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Parameter estimation and speed control of a PMDC motor used in wheelchair

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Abstract

The objective of this paper is to estimate the parameters of a permanent magnet DC motor (PMDC) using the genetic algorithm (GA) and compare the speed control of a PMDC motor using PI, PID, and state feedback controller. The electrical, mechanical and electromechanical parameters estimated using genetic algorithm is used in modelling of the PMDC motor in Matlab/Simulink. The speed controllers are designed from the estimated parameters of PMDC motor in Matlab/Simulink. The performance of PI, PID and state feedback speed controllers are compared. The simulation results of state feedback controller for speed control of PMDC motor provides less peak overshoot as well as faster settling time compared to PI and PID controller.

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Keywords: PMDC motor; PID; genetic algorithm; state feedback controller; wheelchair

1. Introduction

The PMDC motors are used as actuators in various applications such as robotics, wheelchair, etc. due to low cost, low friction, and ease of control [1]. The accurate design of the controller is more important for safety as well as comfort operation of the wheelchair user [2]. The importance of accurate control of PMDC motor in wheelchair necessitates the accurate modelling of PMDC motor to design the appropriate controller. Estimation of parameters

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may lead to poor controller design and leads to the unstable condition. Therefore, appropriate modelling of PMDC motor is vital to estimate the controller parameters.

In literature, various approaches such as frequency response method [3-4], recursive least square method [5], inverse theory [6], moment method [7], quantized sensors [8], etc. are applied for estimation of motor parameters. In addition to these approaches, the experimental approaches to extract the parameters of the model by conducting experiments are in practice. The main drawbacks of experimental approach are costly, difficulty in conducting experiment and complex in computations due to non-linear dynamics. Meta-heuristic optimization methods like Tabu search techniques [9], genetic algorithm [10], particle swarm optimization (PSO) [11], etc. are also attempted for parameter estimation in different motors.

The objective of this paper is to study the application of genetic algorithm (GA) for parameter estimation of PMDC motor and control the speed of the motor using PI, PID and state feedback controllers using estimated parameters. The optimization methods select the motor parameters in search space with good fitness value. The selected motor parameters are updated until the minimum error/end of the iteration is reached. These estimated parameters are used in the design of controller in Matlab/Simulink.

The paper is organized as follows. Section 2 discusses the mathematical modelling of PMDC motor used in the electric wheelchair. Estimation of motor parameters from the genetic algorithm (GA) is discussed in section 3. The design of PI, PID and state feedback controllers is explained in section 4. The section 5, elucidate the performance of PMDC motor from estimated parameters and speed control of PMDC motor using PI, PID, and state feedback controllers.

2. Mathematical Model of PMDC Motor

A schematic diagram of PMDC motor is shown in Fig. 1. It is used in industrial motion control systems like the electric vehicle, electric wheelchair, etc.

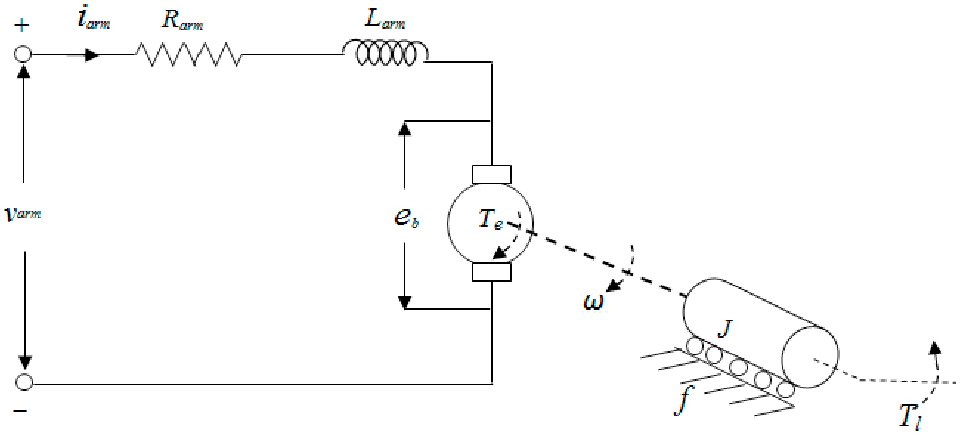

Fig. 1. Schematic diagram of a PMDC motor

The dynamic equations of a PMDC motor are modelled using equations (1) - (4).

