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PARAMETER DETERMINATION AND ONLINE TURNING OF PID CONTROLLER FOR SPEED CONTROL OF A DC SERVOMOTOR

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ABSTRACT

Servomotors play a vital role in both our domestic and industrial appliances. To achieve their desired performance however, it is necessary to overcome its related control problem due to parameter variations. In this research work, parameter determination algorithm is developed and employed to determine the moment of inertia and friction

Introduction

A servomotor is a motor employed for the control of position or speed in the closed-loop control system (Arnob, 2019). The functions of the servomotor are to turn over a wide range of speed and to also perform the control position and speed instructions given (Arnob, 2019). Servomechanisms are widely employed as actuating elements in a great variety of industrial applications, including computer-controlled machines, robot manipulators, printers, and disk drives, among others. Accurate values of the servo inertia and friction parameters are de rigueur in order to design

coefficient of DC servomotor at no load and under dynamic load variations. The results obtained shows that, the determined values of friction coefficient of the motor vary linearly with load torque, the higher the load torques the higher the values of friction coefficient needed to maintain the acceptable performance of the system. Also, the estimated value of moment of inertia of the motor is directly proportional to the load torque, the higher the load torque the higher the moment of inertia of the motor needed to maintain the acceptable performance of the system.

Key words: *Servomotor, Moment of Inertia, Friction Coefficient, PID*

high-performance controllers (Garrido & Concha, 2014). DC servomotors are characterized by high torque, low inertia, and good linearity (Victoria, 2010). They are found in many applications including; Industrial robot manipulators (Tarmizi et al., 2015)

Parameter variations due to load disturbances affect the speed or position control of a DC servomotors resulting to undesirable current fluctuations (Gaiceanu et al., 2014) sluggish response, overshoot, undershoot of rotor speed of DC servomotor (Pandey, 2012), or inaccuracy in performance. Thus, parameter determination plays a vital role in tuning controller parameter. This is necessary because tuning controller parameters demand proper estimation of physical parameters of systems in order to satisfy the desired performance specification. Change in parameter values can lead to poor control and instability (Ganesh et al., 2012).

Furthermore, Cong et al., (2010), identified parameters of nonlinear DC motor model using Genetic Algorithm (GA) and Simplex method. Using the global search ability of GA and fast convergence of simplest method, the accuracy and efficiency of parameter identification are increased significantly. However, this method only uses a set of sufficient excitation input-output data of the actual system. Also, Arshad (2010), estimated parameters of DC motor using Ordinary Least Squares (OLS) and Recursive Least Squares (RLS) algorithms. It was discovered that the value of errors for OLS is far less than achieved using RLS. Also OLS, due to its un-iterative nature, is fast in estimating the unknown parameters. However, OLS will only be a better method for a simple DC motor, but when the system is more complex or noisy RLS will be preferred. It is hard to estimate relatively accurate values for inertia and load torque, since these two are torque are strongly coupled variables due to the degenerate-rank problem (Bosco et al., 2017).

Ming et al., (2018) achieved an on-line parameter identification algorithm to iteratively compute the numerical values of inertia and load torque, this work eliminates this problem and realizes ideal online inertia identification regardless of load condition and initial error using a full-order Kalman Observer and Recursive Least Squares, and introduces adaptive controllers to enhance the robustness. While recommending further work on industrial robotics applications, a field where moment of inertia and load torque are both time-varying.

The task of parameter determination has attracted the attention of so many researchers over the years, and various parameter estimation methods have evolved. For instance, an identification method for the moment of inertia on the basis of the error gain factor model by Xie et al., (2021) is introduced into the controller, so that the moment of inertia can be obtained accurately and quickly under dynamic conditions. An adaptive function is introduced in the inertia identification model and algorithm to replace the fixed parameters as an error gain factor (EGF). The method was compared with the accuracy parameters of the existing identification method, which verifies that the improved algorithm has a better accuracy and speed. This research work dwells on an on-line parameter determination of inertia and friction coefficient of DC servomotor at no load and under dynamic load variation. The determined values of inertia and friction coefficient will be used in tuning PID controller gains online.

