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Comparison of PID and SMC Methods in DC Motor Speed Control

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Abstract: *DC motor speed control was carried out in this study using Proportional Integral Derivative (PID) and Sliding Mode Control (SMC) methods. Disturbance is added to and removed from the motor shaft for short periods using a relay to compare the performances of the controllers. SMC and the PID Controller were designed using LabVIEW and tools. The motor is rotated at the desired speed by controlling the H-bridge through the DAQ card. The experimental setup uses LabVIEW software, an N-6024E DAQ card, an H-bridge, a DC motor, and encoder. A variable PWM signal is used at the PID control, and a constant amplitude voltage (± 5V) is applied to the DC motor by the SMC. The settling time is 450 milliseconds for the PID control and 110 milliseconds for the SMC when the motor is rotated at the reference speed of 1,500 rpm. The performances of the controllers were examined while the disturbance effect was applied to the motor shaft via a relay for two seconds. After that, the experimental results were compared to each other. The PID and SMC controllers reach their respective reference speeds at approximately 1 second and 15 milliseconds when the disturbance effect is applied to the motor. Although SMC reaches its reference speed much faster, it has a chattering problem with the motor. This disadvantage can be eliminated using some methods that remove the chattering.*

Keywords: *LabVIEW, automatic control, PID, SMC, speed control*

I. Introduction

Proportional-Integral-Derivative (PID) controllers are very popular and commonly used in industrial control applications due to their facility of operation, high reliability, stability, recovery of continual failure, simple mathematical structure, and resistance. There are many studies in this field in the literature. PID controllers were designed for the control of DC motors under changing loading conditions (Khan et al. 2015). PI and Fuzzy PI speed controllers were designed and simulation studies were made to compare the efficiency of speed controllers for brushless DC motors (Ahmed et al. 2015). A LabVIEW-based and self-adjusting PID controller was designed for the speed control of DC motor. The designs of the fuzzy logic controller and the conventional PID controller were implemented through the use of a Circuit Design and Simulation toolkit based on LabVIEW (Kumar et al. 2015). A PID-type iterative learning control for a DC motor based on the characteristics of the repeating motion of the DC motor was proposed by Li (2014). Her results showed that the velocity tracking precision of the DC motor was higher and that the error was smaller when increasing the number of iterations (Li 2014). In the study of (Dumanay et al. 2009) the speed control of the DC motor via the Internet using a PID controller was used for educational purposes. Again, the PID and sliding mode controller for the rotating inverted pendulum were designed by (Demirtas et al. 2013). In some studies by Demirtas, a PI controller was designed for the continual magnetic synchronized motor. In his first study, the system was modelled with artificial nerve nets. Optimum values for PI coefficients were obtained by using the genetic algorithms on the model (Demirtas 2011). In his second study on this subject, he obtained successful results for the optimization of parameters using the response surface method (Demirtas & Karaoglan 2012). In the PID control, where three basic controllers are combined and shown on the block diagram in general, each controller has separate features. The integral control recovers state-regime errors, while the derivation control increases the response speed of the system. It is possible to obtain a steady control organ that can respond rapidly and have zero steady state–regime errors through properly adjusted coefficients. The performance of the PID controllers will be reduced if these coefficients are not adjusted correctly. Examining the studies in the literature on Sliding Mode Control (SMC) allows us to observe that it is used in many fields such as resistance regulator designs with SMC, model-reference systems, adaptive control systems, follow-up systems, and stage observer structures. It is also applied successfully in fields such as SMC automatic flight control, chemical processes, space systems, robotics, and the control of electric motors. There are many studies on the development of SMC in literature (Ouyang et al. 2014, Dumanay et al. 2009, Vyoma 2015, Senol et al. 2005, Guermouche et al. 2015). Many practical uses require that the resistance and controller performance against disturbances are perfect; thus, a variable structure system with a sliding mode controller is applied to achieve such performance (Ahmed et al. 2013). SMC is a quite special approach to providing control systems with resistance against external disturbances and changes in system parameters. Moreover, this design method, which is primarily based on Lyapunovstability conditions, provides great facility to the controller design for both direct and indirect systems (Vadim I. U. 1992). One of the main presuppositions underlying the analysis and design of SMC systems is that the control can be infinitely rapidly switched from one value to another. However, it is not possible to reach the high switching speed required for an SMC system in practice for many reasons. For example, there is a delay of a finite time in the control accounts and the elements have physical limitations. An example of this is the direct-current servo motor control. As it is accepted that the system input is current, it is not possible for the current to be adjusted with infinite speed due to the presence of winding inductances. There will always be chattering sliding and determined state modes of these systems because control cannot be switched with infinite speed. In the determined state, the chattering occurs as a high frequency vibration around the desired balance point, and this becomes a source of stimulation (causing instability) for the system's non-modeled high frequency dynamics (Şahin 1997).

