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Identification and Real Time Control of a DC Motor

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Abstract: *This paper presents identification and control of a DC motor. The dynamic model of the DC motor was first developed through system identification using least square parametric estimation method. Based on the developed dynamic model a state feedback tracking controller was then designed using optimal linear quadratic regulator for speed and position control of the DC motor. The developed dynamic model of the DC motor was validated via simulations and experiments. The performance of the controller was also verified through experiment.*
Keywords:*DC Motor, Linear Quadratic Reqgulator (LQR), Parametric Estimation Method (PEM)*

I. INTRODUCTION

DC motors speed and position are easy control and have adjustable range to follow a particular speed or position under load. DC motors are preferred over ac motors in applications because they have lower manufacturing costs and ease of controller implementations, since their mathematical model is simpler [1]. To control the position and speed of a DC motor,an accurate model of the system is required. The specifications given by manufactures may not be accurate; also some motors are produced with coupling gears from manufacturing which add some inertia and viscous damping coefficient to the original motors, therefore changing the original values specified by the manufacturer. Several methods have been employed for parameter identifications of a DC motor [2-4]. Accuracy and adequacy are two major modelling problems that always has to be dealt with [5]. System identification is the best means of obtaining mathematical models of most physical systems, because most systems are so complex, that there is no simple way to derive their models based on physical laws [5].

System identification methods can be applied for DC motor model identification which will give more concise estimate of the DC motor model than mathematical modelling [1, 6, 7]. In [1] the use of artificial neural network was employed to identify the DC motor model, in [6] multilayer perceptron network was used to fit the structure of the model Non-Linear Auto-Regressive Moving Average with Exogeneous Input (NARMAX). Also in [7] the identification was done by direct measurement of input and output signals and the use of the mathematical model was done to estimate the DC motor parameters.

This paper presents identification of DC motor model using Parametric Estimation Method (PEM), and based on the model an LQR optimal controller is design to control the position and speed of the motor. The validity of the model and the controller performance will be demonstrated through simulations and experiments.

The rest of the paper is organized as follows; section two describes the experimental setup and data measurement procedures, also it discuss the modelling process of the motor, section three discuss the controller design, while section four elaborate on the results. Finally, Section five concludes the findings of this work.

II. IDENTIFICATION OF DC MOTOR

2.1 Experimental setup and data measurement

Fig. 1 illustrates the block diagram of the experimental setup used in this work. It consist of FIO STD development board [8] and a personal computer which serves as the data acquisition system, a rotary encoder [9] as the sensors for measuring the motor speed, the motor driver [10] which is served as the servo-amplifier and the DC motor itself.

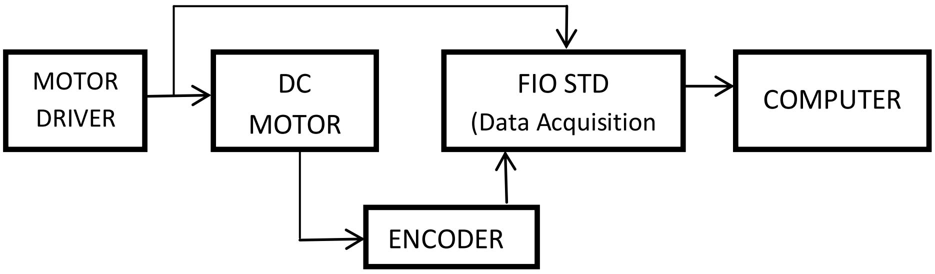


Fig. 1 Experimental block diagram

The Fio Std board is used to read the input voltage to the motor and MATLAB software and Simulink environment was used to measure the voltage which is been adjusted randomly using variable resistor as the control input to the motor driver.

