ADAPTIVE PID BASED SPEED TRACKING CONTROL OF DC MOTOR

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ABSTRACT: *This paper presents a study on the speed tracking control of DC Motor that is developed by using an Adaptive Proportional-Integral-Derivative (APID) control structure. The APID controller is used due to its ability to solve the drawback of conventional PID controller. DC motor system and proposed controller was simulated using MATLAB-Simulink software. Several tests such as step function, sine wave function and saw tooth function were used to examine the performance of the proposed controller. Several speed inputs were used to evaluate the performance of APID controller in term of percentage of overshoot (5%), rise time (0.25 second) and settling time (0.5 second). The results showed that the proposed control structure has the ability to achieve targeted speed control with a good response. The DC Motor test rig were used to investigate in real time experiment for the ability of the proposed controller structure by comparing simulation APID with experiment APID controller. The results show that the proposed control structure proves to be able to track the desire speed with acceptable error.*

KEYWORDS: *DC Motor, Adaptive PID, Speed Tracking Control*

1.0 INTRODUCTION

The electrification trend in automobile technology has led to modern vehicles converting components powered by conventional energy sources to components powered by electricity. Furthermore, the evolution of electric vehicle (EV) demand catalyses the contribution of electrification in automotive technology. As previously stated, conventional vehicles rely on mechanical and hydraulic systems to offer motion applications such as steering and braking. Although while the systems which are very powerful, they can be overly intricate, wasteful, and prone to wear and tear during their lifespan. Automotive mechatronic technology is being implemented in today's new vehicles to solve the shortcomings of the conventional system [1].

The introduction of mechatronic and intelligent systems is considerably replacing traditional mechanical/hydraulic mechanism linkages in vehicle operation. Electronic and electric components, which are integrated with mechanical components in the production of modern vehicles, are being improved from the vehicle powertrain to the auxiliary system. With the advancement of EVs towards intelligent vehicles, systems such as X-by-wire and in-wheel drive systems have been predicted. As a result, the electric motor becomes a necessity in this system. Electric motor is an important element in vehicle and one of the importance components of actuation in the automotive industries. The electric motor converts electrical energy into mechanical energy into a form of rotational motion [2]. The electric motor used in the automotive application should have characteristics such as high starting, high power density, and good efficiency. In the industrial realm, electric motor operation includes electric cars, robotic actuators, paper machines, and residential appliances [3].

In general, there are two types of electric motor that widely used which is DC motor and AC motor. DC motors are widely use in the automotive application because of its low initial cost, simple control of motor speed and high reliability [4] as compared to the AC motors which is less efficient at low speeds, making them less suitable for low-speed applications such as starting and stopping [5]. Several researchers have done investigative studies on DC motor. [6], [7] study the DC motor braking system by controlling the speed and brake the motor. While in [7], DC motor are used as in wheel motor drive to operate an electric vehicle during emergency braking. Thus, many DC motor applications exist worldwide in the commercial and industrial sectors. For effectiveness of DC motor operation, a DC motor control strategies is crucial in applications where precision and protection are necessary [8].

In DC motor operation, conventional controller is extensively used such as Proportional-Integral (PI), Proportional-Derivative (PD) and Proportional-Integral-Derivative (PID) controller. Form listed controller, the PID controller are frequently employed in the DC Motor [9]. However, these controllers only deliver excellent efficiency within a specific operating range and if that range is changed it will affect the performance considerably [10]. Some application of DC motor requires more advance control strategies of position and speed control. Thus, controller in providing an optimal operation and reduce the drawback produce by conventional PI, PD and PID controller of a DC motor are needed. Control design such as, Adaptive PID, Fuzzy Logic Control (FLC), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO), are the most techniques that are applied to control the speed of DC motors to reduce the limitation terms in the classic PID controller [11].