1. Application of PID and SMC to DC motor

In the study, the speed of DC motor was controlled through the use of PID and a sliding mode controller. Software was produced through LabVIEW and a DAQ card. An H-bridge was used as the DC motor driver. The feedback signal from the encoder is transferred to the PC via the DAQ card and the controller output sign is given to the H-bridge again via the same card. While the outputs are obtained as PWM signals in PID control, $^{+}$5V or $^{-}$5V is applied to the motor depending on the used signum function in the SMC. A block diagram of the experimental setup's structure for both controllers is given in Figure 1 (Dumanay 2009).

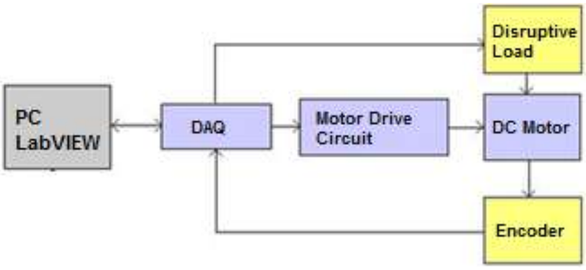

Figure 1. Block diagram of the experimental setup

In the SMC, the H-bridge was used as the driver circuit due to the signum function in the controller sign. Only this circuit was used as the driver circuit in the experimental setup because the H-bridge can respond to the other controllers. The H-bridge used in the experimental setup is given in Figure 2.

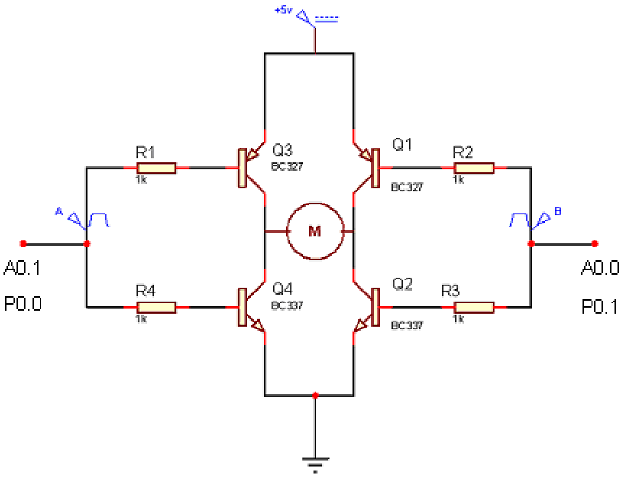

Figure 2. H-bridge circuit

2.1. PID Control of DC Motor

The PID control is made up of a combination of three basic control effects. Each controller structure has a different effect on the system; the PID control transfer function can be written as:

$$\frac{U(s)}{E(s)} = K_p\left(1+\frac{1}{T_i s}+T_d s\right) \tag{1}$$

The output sign of PID can be stated as:

$$u(t) = K_p\left\{e(t)+\frac{1}{T_i}\int e(t)dt+T_d\,\frac{de(t)}{dt}\right\} \tag{2}$$

The system can be controlled successfully by making K_p, T_i, and T_d coefficients stated in the equation suitable for the system. If these coefficients are not adjusted to suit the system, the superior specialties of the PID cannot come to light. Thus, these parameters can be properly adjusted for the system via online and offline adaptation methods. A block diagram of the PID controlled system is given in Figure 3.