MATERIAL AND METHOD

This section entails the parameter determination, algorithm implementation and system simulation.

Parameter Determination

Parameters of DC servomotor such as torque constant, back emf constant, armature resistance, armature inductance, a moment of inertia, friction coefficient determines the characteristic behavior of the motors. DC servomotor parameters that vary with load changes are moment of inertia and friction coefficient. These two parameters affect controller performance.

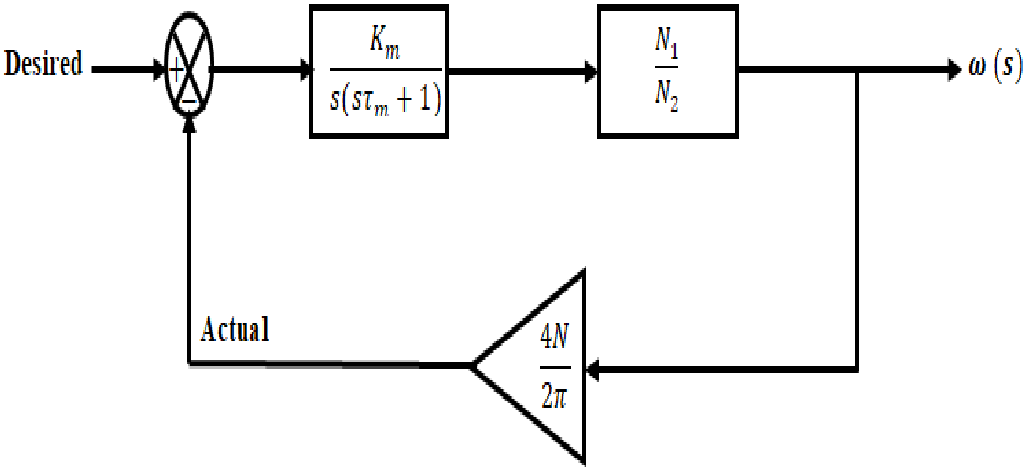

Figure 1: Block Diagram of a DC Servomotor

Friction coefficient

The torque equation of the motor and load arrangement is given by:

$$T_m = J\frac{d\omega}{dt} + F\omega$$
...2.1

Where J and F are inertia and friction coefficient of the motor and load arrangement respectively. When the speed is constant, the torque equation becomes:

$$T_m = F\omega$$
...2.2

$$F = \frac{K_T i_a}{\omega}$$
...2.3

Where:

F is friction coefficient
K_T is torque constant
i_a is armature current
ω is motor speed (rpm)

Thus F is determined using equation (2.3)

Moment of Inertia

When the supply to the armature is switched off, motor speed reduces to zero from its steady speed. Hence, equation (2.1) becomes:

$$J\frac{d\omega_m}{dt} + F\omega_m = 0 \qquad \ldots 2.4$$

The solution for equation (2.4) obtained using the steady state speed as the initial value of speed is expressed by:

$$\omega = \frac{T_m}{F}e^{-\left(\frac{F}{J}\right)t} \qquad \ldots 2.5$$

Where: $t = \tau = \frac{J}{F}$ = mechanical time constant of the motor which is the time taken for speed of the motor to reduce from steady state speed to 36.8% of steady state speed. Mechanical time constant can be determined using equation (2.6) as:

$\tau_m = \frac{J_m R_a}{K_T K_b}$ (Akar et al., 2012) 2.6

Where:

J_m is moment of inertia of the motor
R_a is armature resistance
K_T is torque constant
K_b is back emf constant

From the time constant, the moment of inertia of the motor and load is given by:

$$J = F\tau_m \qquad \ldots 2.7$$

Where: J is moment of inertia of motor and load
F is friction coefficient
τ_m is motor mechanical time constants

Parameter Determination Flowchart

The program of this algorithm is written using Matlab Simulink blocks and it is implemented as shown in figure 2