In this study, PID controller is known as the most utilized in the control strategies of DC motor in controlling both speed and position. However, due to the characteristic on non-linear of the DC motor, controller such as conventional PID controller unable to provide efficiency because of the several factor such as set point changes and for tuning the PID controller are quite difficult under the situation [12]. To address this issue, variety of methods are used in designing control strategies to obtain a better response of DC motor. In this study, the proposed control strategy for the DC motor speed tracking is the adaptive PID (APID) controller. Traditional PID controllers operate with fixed gains, assuming a static system model. However, in real-world scenarios, DC motors often experience varying dynamics, such as load fluctuations and aging effects. The adaptive PID-based speed tracking control addresses this challenge by dynamically adjusting the controller gains. This adaptability ensures that the controller can respond effectively to changes in the motor's behavior, ultimately improving the accuracy of speed tracking. Adaptive control-based PID controllers are used because PID controllers are proven to work effectively in numerous situations especially in automotive technology where they are simple to maintain and implement simulation and experiment conducted [13]. The contribution of work in adaptive PID based speed tracking control of DC motors lies in the development and application of a control algorithm that adapts to the varying dynamics and parameters of the motor system.

This paper is structured as follows: the first section contains the introduction and a review of some related works, followed by the mathematical modelling of a DC motor model in the second section. The third section then presents the proposed control structure for the speed tracking control of the DC motor. The next section provides a performance evaluation of the proposed controller strategy by comparing it with a simulation and experiment control structure. The final section is the conclusion of this paper.

2.0 DC MOTOR MODELLING

DC motor consist of two components, namely mechanical and electrical. Figure 1 illustrate the free body diagram of the DC motor electric circuit, where the rotor and the shaft are assumed to be rigid.

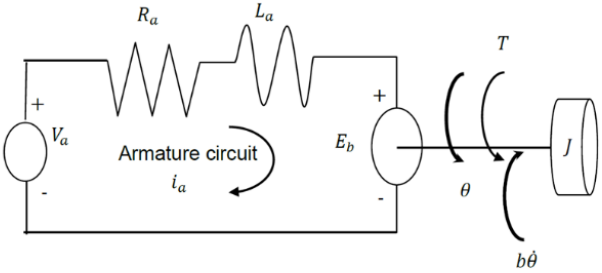


Figure 1: Schematic diagram of the DC Motor model

Base on the Figure 1, the equation of the armature electrical and mechanical of the dc motor are described as:

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + E_b(t) \tag{1}$$

$$J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} = Ki \tag{2}$$

Where, V_a is the armature voltage, R_a is the armature resistance , L_a is the armature inductance, i_a is the Armature current, E_b is the Back emf and T is the motor Torque. Here the T is proportional to current i and is defined as $T = Ki$, while the back electromotive force, E_b is proportional to the rotor angular velocity $\dot{\theta}$ and can be defined as $E_b = K_\omega = K\frac{d\theta}{dt}$. Using the Laplace transform, the equation (1) and (2), the equation can be written as a transfer function described in (3)

$$G_v(s) = \frac{\omega(s)}{V(s)} = \frac{K}{[K^2(R+Ls)(Js+b)]} \tag{3}$$

2.1 Parameter Identification of DC Motor

To determine the value of the parameter, an experiment setup has been developed with integration of real hardware of DC motor, Arduino Uno R3 microcontroller, motor driver, encoder and computer with MATLAB software. In this experiment, the output-input witch is voltage input and output speed are taken by the Arduino Uno R3 microcontroller. The data from the actual DC motor system by applying known inputs (such as voltage or current) and measuring the corresponding outputs (such as angular velocity or position). These input-output measurements serve as the basis for identifying the model parameters. The data from the experiment are collected and recorded to be used as the training data. The experimental training data is analyzed in the MATLAB System Identification toolbox. The value of the transfer function obtained in the identification process in the form of mathematical modeling can be seen in equation (4) based on the provided input-output data. The accuracy of the process is fit to estimation data about 98.89% obtained by the process of System Identification. This indicates that the identified transfer function closely matches the behavior of the actual system based on the estimation data.

