MODELING AND DESIGN OF CRUISE CONTROL SYSTEM WITH FEEDFORWARD FOR ALL TERRIAN VEHICLES

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ABSTRACT

This paper presents PID controller with feed-forward control. The cruise control system is one of the most enduringly popular and important models for control system engineering. The system is widely used because it is very simple to understand and yet the control techniques cover many important classical and modern design methods. In this paper, the mathematical modeling for PID with feed-forward controller is proposed for nonlinear model with disturbance effect. Feed-forward controller is proposed in this study in order to eliminate the gravitational and wind disturbance effect. Simulation will be carried out . Finally, a C++ program written and feed to the microcontroller type AMR on our robot

KEYWORDS

PID controller, feed-forward controller, robot ,modeling and simulation

1. INTRODUCTION

Autonomous operation of mobile robots requires effective speed control over a range of speeds. In this paper, we present an adaptive speed control design and implementation for a throttle-regulated internal combustion engine on an All Terrain Vehicle (ATV), one of the platforms used within the AMOR project figure 1. This is a difficult problem due to significant nonlinearities in the engine dynamics and throttle control.

Although some of the reviewed automatic speed controllers in the literature have been implemented on production vehicles, the control techniques are not directly applicable to the ATV throttle control problem. First, the ATV's engine is mechanically controlled via a carburetor, unlike most production vehicles, which have microprocessor-based engine management systems which guarantee maximum engine efficiency and horsepower.

Second, the ATV carburetor clearances make it difficult to incorporate a sensor to measure the throttle plate angle, which is required in virtually all the automotive speed controllers in the

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literature. Third, and importantly, the automatic speed control (cruise control) of modern automobiles is generally recommended for use at speeds greater than 13m/s. At speeds below 13 m/s most internal combustion engines exhibit considerable torque fluctuations, a highly nonlinear phenomenon which results in considerable variation in engine speed and crankshaft angular speed. This makes it extremely challenging to design an effective controller for speeds below 13m/s. the ATV throttle is actuated via R/C servo instead of a pneumatic actuator, the preferred actuator in most production vehicles. Although the R/C servo setup has the potential to provide faster and more accurate throttle plate control, it provides no explicit feedback of the servo's angular position.

The disturbance due to road conditions ,engine temperature ,gearbox and steering specially at 0 m/sec speed the most important disturbance effect is the road conditions and steering effect which will be take in consideration in this papers.

Figure 1 AMOR autonomous mobile robot

The two main challenges in designing an effective speed controller for the ATV are 1) the lack of a complete mathematical model for the engine, and 2) the highly nonlinear nature of the engine dynamics, especially for the targeted low speed range of 1-13m/s. Both of these reasons make the use of classical control strategies, such as PID Controller not easy.

One of the main reasons for these challenges is the ATV's carburetor. Carburetors are general calibrated for a fixed range of altitudes and ambient temperatures. Since maximum engine efficiency and horsepower are directly related to proper carburetor setting, any significant changes in altitude and ambient temperatures require recalibration of the carburetor, a tedious task. In contrast, modern engine control systems employ microprocessor-based systems to control fuel injection and ignition point. Engine control strategies depend strongly on the current operating point, and there are no complete mathematical models of the engine parameters. As a result, most engine controllers use look-up tables to represent the control strategy. These tables are generated from extensive field experiments and engineering expertise. Therefore, it is very difficult to employ conventional control techniques that require a precise mathematical model to synthesize a speed control algorithm component for a PID controller). The operating point of the ATV's engine moves with respect to changing load conditions, slippage in the PVT and the carburetor nonlinear characteristics. Nevertheless, a PI controller can be used for higher speeds where the carburetor operation is fairly linear, i.e., throttle openings above one-half and speeds above 15MPH, covering the upper portion of our target speed range. This result indicates that a possible approach is to use more than one control strategy via lookup tables, depending on the speed range.