$$v_{arm}(t) = L_{arm}\frac{di_{arm}(t)}{dt} + R_{arm}i_{arm}(t) + e_b(t) \tag{1}$$

$$T_e(t) = J\frac{d\omega(t)}{dt} + f\omega(t) + T_l(t) \tag{2}$$

$$T_e(t) = K_t i_{arm}(t) \tag{3}$$

$$e_b = \omega(t)K_b \tag{4}$$

Equations (1) and (2) can be rearranged using equation (3) and (4)

$$\frac{di_{arm}(t)}{dt} = -\frac{R_{arm}}{L_{arm}} i_{arm}(t) - \frac{K_b}{L_{arm}} \omega(t) + \frac{1}{L_{arm}} v_{arm}(t) \tag{5}$$

$$\frac{d\omega(t)}{dt} = \frac{K_t}{J} i_{arm}(t) - \frac{f}{J} \omega(t) - \frac{T_l(t)}{J} \tag{6}$$

The block diagram of the PMDC motor model using Laplace transform of equations (5) and (6) is shown in Fig. 2.

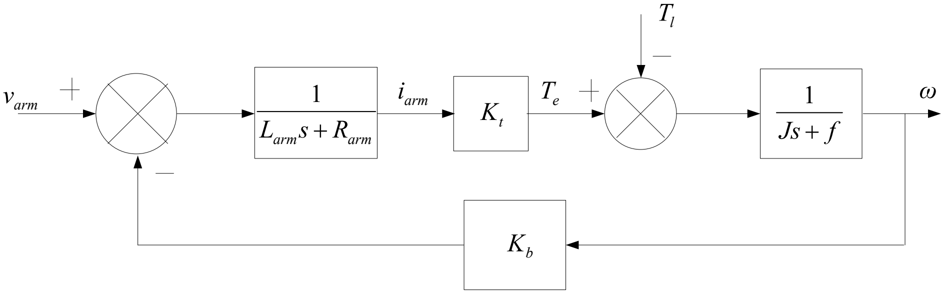

Fig. 2. Block diagram of PMDC motor model

From the block diagram, the transfer function for speed control of PMDC motor is represented using equation (7)

$$\frac{\omega(s)}{v_{arm}(s)} = \frac{K_t}{(L_{arm}s + R_{arm})(Js + f) + (K_t K_b)} \tag{7}$$

The state space model of the PMDC is given below using equation (5) and (6). In this model, $x_1(t) = \omega(t)$, $x_2(t) = i_{arm}(t)$, $u(t) = v_{arm}(t)$, and $y(t) = \omega(t)$.

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} -\frac{f}{J} & \frac{K_t}{J} \\ -\frac{K_b}{L_{arm}} & \frac{R_{arm}}{L_{arm}} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} -\frac{T_l}{J} \\ \frac{1}{L_{arm}} \end{bmatrix} u(t) \tag{8}$$

$$y(t) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} u(t) \tag{9}$$

The accurate design of the controller is possible with appropriate parameters of the motor model. Further, the parameters of PMDC motor are estimated using a genetic algorithm as given below.

3. Motor parameter estimation using Genetic Algorithm

The PMDC motor parameter can be estimated using the genetic algorithm (GA). The genetic algorithm is based on natural selection, reproduction, and mutation; optimize the PMDC motor parameters [9-10]. The algorithm begins with initialization of population, consists of individuals. The individual is a vector representing the motor parameters. The individuals are a combination of genes represented as 1's and 0's to form string variables called chromosomes. In parameter estimation problem, viscous friction coefficient, moment of inertia, torque constant, back-electromotive force constant, armature inductance and armature resistance are chromosomes. The fitness function is evaluated with each individual. In this work, the population size is initialized to 20. Each chromosome with 60 strings is generated. The next generation is created with an individual with good fitness value. The identified best individuals are used for next iteration. Later, the process of selection, reproduction, and mutation is applied for the creation of next generation. The process is repeated until the minimal error/end of the iteration is reached. The flowchart for estimation of parameters using genetic algorithm is shown in Fig. 3.

