Modelling and Position control of Brushed DC motor

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***Abstract*— DC motor is commonly used actuator in Industry and robotics applications. Different control techniques are used for position control of brushed DC motor. Because of the simplicity and reliability of Proportional-Integral-Derivative (PID) controller, it is most popular controller used in industry. In present paper, controller is designed using PID algorithm which is a conventional approach and second is Linear Quadratic Regulator (LQR) which uses state space approach. The main advantage of LQR provides a systematic way of computing the state feedback control gain matrix.LQR design minimizes a weighted squared state error and control effort. In this paper, we have compared the performance of both the controller in presence of disturbance. This is implemented on Quanser QNET 2.0 DC motor board for NI Elvis II and controllers are designed using Labview.**

Keywords*— brushed DC motor, PID, LQR, position control, Labview

I. INTRODUCTION

DC motor has very wide applications in industry as well as in robotics applications. In most of the application, DC motor modelled as a linear system and so linear control strategies are applied such as PID, pole-placement approach, LQR, Incremental motion control etc. [1],[2]. In [3], for position control of linear DC motor, PID, LQR and Model predictive control(MPC) techniques have been implemented. And in [4], Genetic Algorithm (GA) based PID controller is designed for position control of DC motor.

Many researchers modelled DC motor as a Nonlinear considering its non- linearities, partical filtering and Kalman filtering techniques has been implemented [5]. [6] has designed Antiwindup compensator(AWC) for nonlinear DC motor.

In this paper, our objective is to control the position of DC motor. For that two most popular control algorithms PID and LQR has been implemented. Former uses the conventional approach and later uses the state space approach. Performance of both the controllers has been compared using transient specifications. The results also include the performance of the controllers with different disturbances such as step disturbance and sine disturbance.

The paper is arranged as in section II experimental set up of DC motor has been discussed, in section III closed loop control of DC motor followed by section IV with observation and discussions. Section V is the conclusion.

Fig. 1 Hardware Set Up

II. MODELLING OF DC MOTOR

Quanser QNET 2.0 DC motor board for NI Elvis II, is shown in figure 1, is used for experimental setup. The system is driven using a direct-drive 18 V brushed DC motor housed in a solid aluminium frame. The inertia disk that is supplied with the motor can be easily attached or detached using magnets mounted on the connector. A single-ended rotary encoder is used to measure the angular position of the DC motor. It outputs 2048 counts per revolution in quadrature mode (512 lines per revolution). This board also includes a PWM voltage-controlled power amplifier capable to providing 2 A peak current and 0.5 A continuous current (based on the thermal current rating of the motor). The output voltage range to the load is between +/-10 V [7]. The block diagram for the experimental setup is shown in figure 2.

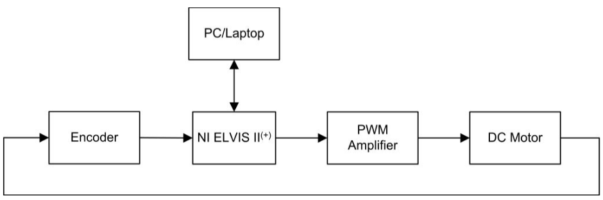

Fig. 2. Block Diagram for Experimental Setup

To obtain the model of DC motor, experimentally, the response of the DC motor for the step input has taken and obtained open loop response is as shown in figure 3, which looks more like first order model. The explanation is that the motor is overdamped (poles are real) and that one of the poles dominates the response. This is typical of a DC motor where the mechanical dynamics are much slower than the electrical dynamics, and hence dominate the response. The first order transfer function can be given as:

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$$\frac{\dot{\theta}}{V} = \frac{K}{\tau s+1} \tag{1}$$

Where K is gain of the system and τ is time constant of the system. Values obtained from figure 3, we get K=28.5 and τ=0.1sec. $\dot{\theta}$ is speed of the DC motor and V is input voltage. Now, in this paper, our aim is to control the position of the DC motor, so the transfer function becomes:

$$\frac{\theta}{V} = \frac{K}{s(\tau s+1)} \tag{2}$$

where, θ is position of the DC motor.