2.2Modelling Process

The Parametric Estimation Method (PEM) is used in system identification when a model is already known for a system [11], therefore from the general position-voltage transfer function of a DC motor is given by equation (1) [12]:

$$\frac{\theta_m(s)}{E_a(s)} = \left(\frac{\left({K_t}/{R_a J_m}\right)}{s\left[s + \frac{1}{J_m}\left(D_m + \frac{K_t K_b}{R_a}\right)\right]}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where θ_m is the anglular position in radians, E_a is input voltage in volts, K_t is torque constant in Nm/A, $K_b$is back e.m.f constant in Vs/rad, J_m is motor inertia in kg-m^2, D_m is motor damping in N-m s/rad, R_a is armature resistance in ohms.

Equation (1) can be written as:

$$\frac{\theta_m(s)}{E_a(s)} = \left(\frac{K}{s(s+\alpha)}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

based on which the speed-voltage transfer function can be written as:

$$\frac{\dot{\theta}_m(s)}{E_a(s)} = \left(\frac{K}{s+\alpha}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

The two general parameters of interest are K and α, which the least square prediction method [11] is used to estimate using MATLAB *pem* function. The input data is the voltage driving the motor, while the speed is the measured output. The best outfit curve was achieved for values $K = 2390.5$and $\alpha = 1000$.

Since our controller is used for speed and position control, the model is written in terms of equation (2) as shown in equation (4):

$$\frac{\theta_m}{E_a} = \left(\frac{2390.5}{s(s+1000)}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

In state-space form:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -1000 \end{bmatrix}, B = \begin{bmatrix} 1 \\ 2390.5 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix}, D = [0] \dots\dots\dots\dots\dots (5)$$

III. CONTROLLER DESIGN

A state feedback controller is used to control the position and speed of the DC motor. The controller gain is computed using the system model in (5). [13]. A optimal linear quadratic regulator (LQR) is a type of this class of controllers. The aim of the LQR is to minimize the cost function;

$$J = \int_0^\infty (\boldsymbol{x} * \boldsymbol{Qx} + \boldsymbol{u} * \boldsymbol{Ru})dt \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Where x is the state variable and u the input, Q is a positive-definite (or positive-semidefinite) Hermitian or real symmetric matrix and R is a positive-definite Hermitian or real symmetric matrix [13]. The matrices Q and R are the tuneable parameters that are tuned to desired system performance and are used to calculate the controller's gain that will be inserted in the system. After some experimental trials, the best values of Q and R matrices are selected, the controllers gains are computed using MATLAB lqr function with the parameters state-space model in equation (5). The block diagram of the controller is shown if Fig 2.

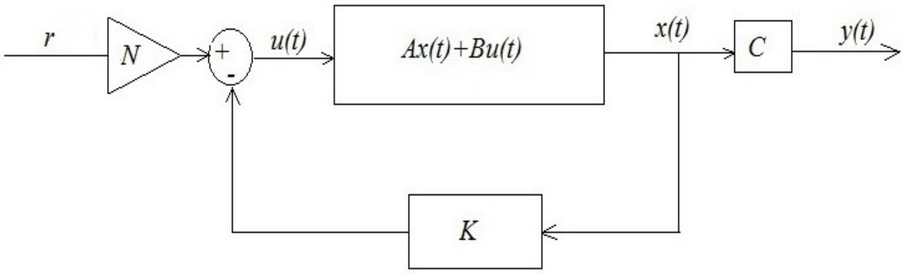


Fig. 2 Block diagram of plant and controller

IV. RESULT AND DISCUSSION

The validation of the model and the performance of the controller is presented in this section. After any plant identification process some form of model validation is required. Figure 3 shows the simulated and the real system speed response to random voltage input.

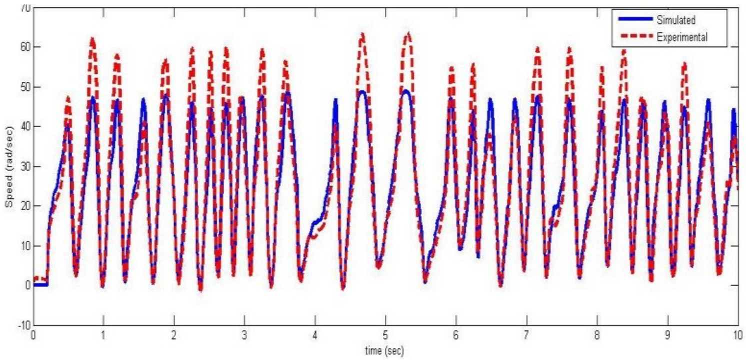


Fig 3. Speed response comparison

With regard to Figure 3 the curves simulated from the identification with the proposed technique are almost identical and close to real measurement experimental curve.

