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POSITION CONTROL OF A DC MOTOR: AN EXPERIMENTAL COMPARATIVE ASSESSMENT BETWEEN FUZZY AND STATE FEEDBACK CONTROLLER

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ABSTRACT

This paper present comparison between model based and non-model based controllers in position control of a DC motor. A Fuzzy Logic Controller (FLC) which is a non-model based controller and a Linear Quadratic Controller (LQR) which is a model-based controller are implemented on a real DC motor. The performances of the two controllers are compared experimentally.

Keywords: DC motor, fuzzy logic controller (FLC), linear quadratic controller (LQR), pulse width modulation (PMW), state feedback controller.

INTRODUCTION

DC motor has excellent performance in speed control; it has been used in industries even though the maintenance costs of induction motor are less than the DC motor. Also, position control of DC motor has attracted researcher worldwide and several methods have evolved [1], but the question "which controller is the best for DC motor position and speed control?" still keep arising. Many researchers have work on this area and trying to give an answer [1-7]. In [1, 2] performances of Proportional-Integral Derivative (PID) and Fuzzy Logic Controllers (FLC) are compared for the position control of a DC. In [3] PID parameters tuning using the popularly known Ziegler Nichols method is compared with metaheuristic technique, Genetic Algorithm tuning in simulation. While in [4-7], speed control of DC motors are compared for different controllers all in computer simulation.

In this paper, a real time experimental comparison will be conducted between model based and non-model based controllers. A Linear Quadratic Regulator (LQR) controller performance, which is model based, will be compared with fuzzy controller which is a non-model based controller. The criteria's to be judge will be the controller's time response specifications, that is overshoot, settling time, steady state errors, oscillation and the control input signal.

The rest of the paper is organized as follows; section 2 is the DC motor model description, section 3 describes the controllers design, section 4 shows the experimental setup, section 5 includes experimental results and the performances comparison of the controllers. Finally, Section 6 concludes the findings of this work.

DC MOTOR MODEL DESCRIPTION

The general position-voltage transfer function of a DC motor is given by equation (1) [8].

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

where θ_m is the angular 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:

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

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

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

The general torque equation of a DC motor is given by:

$$T = J\ddot{\theta} + D\dot{\theta} \qquad (4)$$

The torque developed by the motor can be written in terms of the current (I) drawn by the motor as:

$$T = k_t I \qquad (5)$$

Substituting (5) in (4) gives:

$$k_t I = J\ddot{\theta} + D\dot{\theta} \qquad (6)$$

The block diagram of the experimental setup used for parameter identifications is shown in Figure-1. A Fio STD development board and a personal computer are used as the data acquisition system, a current sensor and a rotary encoder are the sensors which measure the current drawn by the motor and motor speed respectively, the motor driver serves as the servo-amplifier to the DC motor itself.

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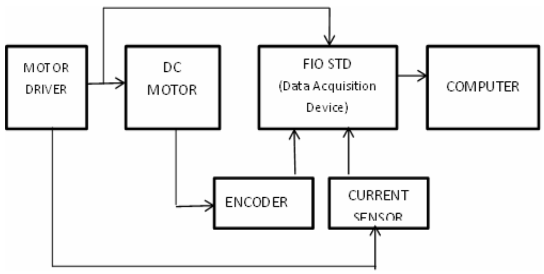

Figure-1. Parameter identification experimental block diagram.

The motor armature resistance R_a of the motor is measured directly using ohmmeter, while the motor constants K_t, K_b are calculated with no load current measured value and using the no load torque from the manufacturer. Various readings of current (I) drawn by the motor, actual angular speed ($\dot{\theta}$) and angular acceleration ($\ddot{\theta}$) of the motor are measured and recorded and average values $J_m$and D_m are computed using equation (6). The estimated parameters are shown in shown in Table-1.

Table-1. Estimated parameters of the DC motor.

Torque constant K_t (Nm/A)	0.2063
Back emf constant K_b(V-s/rad)	0.2063
Armature resistance R_a (ohms)	0.5000
Motor inertia J_m (kg-m^2)	0.3550
Motor viscous friction coefficient D_m (Nm s/rad)	0.0124

Substituting the parameters in Table-1 in equation (1) the transfer function of the DC motor is obtained is as equation (7).

$$\frac{\theta_m(s)}{E_a(s)} = \left(\frac{34.1}{s+16.1}\right) \ldots\ldots\ldots\ldots\ldots (7)$$

CONTROLLERS DESIGN

Detail design of control strategies for both non-model based (FLC) and model based (state feedback LQR) is presented in this section.

a) Non-model based controller (FLC)

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is achieved from expert knowledge into an automatic control system, and does not need any mathematical model [5]. While the others control system use model to provide a controller for the plant, it only uses simple mathematical calculation to simulate the expert knowledge.