Another approach to the control problem is to apply adaptive control techniques. However, a complete mathematical model of the engine parameters is not available, and developing this model requires information about the engine which we were unable to obtain from the manufacturer. This approach will discuss in this paper.

2. MODELING OF CRUISE CONTROL

The purpose of the cruise control system is regulating the vehicle speed so that it follows the driver's command and maintains the speed at the commanded level as shown in figure 2 [3].

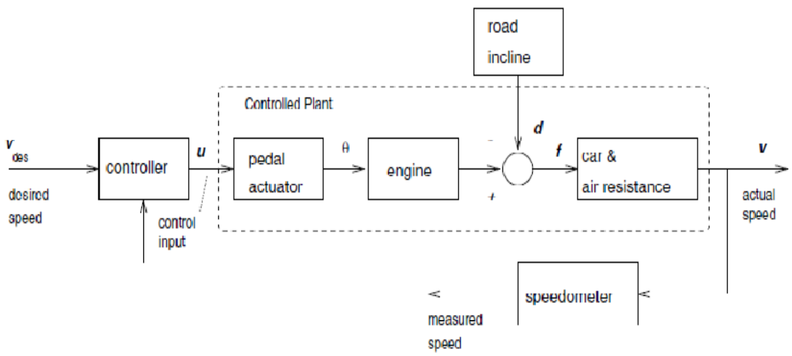

Figure 2 block diagram of cruise control system

Based on the command signal v_R from the driver and the feedback signal from the speed sensor, the cruise controller regulates vehicle speed v by adjusting the engine throttle angle u to increase or decrease the engine drive force Fd. The longitudinal dynamics of the vehicle as governed by Newton's low (or d'Alembert's principle) is.

$$F_d = M\frac{d}{dt}v + F_a + F_g \tag{1}$$

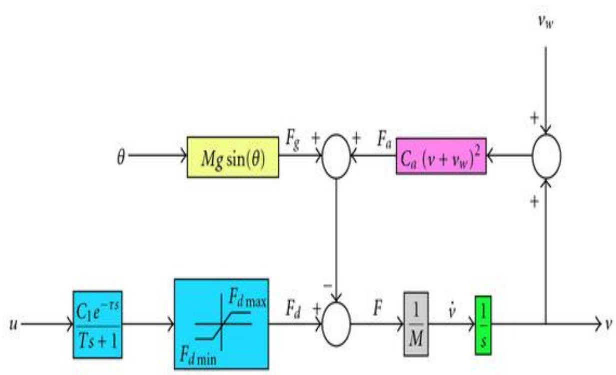

Figure 3 AMOR robot longitudinal by dynamic model

Where $M\frac{d}{dt}v$ is the inertia force, Fa is the aerodynamic drag And F_g is the climbing resistance or downgrade force. The forces Fd, Fa, and Fg are produced as shown in the model of Fig. 3 [1], where $v_w$is the wind gust speed, M is the mass of the vehicle and passenger(s), θ is the road grade, and *Ca* is the aerodynamic drag coefficient. The throttle actuator and vehicle propulsion system are modeled as a time delay in cascade with a first order lag and a force saturation characteristic

$$F_g = Mg\sin\theta$$

$$F_a = C_a(v - v_w)^2$$

The actuator and the vehicle propulsion system are modelled as cascade temporary lag of first order

$$\frac{C_1\, e^{Ts}}{1 + Ts}$$

And a saturation force feature due to the engine physic limitations (Fd is limited between Fd min and Fd max).

The controller design for this system begins by simplifying the model. Consider to set all the initial conditions to zero.