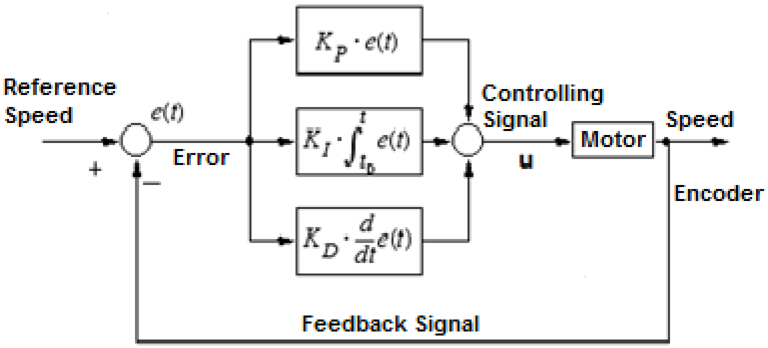

Figure 3. Block diagram of PID controlled system

Parameter adjustments of LabVIEW program can be made more easily in the PID control experiment because it uses the virtual instruments (VIs) and PID toolkit program. The output of the system is instantaneously seen in the parameter changes. In PID control experiments, the AO1 and AO0 analogue outputs are respectively connected to the A and B inputs in the H-bridge. B was grounded with AO0 because the speed control of the motor was made and its one side operation is sufficient for the experimental study. A is given the PWM sign from the DAQ card via AO1. Instantaneous changes of the PWM and speed of the motor can be observed graphically on the interface. Time, duty, and rpm values can be recorded as an excel file (pid.xls). Once the parameters are inputted to the system during the operation of experimental setup by the user, the system can be operated according to the newly changed parameters. A disturbance can be added to the system with a button on the scale to observe the performance of the controller. Disturbance effects can be made by compressing the motor shaft between the contacts of the relay. As shown in Figure 4, disturbances are activated through relay contacts and it goes out of order after two seconds. Thus, the changes in the system in response to disturbances can be examined. The reference speed of the motor was chosen as 1,500 rpm, and thus the disturbance was activated while the motor was rotating at 1,500 rpm. Then, the speed of the motor decreased. PID control was activated again and the motor settled at the reference speed (Dumanay 2009).

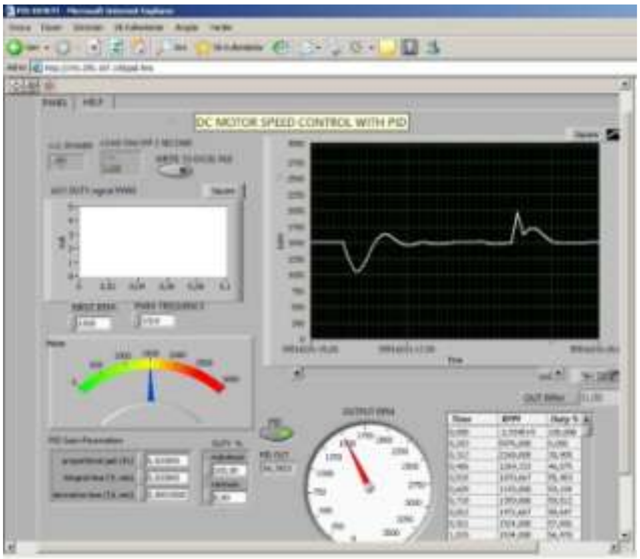

Figure 4. Speed response of DC motor for 1,500 rpm (PID controlled)

2.2. Sliding Mode Control of a DC Motor

SMC is a special state of variable structured control systems. SMC is a non-linear control that provides resistance for the control system against the destructives and changes in the system parameters. This system, mainly based on Lyapunov stability conditions, provides great facility in the design of controllers for linear or nonlinear systems (Vadim I. U. 1992). The SMC has two states: convergence and sliding mode. The aim of the controller is to enable the system states to reach the switch surface as desired and to slide on that surface until reaching its reference value. The switching the control with infinite speed may cause some chattering in the system. In the case of a stable statement, the chattering causes high frequency oscillations around the desired balance point, which becomes a source of stimulation for non-modeled high frequency dynamics of the system (causing instability) (Şahin 1997). In many SMC systems, control includes terms such as relay. Because it is practically impossible to realize relay features, many approaches are used in the literature to reduce the chattering (Demirtas 2002). In the study, the sliding surface is defined as

$$s = Cx_1 + x_2 \tag{3}$$

Here, C is a positive coefficient. x_1 and x_2 are identified as:

$$x_1 = \omega_r - \omega \tag{4}$$

$$x_2 = \frac{dx_1}{dt} \tag{5}$$

In this, ω_r represents the angular velocity. If these expressions are written in place of x_1 and x_2 in equation (3) we get

$$s = C(\omega_r - \omega) + \frac{d(\omega_r - \omega)}{dt} \tag{6}$$

The control sign is taken as

$$u = U_0 sign(s) \tag{7}$$

In this, the value of $U_0$is the tension of 5 volts. In the SMC experiment, the PO0 and PO1 outputs were connected to the A and B nozzles, respectively. A 5V relay was usedto prevent the quantitative outputs coinciding with the analogue signs. The direct current motor used is rotating at a maximum speed of 3,050 rpm at the H-bridge at 5V. The reference speed of the motor was adjusted for 1,500 rpm. The “C” coefficient and reference speed information on the screen may change. The effect of the “C” coefficient on the system and the chattering conditions can be seen in the motor speed graphics in Figure 5 by entering different values (Dumanay 2009).