$$\frac{\omega(s)}{V(s)} = \frac{15390}{s^2+511.4s+5612} \tag{4}$$

3.0 APID SPEED CONTROL DESIGN

Conventional controllers, such as Proportional-Integral (PI), Proportional-Derivative (PD), and Proportional-Integral-Derivative (PID), are widely used in DC motor operation. From listed controller, the PID controller are frequently employed in the DC Motor. However, these controllers only provide excellent efficiency within a specific operating range, and changing that range has a significant impact on performance [10]. Thus, An Adaptive Proportional-integer-derivative (APID) controller design is introduced to overcome the drawback of the conventional PID in this study. The control structure diagram of APID controller is show in Figure 2. APID strategy is used to design the adaptive controller that work on the principal of adjusting the controller parameter so that the output of the actual plant tracks the output of a reference model having the same reference input.

In this control structure, the desired speed (ω_{des}) is used as the controller reference, while actual dc motor speed (ω_{act}) is used as the feedback loop. The APID controller action for the DC motor are describe by the following equation (5) as in follows:

$$u(t) = k_p . e + k_i . e \frac{1}{s} + k_{d.} e \frac{d}{dt} \tag{5}$$

Where the adaptation mechanism for K_p, K_i, and K_d are described as :

$$K_p = 0.08305\omega + 6.625 \tag{6}$$

$$K_i = 1.186\omega + 83.22 \tag{7}$$

$$K_d = 0.00040682\omega + 0.0001339 \tag{8}$$

The constant value archive in equations (5) to (8) of the adaptation mechanism were obtained from the linearization of the gains from the inertial tuning such as tabulated in Table 1.

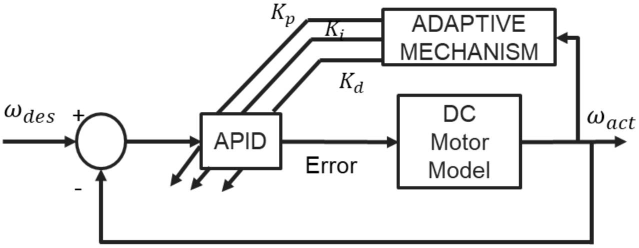


Figure 2: Adaptive PID control structure

Table 1: Controller parameter versus speed

Speed,ω (rad/s)	K_p	K_i	K_d
5	7	100	0.01
10	5.5	80	0.02
20	9	110	0.03
30	8	120	0.02

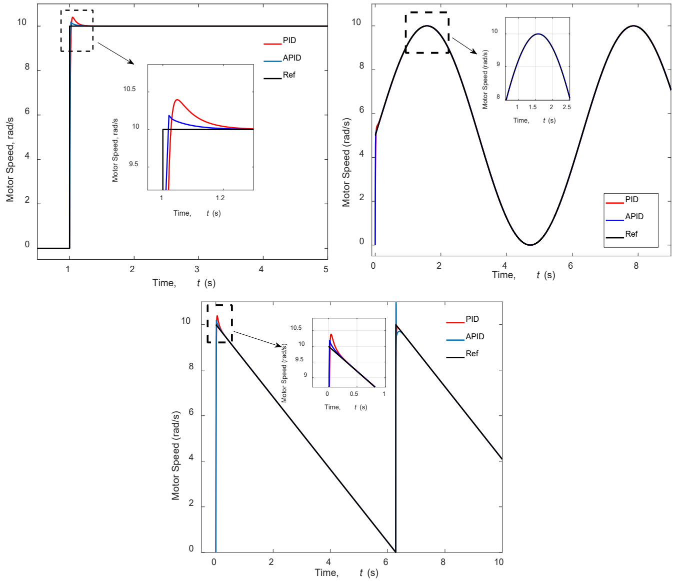
4.0 PERFORMANCE ASSESSMENT OF THE PID AND APID CONTROLLER

To examine the effectiveness of the proposed speed controller, a simulation and real time experiment is implemented in the study. In simulation, the performance evaluation was done by using MATLAB-Simulink software. Meanwhile in experiment evaluation, test rig is being used to monitor and evaluated the DC Motor controller performance. The simulation and experiment test are based on three input which is step input function, sinusoidal function, and saw-tooth function at variable DC motor speed condition. The speed conducted in this simulation is 10 rad/s, 20 rad/s and 30 rad/s with the desire specification target in term of percentage of overshoot (5%), rise time (0.25 second) and settling time (0.5 second).