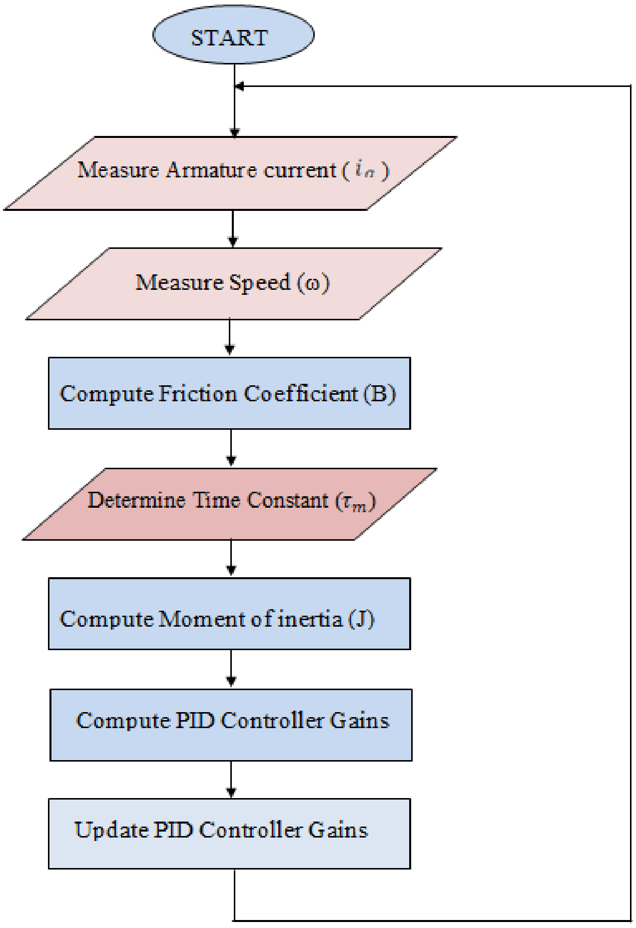

Figure 2: Parameter Estimation Flowcharts

Controller Tuning and Online Updating

The duty of PID tuner is to schedules the gains of PID controller as shown in figure 3 (Akar, 2007) based on the determined parameters (moment of inertia and friction coefficient) for effective controller performance.

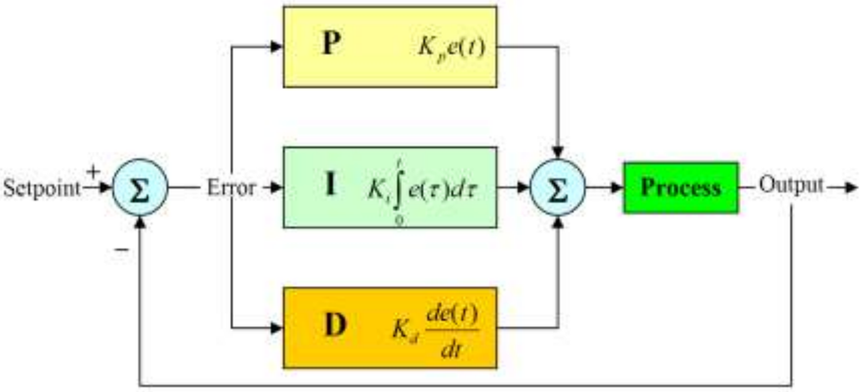

Figure 3: Diagram of PID Controller Structure

From the figure 3, the transfer function of PID controller can be derived as:

$$\frac{V(s)}{E(s)} = \frac{K_p s + K_i + K_d s^2}{s} \qquad \ldots 2.8$$

In terms of change in PID controller gains equation (2.8) can be rewritten as:

$$\frac{V(s)}{E(s)} = \frac{\Delta K_p s + \Delta K_i + \Delta K_d s^2}{s} \qquad \ldots 2.9$$

ΔK_p is change in proportional gain
ΔK_i is change in integral gain
ΔK_d is change in derivative gain
Making V(s) the subject formula yields:

$$V(s) = E(s)\,\frac{\Delta K_p s + \Delta K_i + \Delta K_d s^2}{s} \qquad \ldots 2.10$$