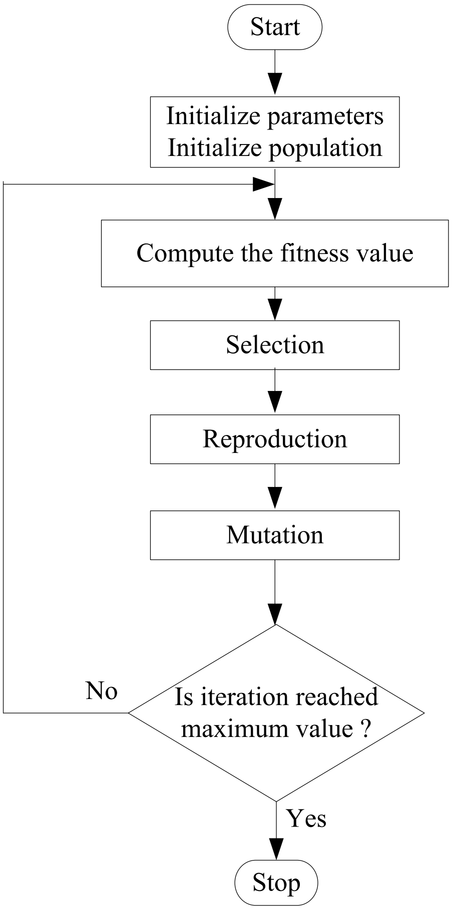

Fig. 3. Flowchart for GA

The fitness evaluation function for motor parameters are estimated based on mean square error and calculated using equation (10)

$$F(\hat{c}) = F_1(\hat{c}) + aF_2(\hat{c}) \tag{10}$$

where

$$F_1(\hat{c}) = \frac{1}{N}\sum_{j=1}^{N}\|\omega_r - \omega_e\|^2$$

$$F_2(\hat{c}) = \frac{1}{N}\sum_{j=1}^{N}\|i_{arm\_r} - i_{arm\_e}\|^2$$

Using the estimated parameters from GA, the speed controller is designed using Matlab/Simulink are elucidated in the following section.

4. Controller design

One of the objectives is to design the accurate speed controller. Therefore PI, PID and state feedback controller are considered in this work and the design of the controller is discussed in the following sub-sections.

4.1. Design of PI and PID controllers

The most popular and widely used controllers in industries are PI (Proportional and Integral), and PID

(Proportional, Integral, and Derivative) because of successful practical application. The transfer function of the PID controller is given in equation (11)

$$G(s) = K_p + \frac{K_i}{s} + K_d s \tag{11}$$

The proportional controller reduces the rise time and does not improve steady-state accuracy. The steady-state accuracy can be improved with an integral controller at a cost of transient response. Therefore, a derivative controller is used along with PI controller to improve the transient response. The appropriate selection of K_p, K_i, and K_d help to achieve the desired performance. The tuning procedure of the controller parameters, to obtain a desired performance of the PMDC speed control system is discussed below.

Ziegler and Nichols proposed sustained oscillations method of tuning PID controller using trial and error method. In this method, only the proportional gain is varied from zero to critical value and other gains are set to zero. Using critical gain the PI and PID parameters are calculated and tuned until desired response is obtained. In PI controller K_p = 0.042346 and K_i = 3.69 and in PID controller K_p = 0.084618, K_i = 5.4121, and K_d = 0.00022659 are obtained and the response is simulated.

4.2. Design of state feedback controller

In state feedback controller design, the desired closed loop poles are chosen to obtain the peak overshoot is less than 5% and settling time is less than 2 sec.

The appropriate state feedback gain to place poles at desired locations is obtained from control law using equation (12)

$$u = -Gx(t) \tag{12}$$

The state feedback gain G is calculated using Ackermann's formula.

5. Result and discussion

The load test results are obtained from 24 V, 320 W, 3 A, 4600 rpm PMDC motor used in the electric wheelchair to study the estimated parameters of the motor. A genetic algorithm is used to estimate the motor parameters and initialized the population size to 20. In a genetic algorithm, the mutation probability is considered as 0.04 and crossover probability as 0.75. The best fitness value versus a number of iterations using genetic algorithm is shown in Fig. 4. The PMDC motor parameters such as viscous friction coefficient, moment of inertia, torque constant, back-electromotive force constant, armature inductance and armature resistance are estimated using genetic algorithm is given in Table 1.

Table 1. Estimated parameters of PMDC motor.