The same applies to the disturbance parameters. Hence, it is assumed is no wind gust and no grading exists during the movement of the car. Applying this zero initial condition to the block diagram, the model is left with the forward path and the unity feedback loop of the output speed. Since the state variables have been chosen to be the output speed and the drive force, the corresponding state and output equations are found to be :

$$\dot{v} = \frac{1}{m}(F_d - C_a v^2) \tag{2}$$

$$\dot{Fd} = \frac{1}{T}(C_1 u(t-T) - F_d\,) \tag{3}$$

$$y = v \tag{4}$$

However, a problem of non linearity arises. There is a squared term in the equation (2). One way to overcome this problem is to linearize all of the state-equations by differentiating both left and right hand sides of the equations with *M*, *Ca*, *C1*, *T* and *v* remain constant. After differentiating, the state-equations become

$$\frac{d}{dt}\dot{v} = \frac{1}{M}(-2C_a v\,\delta v\; - \delta F_d) \tag{5}$$

$$\frac{d}{dt}\dot{\mathrm{F}}\mathrm{d} = \frac{1}{T}(C_1\delta u(t-T) - \delta F_d\,) \tag{6}$$

and the output equation becomes

$$y = \delta v$$

In the equation, δv means that the output is discrete and δFd also means that drive force is discrete. The symbol v means the desired and $\delta u(t\text{-}\tau)$ is the time delay of the engine. Up to this point, both the state and output equations are written in time domain. The linearized model provides a transfer function can be obtained by solving the state-equations for the ratio of $\Delta V(s)$ / $\Delta U(s)$.

$$\frac{\Delta V(s)}{\Delta U(s)} = \frac{ae^{-\tau s}}{(s+b)\ (s+d)} \tag{7}$$

$$a = \frac{C1}{MT}\ b = \frac{2Cav}{M}\ d = \frac{1}{T}$$

Where

It is obvious that the system described by this transfer function is second order system with time delay. Because the complexity of the system and the poor of the engine parameter system identification tool used to define the system transfer function .From system identification

$$G(s) = \frac{\Delta V(s)}{\Delta U(s)} = \frac{0{,}0144e^{-0.001s}}{s^2 + 0.018s + 0.006}$$

3. CONTROLLER DESIGNE

The problem of cruise control system is to maintain the output speed *v* of the system as set by input signal base on the command signal *vR* from the driver. Cruise controller design is applied assuming a single-loop system configuration with a linear model and nonlinear model, as shown in Fig. 4. The controller function Gc(s) is designed to augment or modify the open-loop function in a manner that produces the desired closed-loop performance characteristics. The plant functions Gp(s) represent the actuators and the controller part of the system, and the plant parameters are determined primarily by functional aspects of the control task.

Before make any decision of controller design, a few of design specification have been set. In this design, we take two considerations to be met which are settling time *Ts* less than 1s and percentage of overshoot *%OS* is less than 20%.because the system is nonlinear system proportional-integral derivatives (PID) with feed-forward designed used for this proposed .

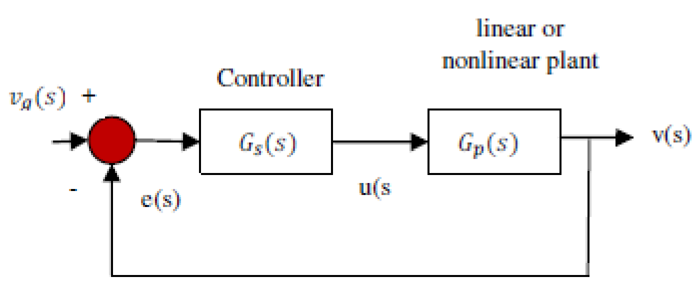

Figure 4 cruise control system configuration

Nonlinear model using PID controller is design of the controller has been based on use of the linearized model. Although a simple and quick check of the design, a more accurate simulation should be done by applying the controller to the original nonlinear model as shown in Fig. 3.