Also from figure 1, the transfer function of a dc servomotor can be written as:

$$\frac{\omega(s)}{V(s)} = \frac{K_T}{Js + F}$$

$\ldots 2.11$

By also making V(s) the subject formula yields:

$$V(s) = \frac{\omega(s)(Js + F)}{K_T} \qquad \ldots 2.12$$

Equating equation (2.10) and (2.12) yields:

$$E(s)\frac{\Delta K_p s + \Delta K_i + \Delta K_d s^2}{s} = \frac{\omega(s)(Js + F)}{K_T} \qquad \ldots 2.13$$

$$\omega(s)(Js + F)s = E(s)(\Delta K_p s + \Delta K_i + \Delta K_d s^2)\,K_T$$

$$Js^2\omega(s) + Fs\,\omega(s) = E(s)\Delta K_p s K_T + E(s)\Delta K_i K_T + E(s)\Delta K_d s^2 K_T$$

By equating the coefficient:

$$J\,\omega(s) = E(s)\Delta K_d K_T$$

$$\Delta K_d = \frac{J\,\omega(s)}{E(s)\,K_T} \qquad \ldots 2.14$$

$$E(s)\Delta K_i K_T = 0$$

$$\Delta K_i = 0 \qquad \ldots 2.15$$

$$E(s)\Delta K_p K_T = F\,\omega(s)$$

$$\Delta K_p = \frac{F\,\omega(s)}{E(s)\,K_T} \qquad \ldots 2.16$$

Equations (2.14), (2.15) and (2.16) are the change in gains of the PID controller which are the derived relationship between the dc servomotor parameters and the PID controller gains. The algorithm was developed based on these relationships as parameter updating mechanism and used to update the gains of the PID controller online as show in equations (2.17), (2.18) and (2.19) respectively;

$$K_p = K_{p\,(int)} + \Delta K_p \quad \ldots 2.17$$

$$K_i = K_{i\,(int)} + \Delta K_i \quad \ldots 2.18$$

$$K_d = K_{d\,(int)} + \Delta K_d \quad \ldots 2.19$$

System Parameter Specifications

The DC motor ratings adapted in this research work are based on the model of Ganesh et al., (2012) and has the specifications as shown in Table 1

Table 1: System Parameter Specifications

Parameters	Specifications
Armature voltage	24V
Armature curent	4A
Armature resistance	12.6Ω
Armature inductance	283mH
Speed (in revolution per minute)	4000rpm
Moment of inertia	2.26e-5kg-m^2
Friction coefficient	2.261e-5Nm- sec/rad
Torque constant (K_T)	0.04Nm/A
Back emf constant (K_b)	0.1V-rad/sec

SIMULATION RESULTS AND DISCUSSION

The performance evaluations carried out together with their respective discussions. Such results include: The determined values of friction coefficient and moment of inertia of the motor and load, tuned values of PID controller gains obtained using the determined parameters. The results obtained are as shown in the following figures. Figure 4 shows that the determined values of friction coefficient of the motor vary linearly with load torque. As the load torque varies from 0.01 to 0.1, the friction coefficient also changes from 0.000004886 to 0.00002778. The figure clearly shows that the higher the load torques the higher the values of friction coefficient needed to maintain the acceptable performance of the system.