Parameters	Estimated parameters
Armature resistance	0.157378 Ω
Armature inductance	0.0003137 H
Back-electromotive force constant	0.0492 Volts/(rad/sec)
Torque constant	0.0501 Nm/Amps
Moment of inertia	0.000466 kg-m^2
Viscous friction coefficient	0.0002546 Nm/(rad/sec)

From the estimated parameters, PMDC motor is modelled in Matlab/Simulinking and obtained angular speed error and armature current error for different load conditions. Fig. 5 and Fig. 6 shows the simulated results are compared with experimental results. From Fig. 5 and Fig. 6, it is clear that the genetic algorithm based motor parameter estimation aids in accurate modelling of PMDC motor for the design of the controller and estimation accounts non-linear dynamics.

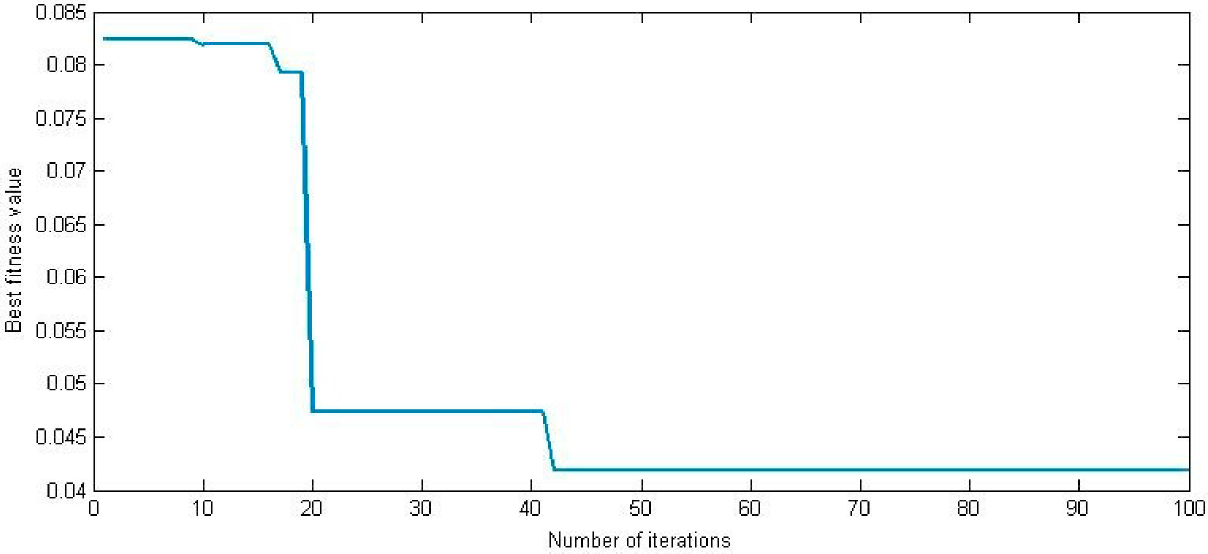

Fig. 4. Best fitness value versus number of iterations using genetic algorithm

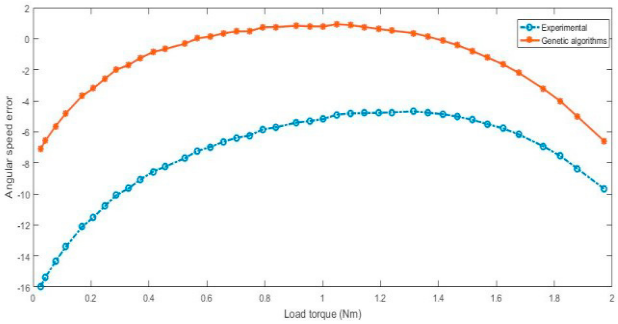

Fig. 5. Angular speed error versus load torque

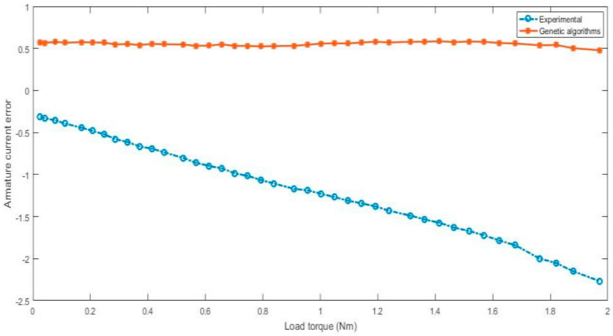

Fig. 6. Armature current error versus load torque

Using estimated PMDC motor parameters, the proposed controllers are simulated in Matlab/Simulink for control of speed in the PMDC motor. The performance of different controllers for set speed at 481 rad/sec is shown in Fig. 7. The PI controller shows 37.83% of peak overshoot and the introduction of derivative controller reduces the peak overshoot to 11.02%. The settling time for PI and PID controllers are 0.16 sec and 0.18 sec respectively. Therefore, state feedback controller has been designed to improve the system response. It has been found that the state feedback controller produces 0.06% of peak overshoot with settling time of 0.08 sec. Table 2 shows the comparison of performance specifications of different controllers.

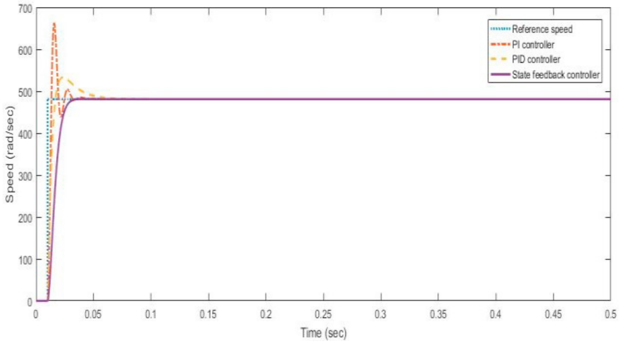

Fig. 7. Step response for PMDC motor

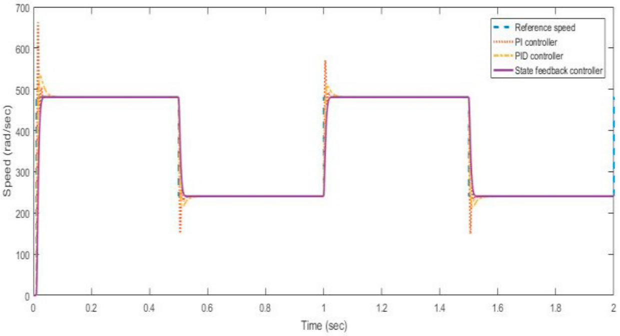

Fig. 8. Step response for PMDC motor with rising and fall of speed