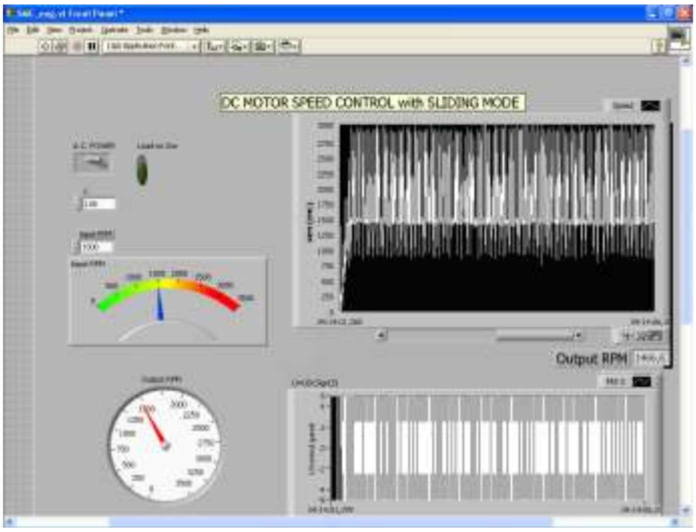

Figure 5. Speed response of the motor for 1,500 rpm (SMC)

2. Comparison of Experimental Studies

Most traditional control systems are based on feedback control. Feedback can be identified as applying an error signal as a result of comparing the output sign to the desired sign in the system input so as to correct a failure in the output. Effective control in an automatic control system with feedback requires that the system tracks many system parameters. In PID control, a PWM signal is produced according to the failure between the reference value and the signal from the feedback. The control sign used in SMC is obtained from the signum function. Thus, the + maximum and – minimum tensions are applied on the motor depending on the state of sliding surface. Applying tension in the opposite direction to the system and at maximum level causes chattering in the system, which leads to the destruction of the dynamic structure of the system. Although SMC is more rapid than PID, it has disadvantages due to the chattering it causes. This disadvantageous condition of SMC can be removed using one of the chattering removal methods. These include methods such as using a low pass filter, using a saturation function instead of the signum function, or creating a border layer with fuzzy logic. However, in such a border layer that aims to remove chattering, the resistance that is an apparent specialty of sliding mode disappears.

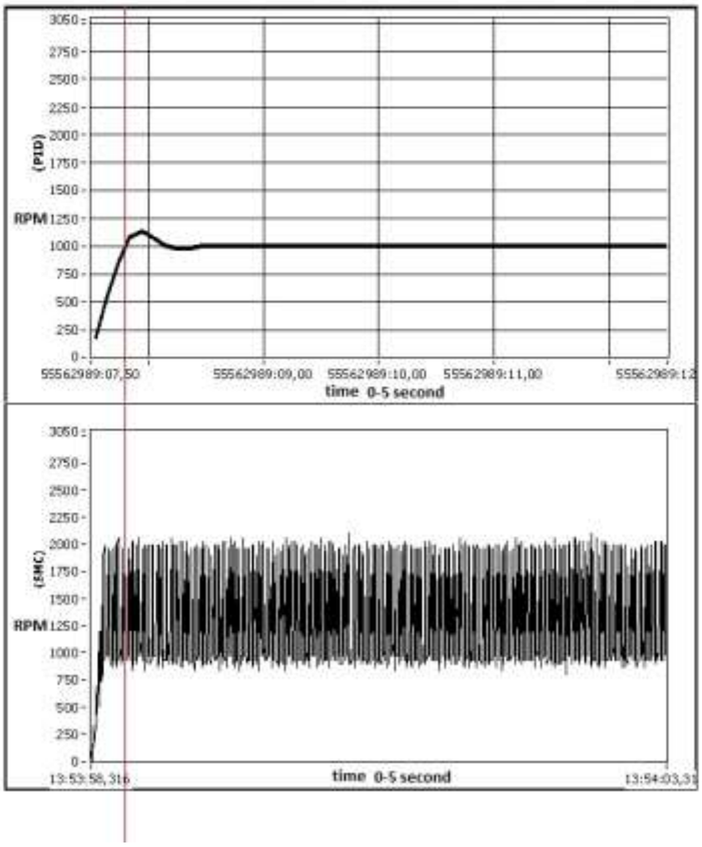

Figure 6. Comparing two control methods (no disturbance)