The PID controller that take in consideration figure 4 describe as $\delta u(t) = A = k_p e(t) + k_i \int e(\tau)\ d(\tau) + k_d \frac{de(t)}{dt}$ (8)

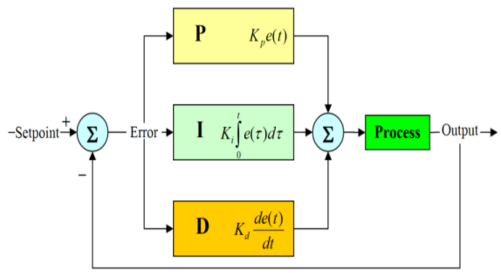

Figure 5 PID controller applied to the nonlinear plant

The basic concept of feed-forward (FF) control is to measure important disturbance variables and take corrective action before they upset the process to improve the performance result. the main disturbance acting on our system is the road incline and the steering effect specially in when the robot start from zero speed this disturbance will take in consideration. A feed-forward control system is shown in Fig.6, where disturbances are measured and compensating control actions are taken through the feed-forward controller. Deviations in the controlled variables can be calculated as:

$$\Delta v\ = GpGff\Delta D + Gd\Delta D \qquad (9)$$

In order to make Δv zero, a feed-forward controller of the following form is designed. Supposed that,

$$Gd = \frac{Kd}{(\tau_d s + 1)} \qquad (10)$$

$$Gp = \frac{Kp\ e^{-\tau s}}{(\tau_{p1} s + 1)(\tau_{p2} s + 1)} \qquad (11)$$

Then from equation (16-17), the ideal feed-forward controller,

$$Gff = -Gp^{-1}Gd = Kff\frac{(\tau_{p1} s + 1)(\tau_{p2} s + 1)\ e^{-\tau s}}{(\tau_d s + 1)} \qquad (12)$$

Where feed-forward controller gain is $Kff\ = \frac{-Kd}{kp}$. In process plant applications, Gff is typically chosen to be of static form, and it is this approach that will be adopted in this project.

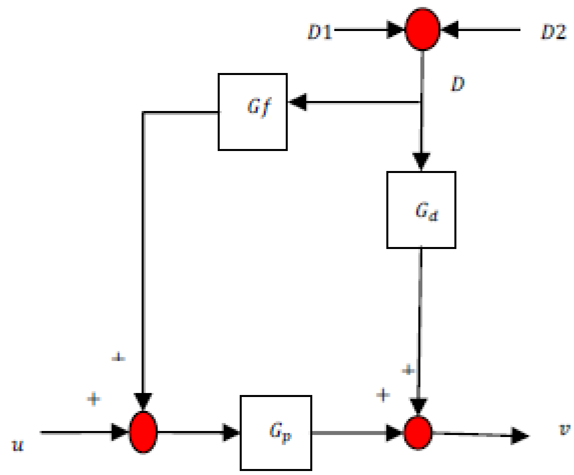

Figure 6 a feed-forward control system

4. EXPEREMENTS AND RESULTS

The system is modeled using Matlab/Simulink as shown in figure.7 to investigate and to find the parameters of PID controller (Kp,Kd,Ki) and the feed forward controller gain due to the road incline which changes with changing the operating point and for each operating point there is new feed-forward gain as it shown in look-up table.1. For the disturbance from the steering system there is also effect on the system so a new gain should apply to the system for each operating point and table 2 shows the gain with the steering angle .

