Identification and Control of a DC Motor for Four-Wheeled SMP Mobile Robot

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Abstract— **This paper intends to identify the parameter of a DC motor used in Surface Mobile Platform (SMP) mobile robot. SMP is optimized for rough surface or off-road driving situations. DC motors are used in many fields due to their high starting torques and speed regulation characteristics. In particular, the operation of DC motors must control their speed accurately in order to obtain the desired efficiency. There are two main parts in this paper. The first one is to create the mathematical model of a DC motor model by using MATLAB system identification toolbox. The PID tuning method is used to simulate and test DC motor control. The second part is the real-time testing of the DC motor control in SMP mobile robot. The experimental results were successfully consistent with the driving parameters controlled by four DC motors installed on the SMP**.

Keywords—DC motor, PID controller, MATLAB simulation, PWM input signal

I. Introduction

Nowadays, DC motors are used for various types of vehicle designs for autonomous mobile robot with features such as positioning, orientation, sensing and planning. The principle of autonomous mobile robot is based on controlling the relative velocities of both tracks in a similar way to the control of differential wheeled vehicles and to control and track the speed of mobile robot DC motor are widely used. Moreover, DC motors are widely used in industrial applications due to their speed, position control and wide adjustability advantages. The performance of control system of DC motor such as speed and position information is very important for effective use. To control the mobile robot with suitable control laws, it is necessary to create a mathematical model of the system [1].

To control the speed of a DC motor, proportional, integral and derivative (PID) controllers are often used to obtain efficient operating performance. In order to determine the PID coefficients of a DC motor to be used in any system, the technical characteristics of the motor must be known [2].

The parameters for each DC motor may be changed during the operation condition. In autonomous mobile robot application, trial and error is often used to find the optimum PID constants [3]. It is need to analysis the performance of control system for speed and position data in a DC motor. Therefore, it is important and necessary to create a mathematical model of the system. To describe the unknown system, experimental methods are important and important to determine the parameter of the approximate mathematical model of DC motor [5][6].

This paper is structured as follows: Section I mentioned the introduction of this paper, section II introduces the system model of the DC motor and proposes control structure and method. In Section III, experimental results discussed. Finally, conclusion remarks and perspectives are given in Section IV.

II. System Modeling

The main idea of this research is to identify the unknown parameters of four DC motors for driving the SMP in rough surface. These parameters are obtained using MATLAB simulation and a mathematical model of the DC motor. In this study, the control system of SMP is implemented with four gear encoder DC motors, a main controller, DC motor driver and 12V power supply. The microcontroller detects the motor encoder signal, calculates the motor speed, and estimate errors between the actual and desired speed. This experimental set up the four DC motors mounted on SMP is shown in Fig. 1.

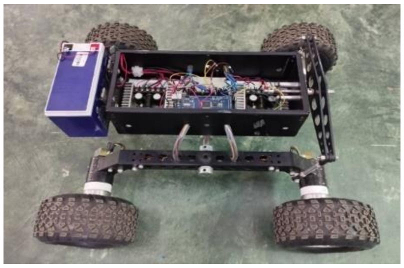

Fig. 1. The experimental set up of the SMP mobile robot.

A. DC Motor Model

The DC motor is a power actuator device that delivers energy to a load. The DC motor converts direct current (DC) electrical energy into rotational mechanical energy. A major with fraction of the torque generated in the rotor (armature) of the motor is available to drive an external load [2]. The speed of the DC motor is proportional to the applied voltage and motor torque is proportional to current. Therefore, the speed of DC motors can be controlling by changing the supply voltage, resistance or electronic control [4]. The dynamic model of a DC motor is showing in Fig. 2. The DC motor speed control block diagram is shown Fig. 3.

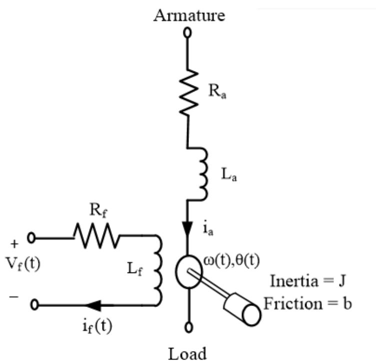

Fig. 2. DC motor model.