Table 2. Performance of different controllers.

Controllers	Maximum peak overshoot (%)	Settling time (sec)
PI controller	37.83	0.16
PID controller	11.02	0.18
State feedback controller	0.06	0.08

Further, the performance has been studied varying the speed from 481 rad/sec to 240.5 rad/sec as shown in Fig. 8. It has been found that the state feedback controller improves the response compared to PI and PID controllers.

6. Conclusion

In this paper identification of PMDC motor parameters using genetic algorithm has been proposed. Using estimated parameters, the motor is modelled and validated the model parameter with experimental results. Further, speed controller has been designed. It has been found that the state feedback controller produces less peak overshoot compared to PI and PID controllers. Also, the state feedback controller for PMDC motor settles faster compared to other controllers considered.

Nomenclature

a	weight to mean square current error
e_b	back electromotive force in Volts
F	fitness function
f	viscous friction coefficient in Nm/rad/sec
G	state feedback gain
i_{arm}	armature current in Amps
i_{arm_e}	estimated armature current in Amps
i_{arm_r}	real armature current in Amps
J	moment of inertia in kg-m^2
K_b	back-electromotive force constant in Volts/rad/sec
K_d	derivative gain
K_i	integral gain
K_p	proportional gain
K_t	torque constant in Nm/Amps
L_{arm}	armature inductance in Henry
N	number of measured samples
R_{arm}	armature resistance in Ohms
T_l	load torque in Nm
T_e	electromagnetic torque in Nm
u	input variable
v_{arm}	armature voltage in Volts
x_1, x_2	state variables
y	output variable
ω	angular speed in rad/sec
ω_e	estimated angular speed in rad/sec
ω_r	real angular speed in rad/sec
$d\omega/dt$	angular acceleration

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Appendix

Specification of PMDC motor for electric wheelchair
24 V, 3 A, 320 W, 4600 rpm, Motion Technology Electric & Machinery Co., Ltd., Taiwan.