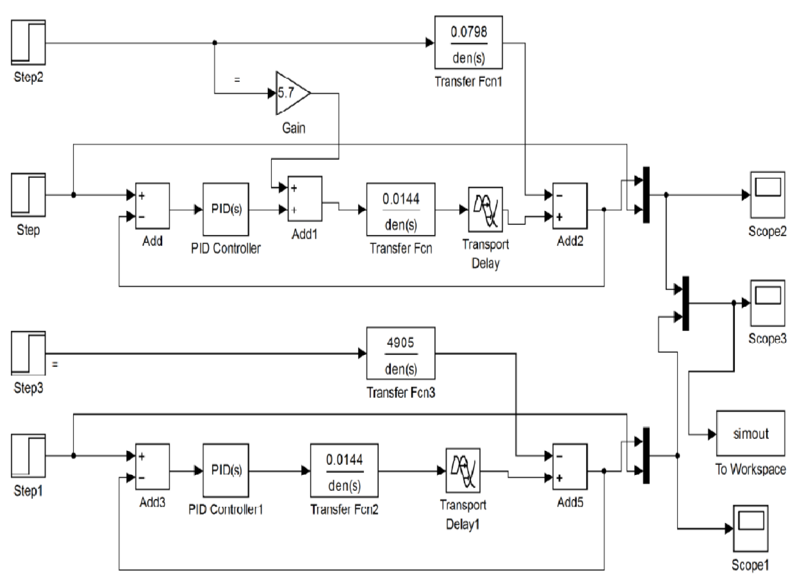

Figure 7 block diagram of simulate cruise control with FF

For implement the PID controller on AMOR Robot with feed-forward control a program written in C++ by taking the sensors value and compare it with the reference value and calculate the error, for feed-forward a function written to take the value from look up table when the disturbance from road and from the steering occur and measured before it effects the system,

Angle	**Gain(Kff)**
4.0	5.7
5.0	7.0
6.0	8.0
7.0	9.0
8.0	10.0
9.0	11.0
10.0	12.0
12.0	14.0
14.0	16.0
15.0	17.0

Table 1 Road incline disturbance lookup table

Angle	**Gain(Kff)**
0.0	6.5
10	6.0
40	7.0
80	2.0
96	0.0
127	0.0
140	0.5
150	0.5
160	0.5
170	1.5

Table 2 steering disturbance lookup table

many experiments has done to get the best result for the cruise control of AMOR robot and as shown in figure 7 the simulated cruise control system by using PID controller with feed-forward to cancel the effect of the disturbance from the road incline and from the steering and figure 8 shows how is the system signal if we used the PID controller and if we did not use the PID controller it show that the signal is speed up over the reference speed but with PID controller it still in near the reference speed with small error .Figure 9(b) illustrates the real system signal during the driving on the flat and up and down hill with using PID controller without feed-forward and figure 9 (a) shows the PID controller with feed-forward controller with 2.5m/sec reference speed. Table 3 shows the controller parameters and specifications that meet our design specifications .

parameters	value
P	6
I	0.45
D	0.00
K_{ff}	5.7
Rising time	0.120 millisecond
Overshoot	8.92%
Steady state error	0.00