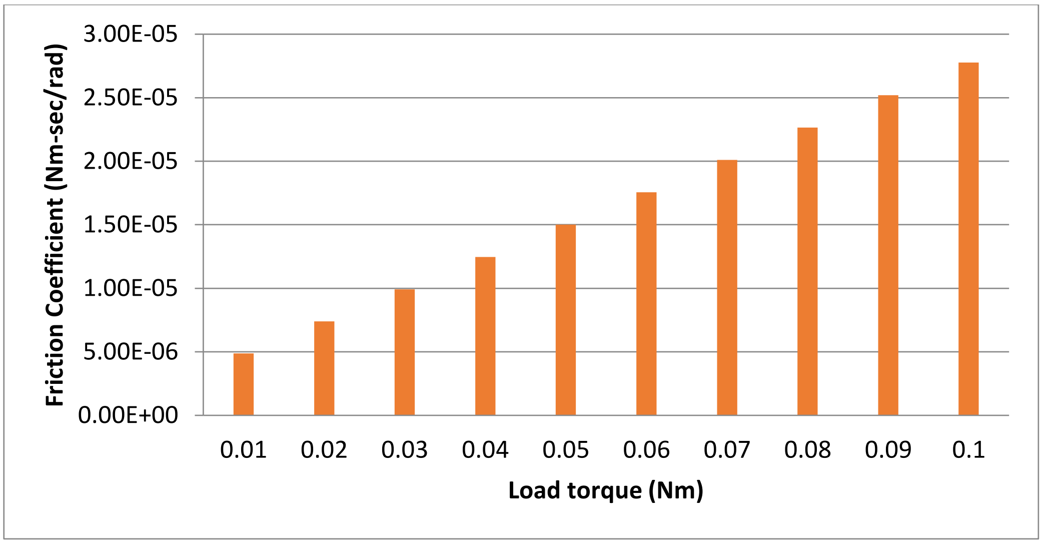

Figure 4: Friction Coefficient against Load torque

Figure 5 reveals that the estimated value of moment of inertia of the motor is directly proportional to the load torque. As load torque varies from 0.01 to 0.1 the moment of inertia also changes from 0.0000008696 to 0.000004945. The chart indicates that the higher the load torque the higher the moment of inertia of the motor needed to maintain the acceptable performance of the system.

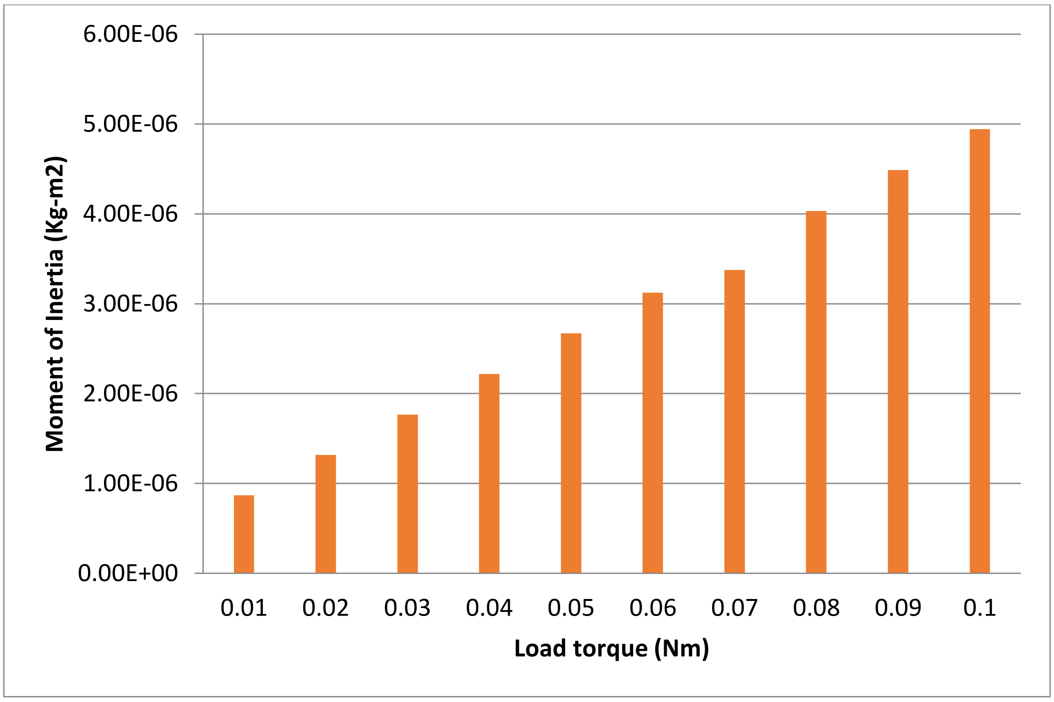

Figure 5: Moment of Inertia against Load torque

Figure 6 show that the Proportional gain of the PID controller is directly proportional to the determined friction coefficient. The higher the friction coefficient of the motor, the higher the value of proportional gain needed to maintain acceptable performance of the system.