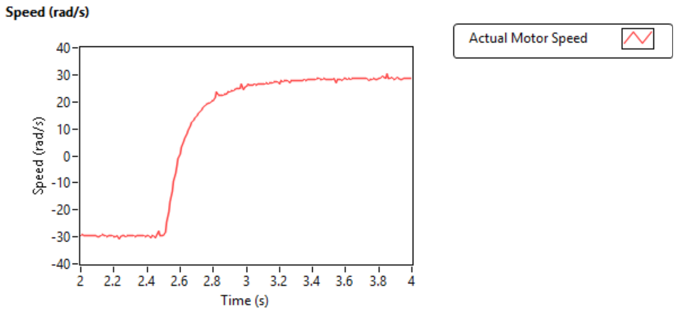

Fig. 3 Open loop response

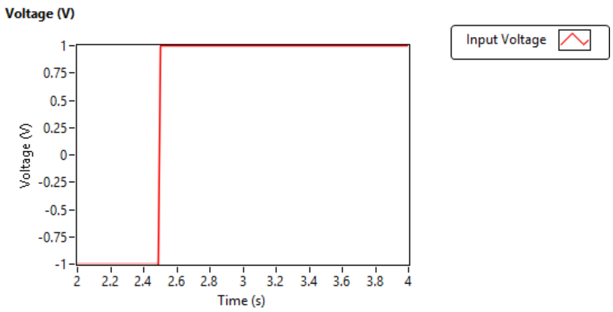

Fig. 4 Step input

III. CONTROLLER DESIGN

The position control of DC motor is achieved using PID and state feedback using LQR technique. The following paragraphs details the same:

A. Position Control using PID

The usefulness of PID controls lies in their general applicability to most control systems. In particular, when the mathematical model of the plant is not known for complicated systems analytical design methods cannot be used, PID controls prove to be most useful. And for known plant model, we can apply various design techniques for determining parameters of controller to meet transient and steady state specifications In industrial control systems, it is well known that the basic and modified PID control schemes have proved their usefulness in providing satisfactory control, although in many given situations they may not provide optimal control.

PID controller in continuous time is given by:

$$u(t) = K_p\left\{e(t) + \frac{1}{T_i}\int e(t)dt + T_d\frac{de(t)}{dt}\right\} \tag{4}$$

Where $u(t) = Controller\ output,$
$e(t) = Error\ signal,\ K_p = Proportional\ gain,$
$T_i = Integral\ time,\ T_d = Derivative\ time.$

For proper implementation of PID controller for any system finding the values of K_p, T_i and T_d i.e., tunning of the PID controller is very important aspect of designing PID controller. Equation (1) is compared with First Order Plus Dead Time (FOPDT) model as given in [8] to obtain the gains of PID controller using Ziglor-Nicholus tunning method using table 1. For Sampling frequency of 100 Hz and Input frequency of 0.2 Hz,

FOPDT model obtained given in equation (5)

$$\frac{\dot{\theta}}{V} = \frac{28.5e^{0.03s}}{0.1s+1} \tag{5}$$

TABLE 1. Ziglor-Nicholus tuning Rule (T=0.1 and L=0.03)

Controller	K_p	T_i	T_d
PID	1.2T/L	2L	0.5L

Obtained PID controller gains are $K_p = 4$, $T_i = 0.06$ and $T_d = 0.003$.

B. Position Control using LQR

The theory of optimal control is concerned with operating a dynamic system at minimum cost. The case where the system dynamics are described by a set of linear differential equations and the cost is described by a quadratic function is called the LQ problem. One of the main results in the theory is

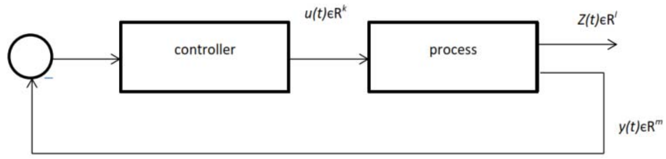

Fig. 5 LQR Feedback configuration

that the solution is provided by the linear–quadratic regulator (LQR), a feedback controller whose equations are as follows:

For a continuous-time linear system, defined on $t \in [t_0, t_1]$,

described by $\dot{x} = Ax + Bu$ with the quadratic cost

$$J = \int_0^\infty (x^T Qx + u^T Ru + 2xNu)dt \tag{6}$$

The feedback control law that minimizes the value of the cost is

$$u = -Kx \tag{7}$$

For finding the out the value of gain K we need to solve the Algebraic ricatti equation, which needs the values of Q and R. Large Q penalises transients of x, large R, penalises usage of control action u.