The mathematical equations of DC motor by applying KVL are as follows:

$$v = i_a R_a + L_a \frac{di_a}{dt} + e_b \qquad (1)$$

R_a = armature resistance (Ω- ohm).
L_a = armature inductance (mH).
T_m = motor friction torque (N m).
i_a= armature current (A).
$V_a(s)$= armature voltage (4.6V).
E_b=back emf (V) .
J_m= motor inertia (kg m^2).
K_m= motor torque constant (Nm/A).
K_b= back emf constant (V s/rad).
ω = angular speed (rad/s).
θ = angular position of rotor shaft (rad/s).
V = 12 (V) (motor $with\ gearbox$) (1: 65.5 $ratio$).
Encoder = 500 (cpr).

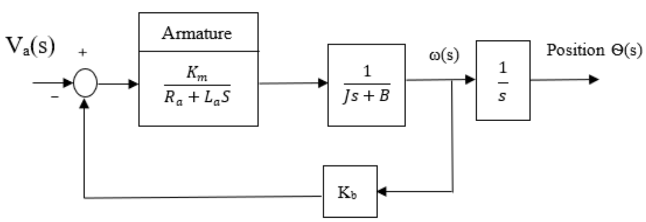

Fig. 3. Block diagram of DC motor.

B. *Control Structure and Methodology*

PID speed controller is a low-level controller used to control the rotational speed of DC motor with the help of the values of the constants K_p, K_i, and K_d. PID stands for Proportional-Integral-Derivative. These three types of control mechanism are combining that it produces an error signal, and this error signal is using as feedback to control the SMP. From the moment the desired speed is introduced until it is changed by closed-loop adjustments, it is desired to move the robot to a specific position on the playing field. They provide control signals that are proportional to the error between the reference signal and the actual output (proportional action), to the integral of the error (integral action), and to the derivative of the error (derivative action).

$$U(t) = K_I\, e(t) + K_I \int_0^t e(\tau)d(\tau) + K_d \frac{d(e)}{d(t)} \qquad (2)$$

where U(t)= control signal
e(t)= error signal
K_p=proportional gain
K_i=Integral gain
K_d=The derivative gain

The PID controller is mainly used to adjust an appropriate proportional gain (K_p), integral gain (K_i), and differential gain (K_d) to achieve the optimal control performance.

C. *System Identification and Analysis*

Simulink model for DC motor with PID controller is shown in Fig. 4. The model is created by the Matlab/Simulink package, and a Simulink model of the entire SMP mobile robot system can be developed from this model. PID controller is used with gear DC motor in order to control the speed of wheel actuators of the motor.

In this paper, DC motor encoder is used to detect the error between actual and desired speed of the DC motor and the error signal is input for the PID controller. PID gains K_p, K_i, K_d are tuned to reach at the desired linear speed.

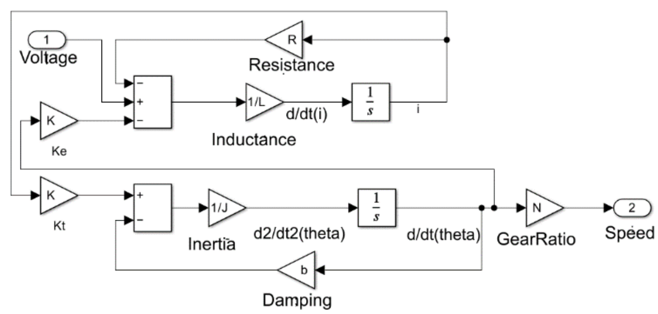

Fig. 4. DC motor with PID controller simulink model

III. Experimental Results

In this paper, system identification model is obtained and the PID controller is designed. All motors used in SMP have different resistance values. Motors No.1, No.2 are installed on front wheels and motors No3, No.4 are installed on the rear wheels of the SMP. The left-front motor has greatest resistance but the right rear motor has the lowest resistance. For SMP mobile robot, a model was created to design the controller of a DC motor system. Among the acquired models, the one with the highest fit was selected and the PID coefficients were adjusted accordingly.