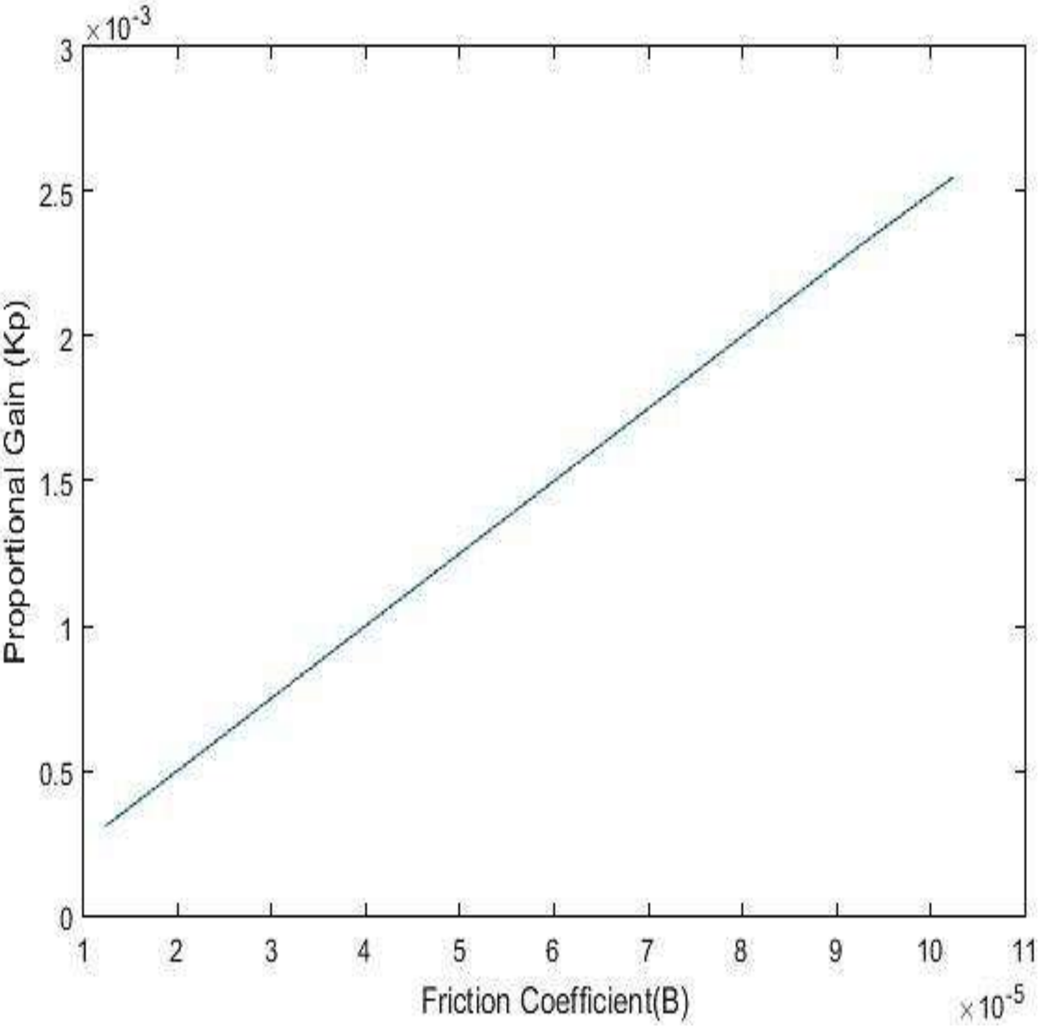

Figure 6: Proportional Gains against Friction Coefficient

Figure 7 shows the Derivative gain of the PID controller varies linearly with the moment of inertia of the motor. The diagram clearly showing that derivative gain of the PID controller increase with increase in moment of inertia and decrease with its decreases. The higher the moment of inertia of the motor, the higher the value of derivative gain of the PID controller needed to maintain acceptable performance of the system.