4.1 Simulation Assessment of the PID and APID Controller

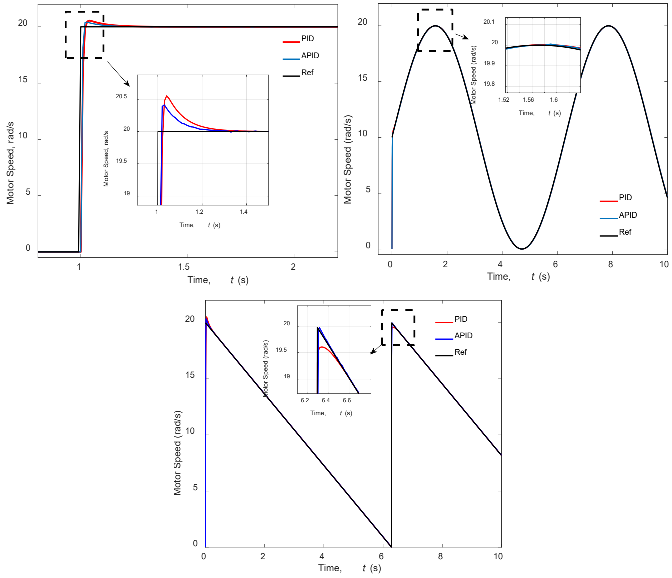
Simulation result on DC motor speed at 10 rad/s using PID and APID controller are shown on Figure 3. It can be seen that the proposed APID controller for producing the desired motor speed is very encouraging as shown in step response in Figure 3(a). In term of sine wave function as in Figure 3(b), and saw tooth wave function in Figure 3(c) show that control scheme of APID controller similar with the reference. The performance compared to APID and PID controller show that APID controller capable to archive the desire specification and present a good response in tracking the desire speed. Another speed test is carried out at 20 rad/s to evaluate the performance of the PID and APID controller in medium DC motor speed. Figure 4 show the simulation result under 20 rad/s. From the observation, the performance under the target specification show that under step function response in Figure 4(a), the overshoot percentage of PID are higher that APID controller. Meanwhile under sine wave function and saw tooth function in Figure 4(b) and Figure 4(c), indicate that APID capable in achieving the design criteria. However, APID controller provide near tracking to the reference. For saw tooth wave function condition, its show that PID response in t=6.3 second, the speed is reduced below the reference compared to the APID controller. This is because of sudden changes the causes the controller being unable to tune the motor speed base on the reference.

The evaluation was continued at 30 rad/s motor speed, as shown in Figure 5. For step function response, APID show a lower overshoot percentage and archive the design specification. PID produce 6% of overshoot in this simulation and above the desire value. In term of evaluation of the rise time, APID recorded 0.0088 second while PID recorded 0.0174 second respectively. Settling time for controller recorded APID settling time are faster than PID. As for sine wave function and saw tooth wave function is shown in Figure 5(b) and Figure 5(c). In term of sine wave function, PID and APID capable in achieving the design criteria. However, APID controller provide near tracking to the reference. For saw tooth wave function, its show that PID response in t=6.5 second, the amplitude of the speed is recorded below the reference compared to the APID controller.