As seen in Figure 6, the reference circuit number of the motor in the study made for comparison was for 1,000 rpm without disturbance. As the graphics obtained are examined, the settling time required to reach the desired speed was measured as 110 ms, and it was measured as 450 ms in the PID control. The period the SMC requires to respond to the system seems to be better than that of the PID control. While it can be observed in the SMC that the speed value changes with little variation around 1,000 rpm in the dial-operated speed menu on the screen, when it is transferred to a graphic, the average speed seems to be higher due to the high frequency signals caused by chattering. PID control is observably better with regard to the maximum excess point, and the continuous state error is better with PID control. A comparison was made according to the x point (Dumanay 2009).

Disturbances are put into the system for two seconds to see the effect of the controllers. The results obtained for both methods are given in Figure 7. Disturbances are activated at the x point and deactivated at the y point. As the graphics are examined, it can be stated that the SMC is more durable against disturbances. Recovery is seen in the SMC at 15 ms, whereas this period rises up to 1 second for the other control (Dumanay 2009).Therefore, the SMC method is more durable than the PID control when compared in terms of being affected by disturbances and recovery.

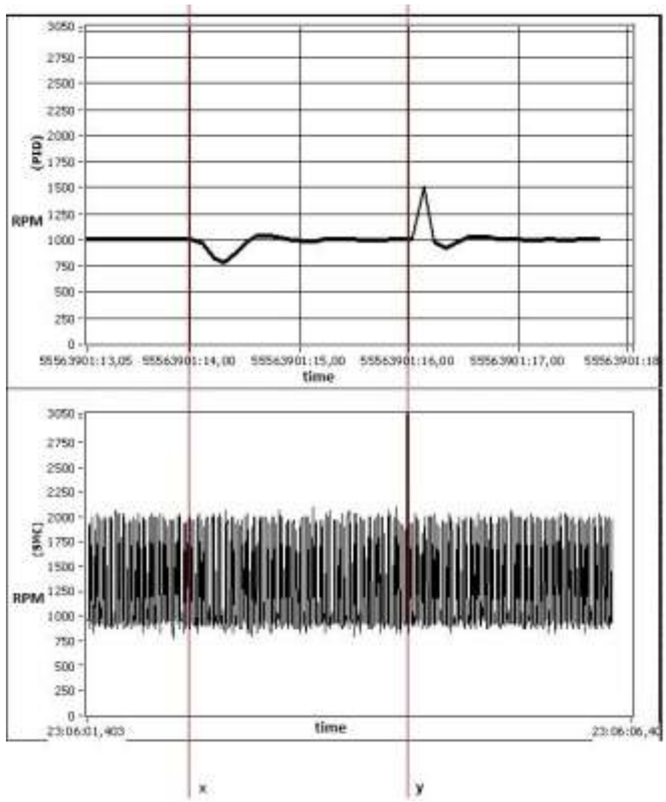

Figure 7. Comparison of both control methods (x: Disturbance is active, y: Disturbance is inactive)

3. Result and Suggestions

PID and sliding mode applications are commonly used in literature. The size and time of a disturbance cannot be estimated in normal systems, thereby making it difficult to examine the disturbance effects. In theoretical studies, solutions are made using acceptances or limitations. In the prepared experimental setup, an electronic relay was used to create a disturbance effect in the system. This loading is put into the circuit optionally and removed after two seconds to observe the performances of controllers against the load. In this way, what a disturbance affecting the system means, how it affects the motor physically, how the controller removes the effect of the disturbance, how the controller responds to the removal of a disturbance, how it keeps systems at the reference value, and how oscillations can occur can be observed by the user and understood in a better way. Different controller structures can be developed through designing the interface. New methods can be developed and parameters can be optimized in different ways to remove the chattering that occurs as a disadvantage of SMC. According to the obtained results, it can be concluded that SMC is more robust than PID control.

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