A simple and reasonable choice for the matrices Q and R is given by Bryson's rule. Select Q and R diagonal, with In essence, Bryson's rule scales the variables that appear in LQR so that the maximum acceptable value for each term is 1. Although Bryson's rule usually gives good results, often it is just the starting point for a trial-and-error iterative design procedure aimed at obtaining desirable properties for the dosed-loop system [9].

The advantages of used LQR are it is easy to design and increases the accuracy of the state variables by estimating the state. The nice feature of the LQR control as compared to pole placement is that instead of having to specify where a eigen values should be placed a set of performance weighting are specified that could have more Intuitive appeal. The result is a control that is guaranteed to be stable [10].

For the DC motor as in (1), by proper selection of

$$Q = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$R = [1]$$

We obtain K= [0.1562 1.0000] and practical value adjusted to K= [0.09 1.5]. From equation (2) model of the DC motor is obtained as:

$$A = \begin{bmatrix} -10 & 0 \\ 1 & 0 \end{bmatrix} \text{ and } \quad B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

IV. Results and Discussions

As obtained in section III, the PID controller is applied to Quanser DC motor, using the values of gain parameters. As seen in figure 6, the step input with final value 2 rads, which gives settling time of less than 1 sec. Figure 7 shows the control efforts u. figure 8 shows the performance of LQR controller, which gives settling time of less than 0.5 sec. The control effort u for LQR is shown in figure 9.

In the presence of disturbance, the performance of PID and LQR are analysed. The disturbances considered are step of 1 rads at T= 8 secs as well as sine type of disturbance 0.5sinπt.

In figure 10, the performance of the PID controller is satisfactory as the effect of the disturbance is rejected by the PID controller. Figure 11 shows the control efforts for the same. Figure 12 shows the effect of disturbance on LQR, which generated permanent offset error, figure 13 shows the control efforts for the same. Figure 14 and figure 16 gives the performance of PID and LQR respectively for sine disturbance. Figure 15 and figure 17 show the control efforts respectively.

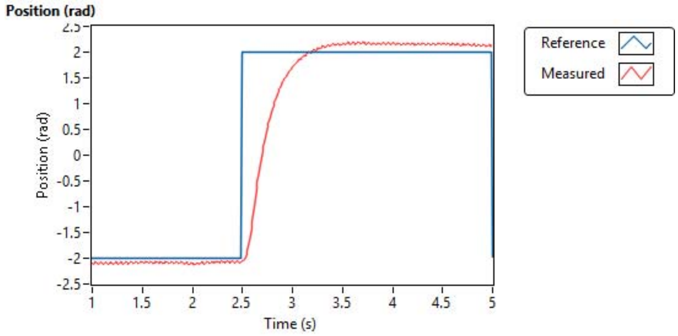

Fig. 6 Tracking of set point using PID, ($K_p = 4, T_i = 0.06$ and $T_d = 0.003$)

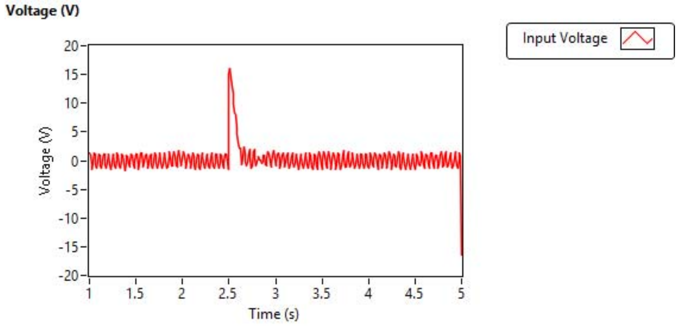

Fig. 7 PID controller controller effort u(t)

