is improve in all aspects. By implementation of PID, speed of autonomous car system is able to maintain. The speed of motor follows the input speed given by raspberry pi controller and observed by using incremental encoder.

ACKNOWLEDGMENT

The author would like to express her gratitude to Faculty of Electrical Engineering, Universiti Teknologi MARA Shah Alam Selangor for the support and funding.

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