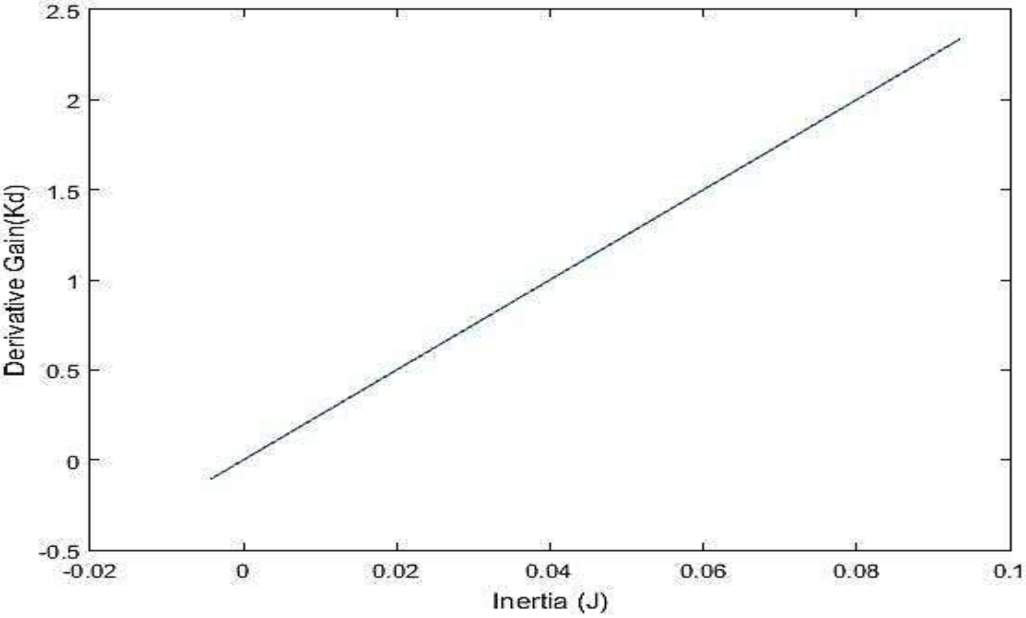

Figure 7: Derivative Gain against Moment of Inertia

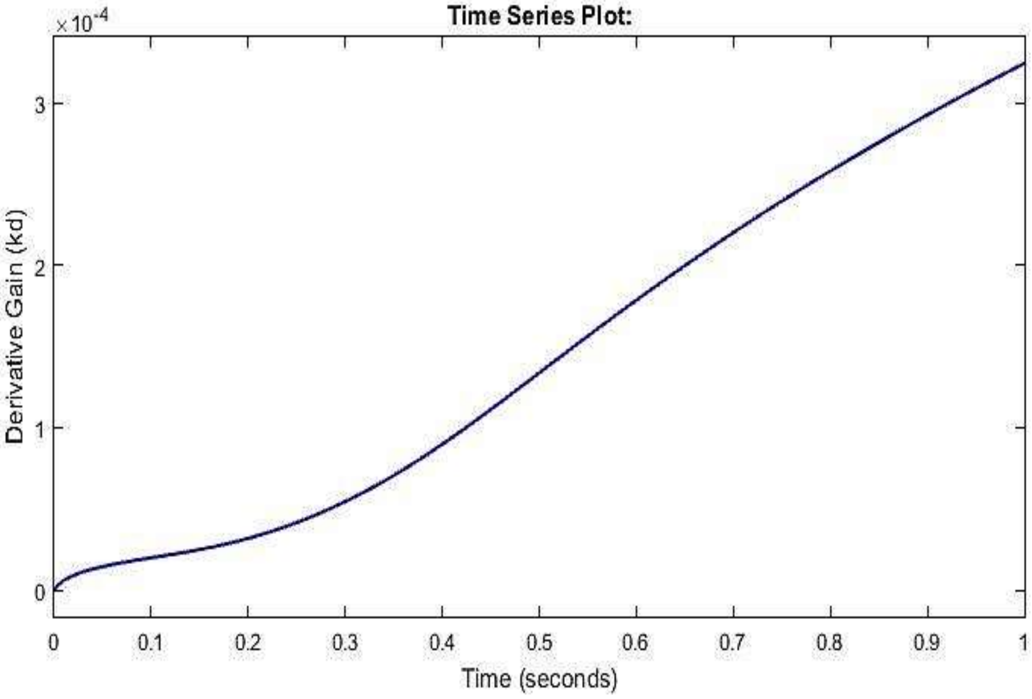

Figure 8: Derivative Gain against Time

CONCLUSIONS

In this work, parameter determination algorithm was developed and employed in determining the moment of inertia and friction coefficient of the DC Servomotor and load. These parameters were then used in tuning PID controller gains online for the speed control of a dc servomotor, which is the main objective of the work.