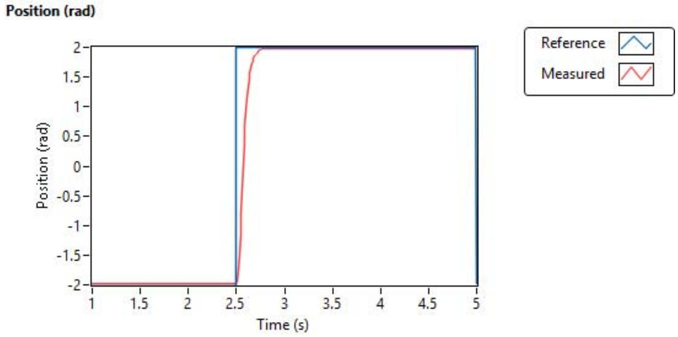

Fig. 8 Tracking of set point using LQR , K= [0.09 1.5]

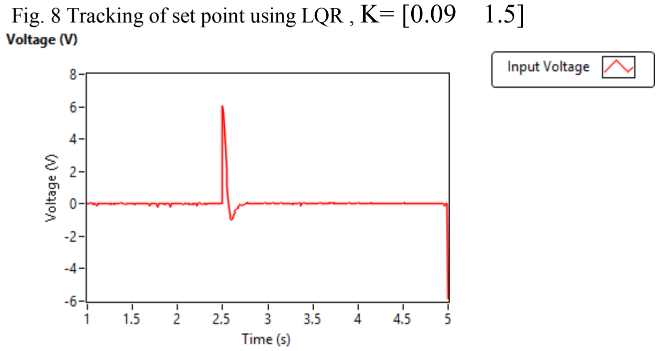

Fig. 9 LQR controller effort u(t)

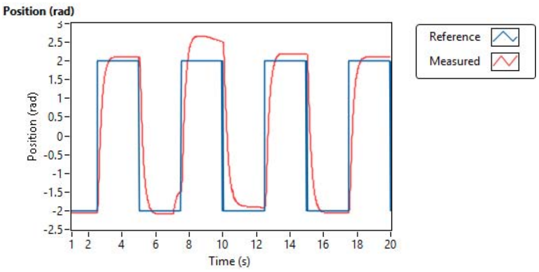

Fig. 10 Tracking of set point using PID with step disturbance of 3

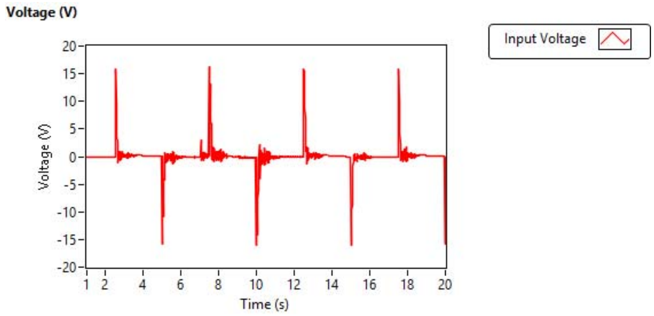

Fig. 11 PID controller output u(t) for step disturbance

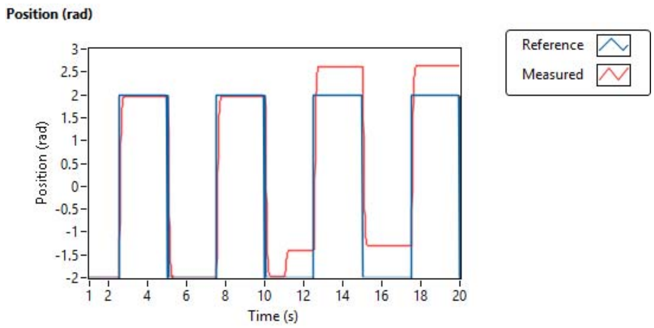

Fig 12. Setpoint tracking using LQR with step disturbance of 1

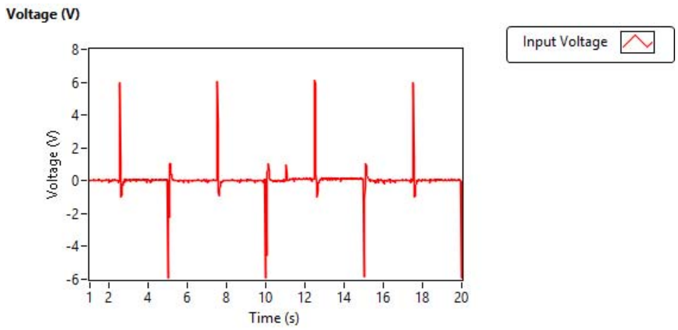

Fig. 13 LQR controller output u(t) for step disturbance of Amplitude 1.