This paper considered the fuzzy controller which has two inputs and one output, the inputs are the position error (θ) of the motor and the speed error of the motor, that is the position error derivative ($\dot{\theta}$), the output of the fuzzy control is the signal generated based on decisions as design using rule base. The block diagram of the system is shown in Figure-2.

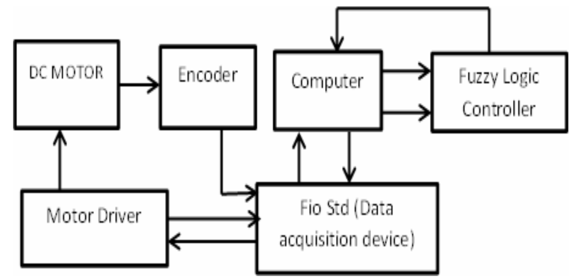

Figure-2. Block diagram of fuzzy system.

A Fuzzy logic controller design involves the following [9]:

a) Selection of type and number of membership function
b) Selection of rule base
c) Inference mechanism and
d) Defuzzification process

For this controller, the membership function and rule base are developed as in [10]. Triangular membership function is used. Table-2 shows the appropriate fuzzy control signal for different position error (θ) and its derivative ($\dot{\theta}$), and also the chosen membership. The system has 49 possible control signals (rule based).

Table-2. Fuzzy rule base [10].

$\dot{\theta}/\theta$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The selected scale is of the position error the range of [-5 5], while that of the derivative of the error is [-10 10]. The membership functions of the output are both implemented with seven membership function just as the inputs, and scale of the range of [-100 100] was found to be optimal after tuning.

b) Model based state feedback controller (LQR)

These type of controllers uses linear mathematical model of a system in state-space form. The transfer function is given in equation (7).

Transforming equation (7) to state-space model yields equation (8),

$$A = \begin{bmatrix} 0 & 1 \\ -16.1 & 0 \end{bmatrix}, = \begin{bmatrix} 1 \\ 34.1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix}, D = [0] \ldots. (8)$$

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A optimal linear quadratic regulator (LQR) is a model based controller that estimate the controllers gain using system model [8]. The aim of the LQR is to minimize the cost function;

$$J = \int_0^\infty (x * Qx + u * Ru)\,dt \ldots\ldots\ldots\ldots\ldots (9)$$

Q is a positive-definite (or positive-semi definite) Hermitian or real symmetric matrix, and R is a positive-definite Hermitian or real symmetric matrix. The general linear model based LQR controller block diagram is shown in Figure-3.

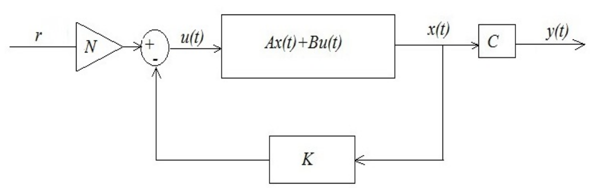

Figure-3. Block diagram of plant and model based controller.

After tuning the Q and R matrices with experimental trials, the values of the controllers gain *K* and *N* are computed using MATLAB *lqr* function.

EXPERIMENTAL SETUP

The block diagram of the experimental setup used is shown in Figure-4.

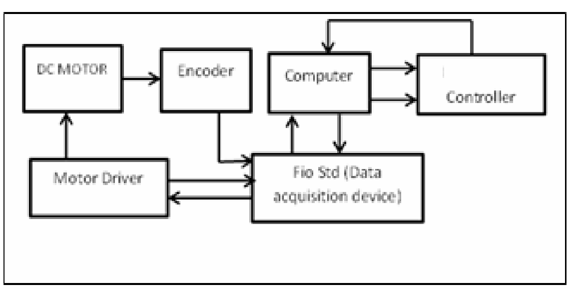

Figure-4. Experimental block diagram.