The signal in figure 4 is used as the control signal for position control of the DC motor.

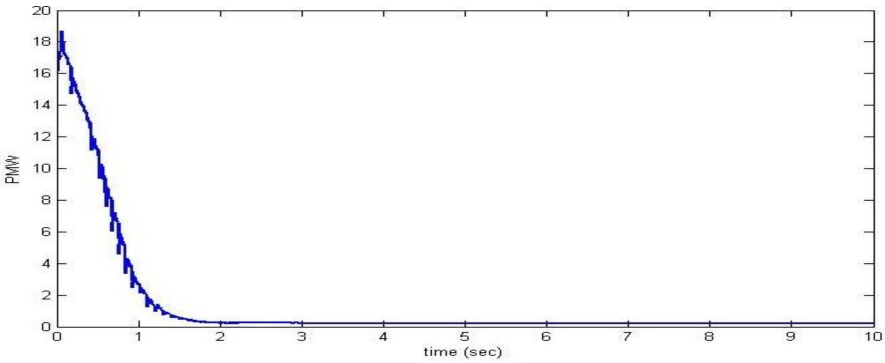


Fig 4. Control signal for step input position control

Figure 5 and 6 shows the performance of the LQR controller to step input and square wave input respectively.

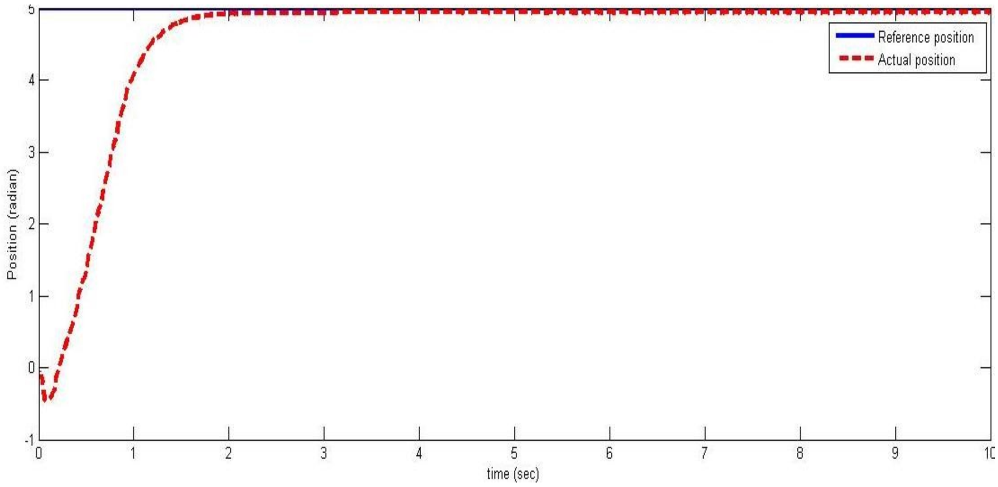


Fig. 5. Position tracking for step input

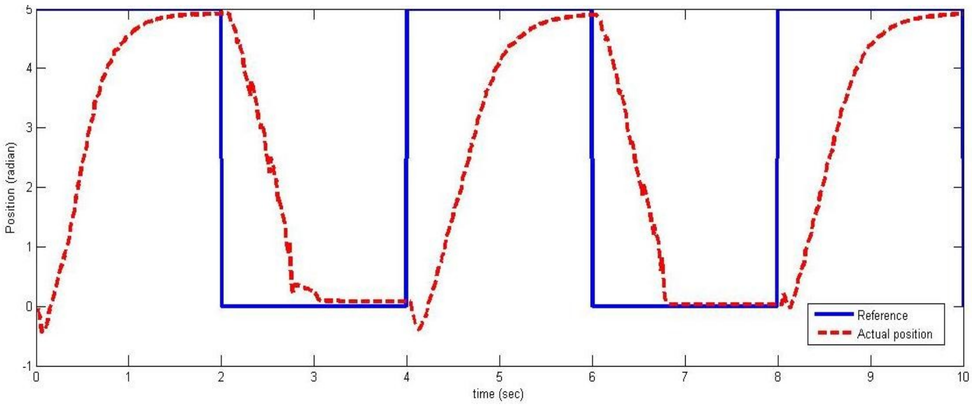


Fig. 6. Position tracking for square wave input

Figure 7 shows the control signal for the velocity tracking of the controller, while figure 8 shows the performance of the controller to track constant velocity