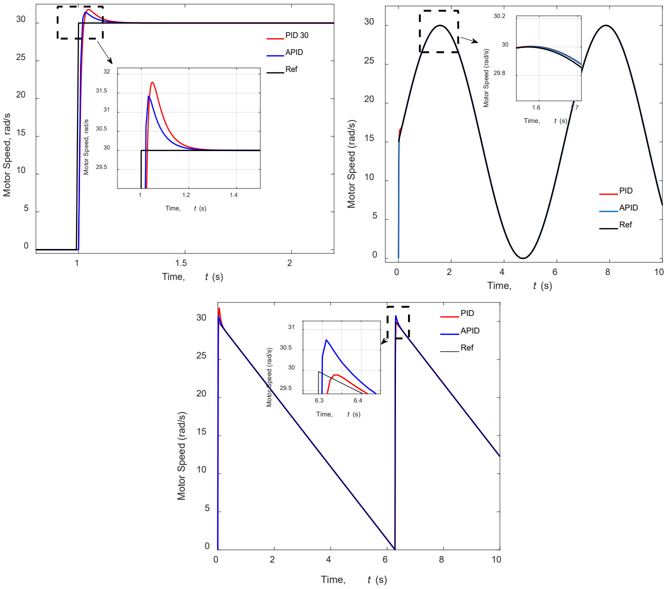
(a) (b) (c)

Figure 3: Simulation result at 10 rad/s



(a) (b) (c)

Figure 4: Simulation result at 20 rad/s

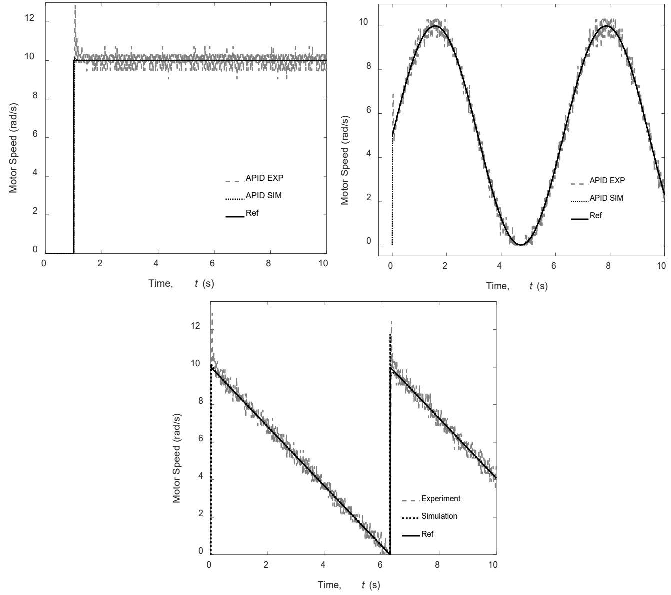


(a) (b) (c)

Figure 5: Simulation at 30 rad/s

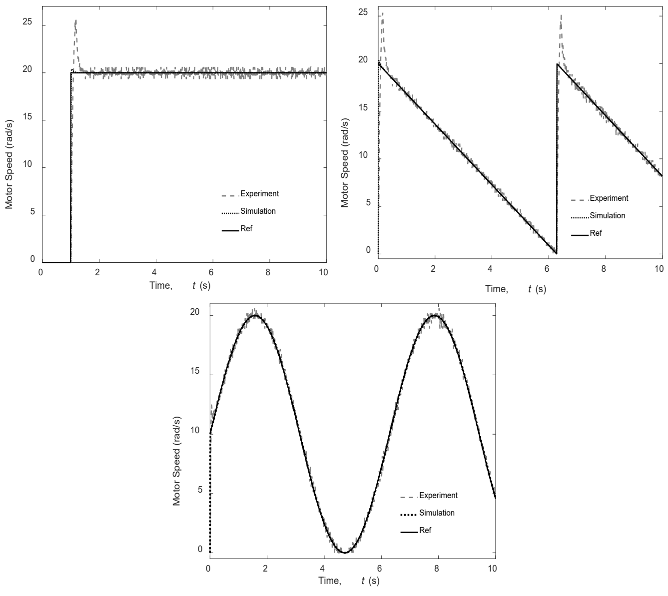
4.2 Experiment Assessment of APID Control Structure of The DC motor