In this study, the system needs to measure the resistance of the motor's armature winding using ohmmeter during no load current. Sine wave, square wave and fourier wave were used input signals and then collect data on the motor's speed, voltage, motor angle, encoder count and PWM under operating conditions. This data will be used for parameter estimation. By using this data into MATLAB optimization tools to estimate the unknown parameters in DC geared model. Afterall developed a mathematical model of the DC geared motor. This model typically consists of the parameters of inertia(J), back emf constant (K), inductance(L), and damping (b). After tunning the model parameters to match the measured data, by using MATLAB simulation toolboxes, and obtained the model of DC motor used in SMP is shown in Table. 1.

Table.1 Result of estimated parameters of DC motors used in SMP

Motor No.	J	K	L	R	b
1	1.13E-06	0.011029	0.30994	12.919	2.40E-05
2	6.60E-07	0.001761	0.06754	4.5516	2.23E-05
3	1.40E-05	0.030117	0.06383	3.2843	5.53E-05
4	2.21E-05	0.035314	0.03995	2.7031	6.45E-05

Using DC motor Simulink model and PID tuning method, the coefficient parameter values (K_p, K_i, K_d) required for the SMP mobile robot were obtained. PID coefficient parameters of DC motors used in SMP are shown in Table. 2.

Table.2 Result of estimated PID gains used in the propose system

Motor No.	K_p	K_i	K_d
1	5.6118	137.8855	0.055295
2	7.7383	252.5987	0.053161
3	5.5694	137.7014	0.053119
4	5.665	158.2641	0.049155

The simulation response curve is obtained when Step input applied to simulation block. In this study, for all motors to reach the target amplitude high value of K_i and low value of K_d were needed. The simulation response curve of the DC motor No.1 is shown in Fig. 5.

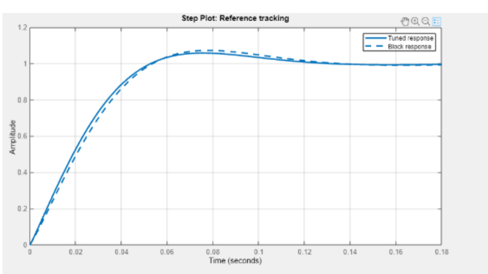

Fig. 5. Simulation response curve of a DC motor 1.

In real time test, the PID controller outputs of all motors did not over shoot. Although the settling times of motor No.1, No.4 and No.3 are late by 8(ms) and 12(ms) respectively, the settling time of motor No.2 is the same as the simulation results. The comparison of the real time testing of the proposed system (magenta, green, red and black) and target speed value (blue) has been made using PID coefficients are shown in Fig. 6.

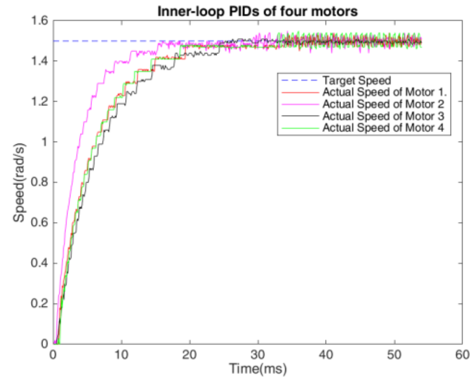

Fig. 6. Comparison of target speed and actual speed of SMP

IV. Conclusion

In many cases of unknown models, it is not easy to obtain a full mathematical model of a control system. It is cleared that a DC motor can be controlled very well by experimental results, by using unknown mathematical model of a DC motor. System identification allows the definition of dynamic system models based on measured input and output. This paper creates a model to design a controller for a DC motor system. The use of system identification and parameter estimation toolboxes were studied while creating the model. In this experiment, it can be found that the SMP travels on the ground according to changing fractions and disturbances, and all the motors cannot reach desired speed at the same time. For further studies, in order to quickly and smoothly reach the desired speed of the DC motor the techniques like the Ziegler-Nichols method or trial-and-error tuning can be considered. To control the direction and orientation of SMP, IMU sensor can be considered.

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