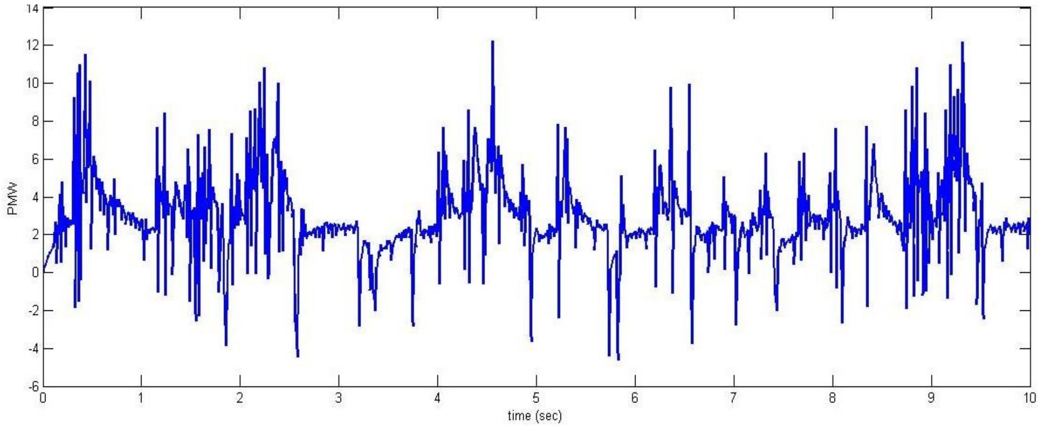
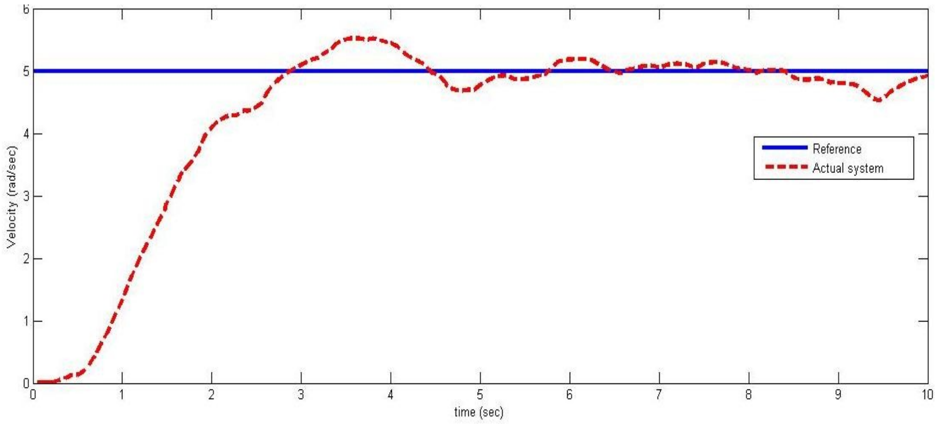


Fig. 7. Control signal for constant input velocity control

Fig. 8. Velocity tracking for step input



From the graphs, the controller performance is satisfactory.

V. CONCLUSION

A DC motor model is derived via system identification least square PEM method, after which LQR state feedback controller is design based on the derived model for position and velocity control. The identification and the controllers results were shown, and the results were successful.

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