Table 3 controller Parameters and specifications

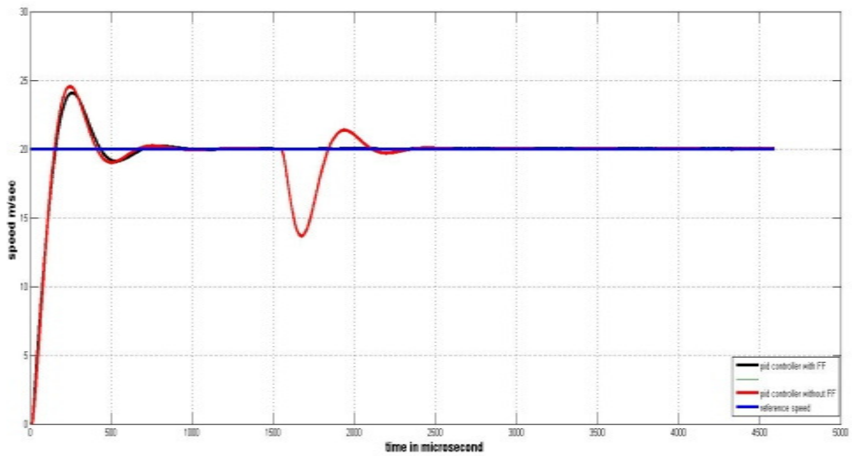

Figure 7 simulated PID controller

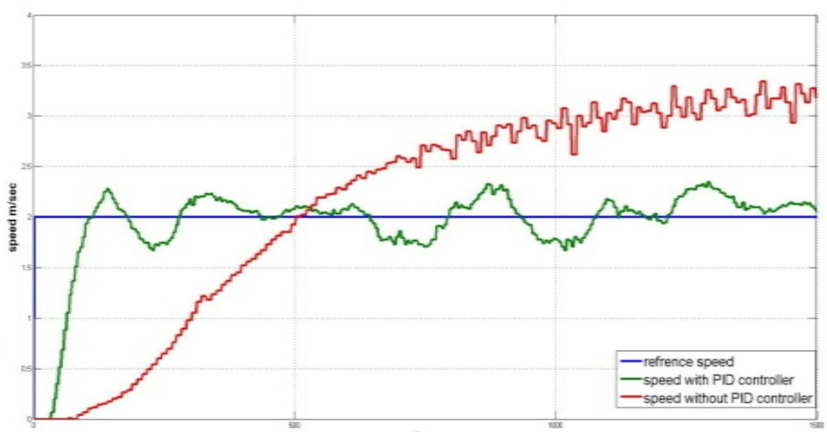

Figure 8 the real system with and without controller

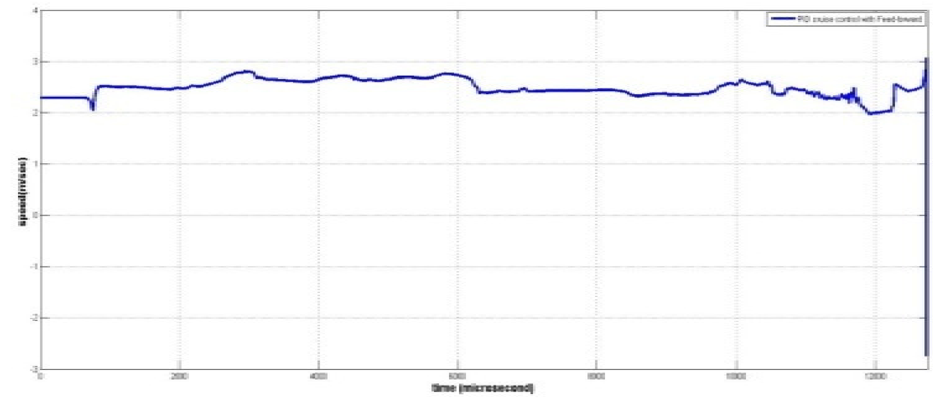

Figure 9 (a) PID controller with Feed-forward

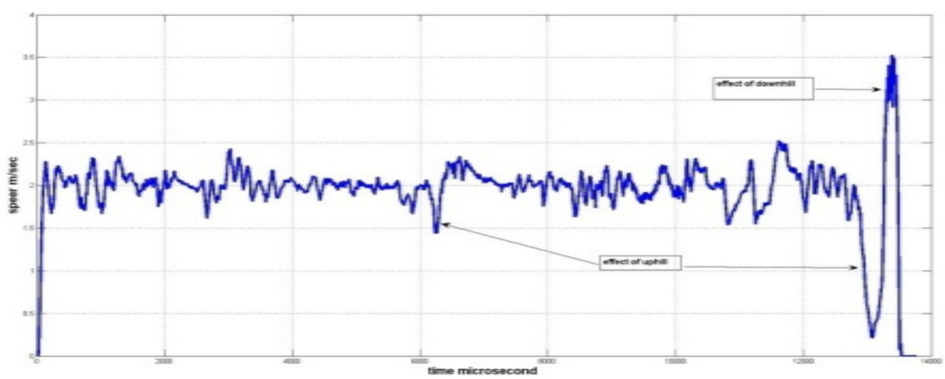

Figure 9 (b) PID controller without Feed-forward

6. CONCLUSIONS

The mathematical model for cruise control system has been derived successfully .simulated cruise control system for our plant (AMOR robot) and the effect of disturbance from the incline road and from the steering is also simulated and the parameters for the PID controller and for the Feed-forward controller that meet the system specification estimated . This result from the simulated model feed to the real system by written a program in C++ language and upload the C++ code to the AMR Robot microcontroller and the best results that meets our system specification and overcome the effect of disturbance is achieved .

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