The thesis is concentrated on online parameters determination of friction coefficient and moment of inertia for speed control of a DC servomotor did not include the issues of noise rejection which can impede the performance of the system. It is highly recommending considering robustness to noise disturbance in future research.

REFERENCES

Akar, M. (2007). *Motion controller design for the speed control of dc servo motor*. *1*(4), 131–137.

Akar, M., Hekim, M., Temiz, I., & Dogan, Z. (2012). *The Speed and Torque Control of Direct Current Servo Motors by using Cascade Fuzzy PI Controller*. *5*, 123–127.

Arnob, S. (2019). Speed Performance Analysis and Control of DC Servomotor Using Linear & Nonlinear Controller. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, *6*(3), 1338–1347. https://doi.org/10.22214/ijraset.2018.1206

Arshad, S. (2010). Parameter Estimation of a DC Motor using Ordinary Least Squares and Recursive Least Squares Algorithms. Journal of Engineering Sciences, Assiut University,Vol. 39 (1), 87-98, January 2010

Bosco, M. C., Guedes, J. J., Castoldi, M. F., Goedtel, A., Ravazzi, E., Francisco, L., and Buzachero, S. (2017). Estimation of Parameters and Tuning of a Speed PI of Permanent Magnet DC Motor Using Differential Evolution. 978-1-5090-4281-4/17/$31.00 IEEE

Cong, S., Li, G., and Feng, X. (2010). Parameters Identification of Nonlinear DC Motor Model Using Compound Evolution Algorithms. I.IEEE Trans. on Industrial Electronics, vol. 48, no.1, pp. 169-176,2010.

Gaiceanu, M., Solea, R., Codres, B., and Eni, C. (2014). On-line Identification of the DC motor Parameters. (3), 85–96. ISA Transactions, vol. 41 (2), 225-234.

Ganesh, C., Abhi, B., Anand, V. P., Aravind, S., Nandhini, R., & Patnaik, S. K. (2012). *DC Position Control System – Determination of Parameters and Significance on System Dynamics*. *03*(01), 2–6.

Garrido, R., & Concha, A. (2014). Inertia and Friction Estimation of a Velocity-Controlled Servo Using Position Measurements. *IEEE transactions on industrial electronics*, *61*(9), 4759–4770. https://doi.org/10.1109/TIE.2013.2293692

Ming, Y., Zirui, L., Jiang, L., Wanying, Q., & Dianguo, X. (2018). An Algorithm for Online Inertia Identification and Load Torque Observation via Adaptive Kalman. *Energies-MDPI Publishers*, *11*(778), 1–17. https://doi.org/10.3390/en11040778

Pandey, A. K. (2012). Speed Control of D.C Servo Motor By Fuzzy Controller. International Journal of Scientific & Technology Research Volume 1, Issue 8, September 2012, ISSN 2277-8616, IJSTR©2012, www.ijstr.org

Tarmizi, W. F. W., Elamvazuthi, I., Perumal, N., and Nurhanim, K. (2015). A Particle Swarm Optimization-PID Controller of a DC Servomotor for Multi-Fingered Robot Hand. 1–6.

Victoria, U. P. De. (2010). Parameter Identification of a Perturbed Servomechanism Operating in Closed Loop under PID control. (2), 151–155.ICCAS-SICE International Joint Conference 2010,Fukuoka, Japan

Xie, F., Yu, F., & An, C. (2021). Research on Dynamic Identification of Servo Motor Load Inertia Based on the Error Gain Factor Model. *Energies-MDPI Publishers*, *144*, 1–16. www.mdpi.com/journal/energies