Experimental evaluations were conducted in this study to validate the effectiveness of the purposed control structure in term of comparison between simulation and real time experiment of APID controller. The results shown in at Figure 6 to 8 reflecting the experimentation conducted at 10 rad/s, 20 rad/s and 30 rad/s motor speed respectively. Here, it can be seen that the APID can track speed and match simulation data, but at higher DC motor speeds, there are slight deviancy errors, especially at 30 rad/s at step function and saw tooth wave function response. The proposed controller's performance was affected by motor inertia, DC motor gearbox mechanism, and battery power degradation. In experiment, the percentage error between simulation and experiment from test of 10 rad/s to 30 rad/s recorded <5% error as presented in Table 2. This concluded, APID controller work well in the DC motor model.



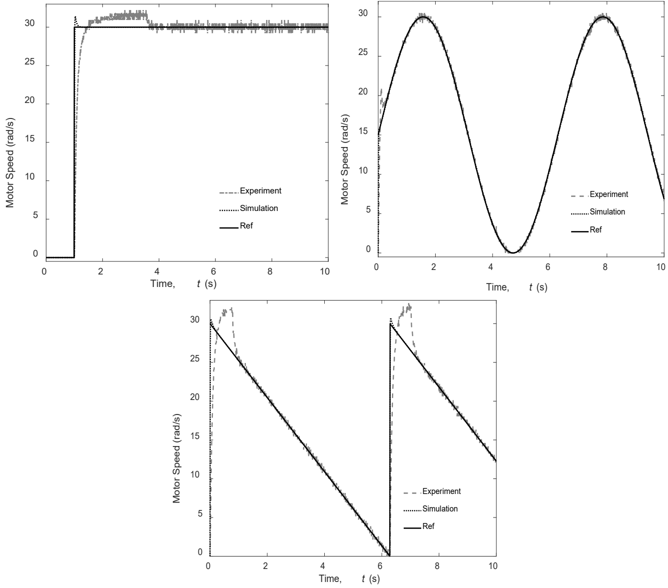
(a) (b) (c)

Figure 6: Experiment at 10 rad/s of motor speed



(a) (b) (c)

Figure 7: Experiment at 20 rad/s of motor speed



(a) (b) (c)

Figure 8: Experiment at 30 rad/s of motor speed

Table 2: Steady State Error Between Simulation and Experiment

Test (rad/s)	Error between Sim & Exp (%)		
	Step	ine	Saw t
10	3.37	1.7	2.24
20	3	0.42	0.5
30	5	2.5	2.04

5.0 CONCLUSION

In this study, a DC motor model has been developed in Matlab Simulink Software with the second order transfers function that simulate the characteristic of the DC motor accomplished the accuracy of the process is fit to estimation data about 98.89%. In this study, speed tracking control for the DC Motor has been developed using an adaptive proportional-integral-derivative (APID) control scheme. Simulation studies of the speed tracking are presented to demonstrate the effectiveness of using the proposed controller by comparing the responses with the same system using a PID controller and the desired control. Meanwhile, real time experiment is presented to validate the effectiveness of the proposed control structure compare to simulation results. Several tests have been performed in order to verify the effectiveness of the proposed controller, namely a sine wave function test, step function test and saw tooth function test. The simulation results show that the use of the proposed APID control technique proved to be effective in controlling the speed of the DC Motor with good accuracy between performance target which is overshoot 5%, settling time 0.5 sec and rise time 0.24 sec. The experiment result showed that the proposed APID controller provided good accuracy with the behaviour of the simulation and experiment data are almost similar with less than 5% error. From the study it can be concluded that the proposed controller is successful as the behaviour of the simulation and experimental data is almost similar with less than 5% percentage error. For future works, an addition of load disturbance in simulation and experiment would enhance the understanding and characteristic of APID controller and also incorporated the DC motor, the test rig and APID in real application for further study.

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