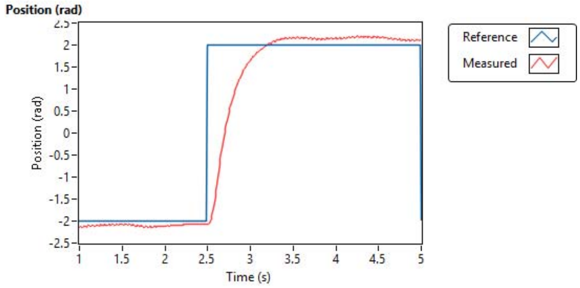

Fig. 14 setpoint tracking using PID with sine disturbance of Amplitude 0.5 and frequency 0.5Hz

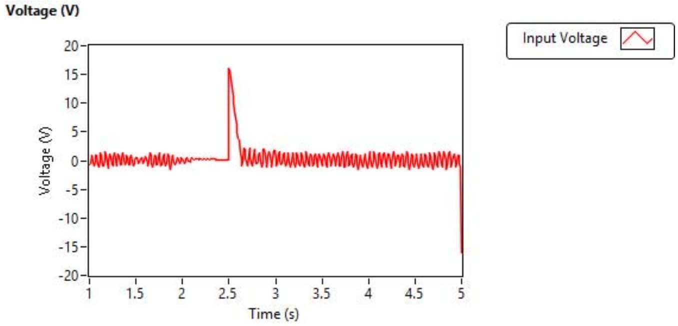

Fig. 15 PID controller output u(t) with sine disturbance of Amplitude 0.5 and frequency 0.5Hz

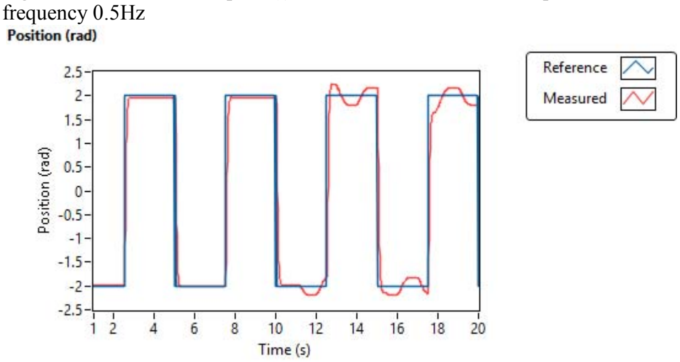

Fig. 16 setpoint tracking using LQR with sine disturbance of Amplitude 0.5 and frequency 0.5Hz

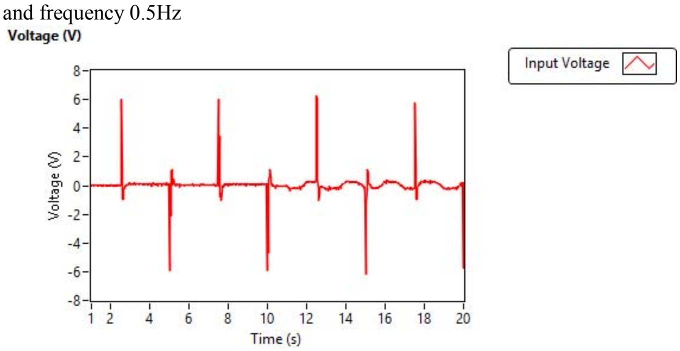

Fig. 17 LQR controller output u(t) with sine disturbance of Amplitude 0.5 and frequency 0.5Hz

V. CONCLUSION

In this study, LQR control design among the optimal control techniques and PID control design, one of the classic control methods, was conducted for the dc motor position control. Comparing the performance of controllers, settling time t_s achieved by PID is 0.75 sec. While settling time t_s achieved by

LQR is 0.3sec and we can also compare the cost function u, which is minimized using LQR. By observing the response we can conclude that LQR is better in the absence of disturbances, in terms of settling time and also the control efforts required. In the presence of disturbance, LQR introduces permanent offset error, which can be reduced by proper designing of Q and R matrices.

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