Novel Robust Control Algorithm of DC Motors

Ba-Hai Nguyen
Korea University of Technology and Education
nguyenbahai@hocdelam.org

Hai-Bac Ngo
Korea University of Technology and Education
ngohaibac@hocdelam.org

Jee-Hwan Ryu
Korea University of Technology and Education
jhryu@kut.ac.kr

Abstract - In this paper, a novel speed control algorithm of DC motors is presented. The key contribution here is a simple speed controller only with speed feedback and without an inner current control loop. This is possible by adjusting the reference speed based on a certain rule. Therefore, the proposed speed controller here becomes simpler while maintaining the control performance. Moreover, with the proposed controller, the system response can be tuned with less complexity. This proposed control method is investigated both mathematically and experimentally.

Keywords - DC motor control, speed control of motor, robust control of DC motor, angular velocity control.

1. INTRODUCTION

Direct current (DC) motors are widely used in industrial applications including mechatronics, automobile, robotics, and aerospace systems [1, 2]. In those applications, speed control is one of the most essential aspects. It includes the speed control of mobile robots, CD-ROM, electrical screw driver, computer hard-disk, and so on.

In general, an accurate speed control scheme requires two closed-loops, an inner current control loop [1,3] and an outer speed control loop. In this paper, a novel robust control method of DC motors is presented. Our proposed speed control algorithms for DC motors need only a simple PWM signal. The current control loop can be removed while the performance of the system is maintained. Moreover, after this method is developed, a simpler controller as well as a less complex tuning method is possible.

2. GENERAL SPEED CONTROL METHOD OF DC MOTORS

2.1 DC motor modeling

The electrical diagram of the permanent magnet DC motor is shown as Fig. 1. According to the Kirchhoff law, the electrical equation of DC motors can be expressed as in Equation (1).

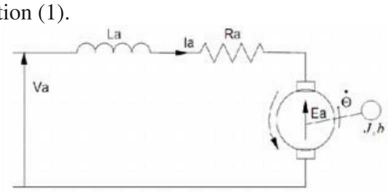

Fig. 1. Electrical diagram of permanent magnet DC motors

By applying the Newton's law and Kirchhoff's law to the DC motor system, we come up with mathematical equation (1) and (2) of DC motors.

$$V = L\frac{di}{dt} + Ri + Ea \quad (1)$$

$$J\ddot{\Theta} + b\dot{\Theta} = \tau_m \quad (2)$$

Where, V is the supply voltage, i the armature current, Ea is the back-emf (electromotive force). L and R are the electric inductance, and electric resistance respectively. J is the moment of inertia of the rotor, b is the damping ratio of the mechanical part. The motor torque, τ_m , is related to the armature current, i , by a constant factor k_t (In SI units, k_t (armature/torque constant) is equal to k_e (motor/speed constant)). The back emf, E is related to the rotational speed by the equation (3).

$$\tau_m = k_t.i \quad (3)$$

2.2 Typical speed control structure for DC motors

Figure 2 illustrates a typical speed control structure of DC motor [4-6].

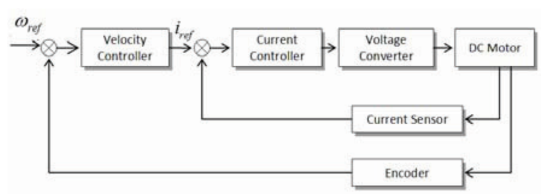

Fig. 2. A typical speed control structure for DC motor

The control scheme consists of an inner current control loop and an outer speed control loop. The output signal of speed controller is the input of the current controller. Those two controllers can be designed independently because the mechanical dynamics of the system is usually much slower than the dynamics of the armature circuit.

Reference speed ω_{ref} is the desired speed which the motor should be achieved after a designed time. The controller found in typical industrial systems is PID control algorithm. It can also be included fuzzy, neural network, or adaptive controllers. The current sensor and encoder are usually used as feedback devices in the system.

The general equation of a PID controller can be seen in [7-8]. $U(t)$ is the output signal of PID controller which is the summation of proportional term, integral term, and derivative term.

$$U(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}.$$

With a large proportional gain (K_p), the system enhances faster response and causes a larger error. An excessively large proportional gain will lead to instability and oscillation of the system. With a larger integral gain (K_i), the steady state errors of system are reduced more quickly. With a larger derivative gain (K_d), the overshoot of system can be reduced. But the derivative gain also plays as a damper of the system. In addition, the noise amplification in the differentiation of the error may make the system unstable. There are several methods to calculate these three terms. The reference [8] provides the detail of all tuning methods.

3. NOVEL ROBUST SPEED CONTROL ALGORITHMS

3.1 Overview of proposed speed control algorithms

To simplify the speed control of DC motors, we have proposed a new control scheme shown in Fig. 3. The novel concept here which is the original reference speed is multiplied by the gain m. The modified reference now becomes the reference input of the controller. With this modification, the current control loop can be removed in the control scheme while steady-state error can be converged to zero. The detail analysis of steady-state error and the method to find the exact value of m are presented in session 3.2.