It consist of Fio Std [11] microcontroller which serves together with a personal computer as the data acquisition system, a rotary encoder [12] as the sensors for measuring the motor speed, the motor driver [13] which is served as the servo-amplifier and the DC motor itself.

The DC motor considered in this paper is MY1016Z2-250W manufactured by Yeuqing Onlybo Instruments. The specifications of the motor are given in Table-3.

Table-3. DC motor specifications.

Operating voltage (v)	24
No load speed (rpm)	434
No load current (A)	1.8
Maximum current (A)	9.74
No load torque (Nm)	0.39
Maximum torque (Nm)	11.5

RESULT AND DISCUSSIONS

The experimental performance of the controllers to a step reference and a square input will be presented in this section. The input is voltage in pulse width modulation (PMW) form. The PMW ranges from -100 to 100 which is equivalent to -24 to 24v; the output is the position of the DC motor. The control signal and response to a step input reference signal is shown in Figure-5 and Figure-6, respectively.

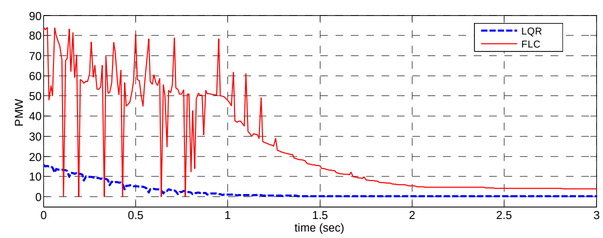

Figure-5. Control signal for step input.

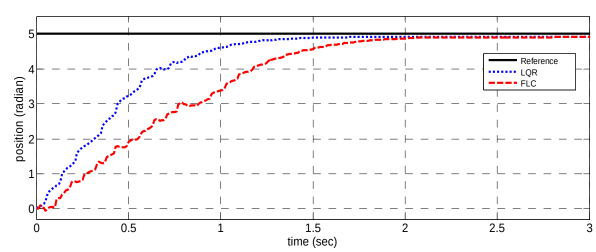

Figure-6. Response for step input.

From the figures it is observed that the control signal required for fuzzy controller is much higher than the LQR, the LQR has faster rise and settling time, but both have no oscillations. The time response specification for step input reference is summarized in Table-4.

Table-4. Comparative assessment of time response specification to a step response.

Controller	Rise time (s)	Settling time (s)	% Overshoot	Control input maximum (PMW)
FLC	1.8	1.81	0	85
LQR	1.07	1.57	0	15

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The control signals for the step response and response to a square wave input reference signal of period 4 seconds are shown in Figure-7 and Figure-8, respectively.

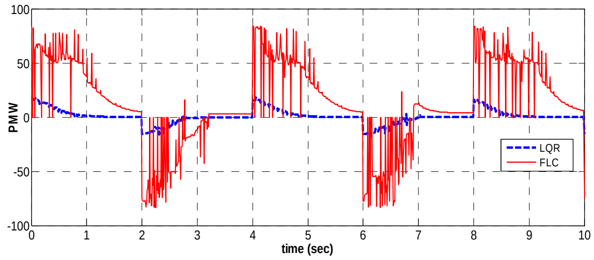

Figure-7. Control signal for square wave input.

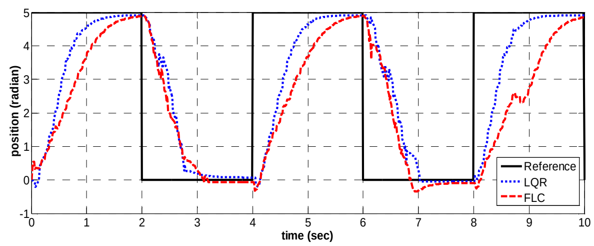

Figure-8. Response for square wave input.

From Figures 7 and 8, just as with the step response, for the pulse response the control signal required for fuzzy controller is much higher than the LQR, small percentage of oscillations is observed in FLC when stopping the DC motor. The LQR controller tracks the reference faster than the FLC; this is due to the computational time needed by the fuzzy controller to perform the decision and to scan through the if then rules.

CONCLUSIONS

Comparison between model based and non-model base controllers for a DC motor position control is presented. The Model of the DC motor is derived through parameter identifications and measurements. Practical experiments were carried out to test the controllers for position control, and the results are shown and compared. An LQR controller which is model based performs better than the FLC which is non-model based controller in terms faster response and lesser energy consumption, because LQR requires less control input signal.

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