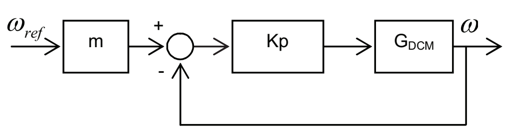

Fig. 3. Proposed scheme for motor speed control

3.2 Mathematical analysis of the proposed algorithm

Let consider a P controller for speed control loop in typical control scheme in Fig. 3. The closed loop system can be described as:

$$\omega = \frac{K_p G_{DCM}}{1 + K_p G_{DCM}} m\omega_{ref}$$

Where, $G_{DCM} = \frac{1}{Js + B}$ and $\omega_{ref} = \frac{\Omega^d}{s}$

$$\longrightarrow \omega = \frac{K_p m}{K_p + Js + B} \frac{\Omega^d}{s}$$

$$\omega_{ss} = \lim_{s->0}[\omega(s).s] = \lim_{s->0} \frac{K_p m\Omega^d}{K_p + Js + B}$$

$$= \frac{K_p m\Omega^d}{K_p + B}.$$

$$\omega_{ss} = \Omega^d \quad \longleftrightarrow \quad m = \frac{K_p + B}{K_p}.$$

Where, B represents the effective damping [9]. This analysis means that the steady state speed is equal to Ω^d when m is equal to $(K_p + B)/K_p$. In other word, if a K_p is given, it is always possible to find a value of m which make the steady state speed the same as the reference speed. However, K_p must not be equal to zero.

Let consider the system with PD controller shown as in Fig. 4.

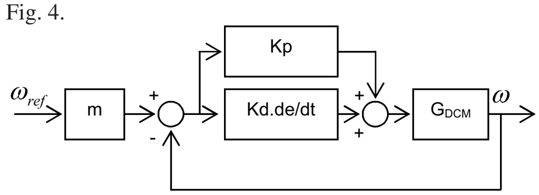

Fig. 4. Proposed control algorithm with PD control

The output speed of motor ω will be:

$$\longrightarrow \omega = \frac{(K_p + K_d s)m}{(K_p + K_d s) + Js + B} \frac{\Omega^d}{s}.$$

$$\omega_{ss} = \lim_{s->0}[\omega(s).s] = \lim_{s->0} \frac{(K_p + K_d s)m\Omega^d}{(K_p + K_d s) + Js + B}$$

$$= \frac{K_p m\Omega^d}{K_p + B}.$$

$$\omega_{ss} = \Omega^d \quad \longleftrightarrow \quad m = \frac{K_p + B}{K_p}.$$

This means if a K_p is given, it is always possible to find a value of m which make the steady state speed the same as the reference speed. In other words, the proposed control algorithm is not affected by the derivative term.

4. EXPERIMENT AND RESULT

4.1 Experimental setup

The experiment was set as in Fig. 5. A DC maxon motor was used. The encoder had 4096 pulse/revolution. An PCI board (NI PCI 7356) was used to connect the DC motor with a user interface developed in LabVIEW environment.

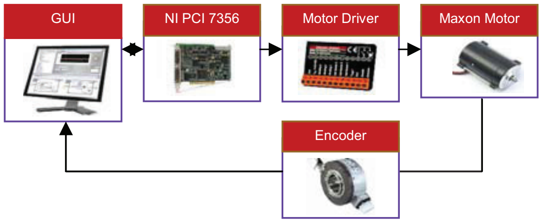

Fig. 5. Proposed scheme for motor speed control

In the PID control experiment, a Maxon motor driver is used. The Maxon motor driver has current mode control. Therefore, the current loop control can be easily implemented. In the experiment based on the proposed method, a simple H-bridge motor driver is used. The PWM signal is generated using LabVIEW function.

In addition, the proposed control algorithm and a graphical the user interface (GUI) are programmed in LabVIEW environment shown in Fig. 6. The GUI allows users to set the reference speed, and observe the acquired data. User may change two control modes, PID control and robust control by swiching a button.

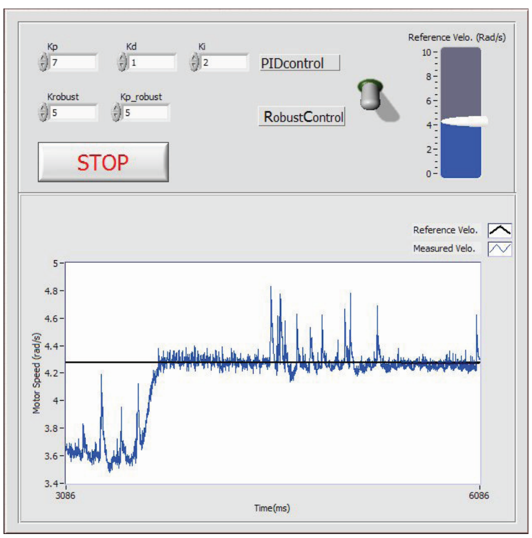

Fig. 6. The proposed control algorithm and graphical user interface are developed.

4.2 Experimental result

The first experiment was conducted with conventional PID control of motor speed. The Ziegler–Nichols method was used to tune the PID controller. In Fig. 7, the result of this experiment showed noise behavior due to the change in sign of error. To explain this more clearly, it is important to notice the difference between position control technique and speed control. In position control, once the position error reaches zero the control signal should be zero. However, the control signal must remain at a stable value when speed error approaches zero.

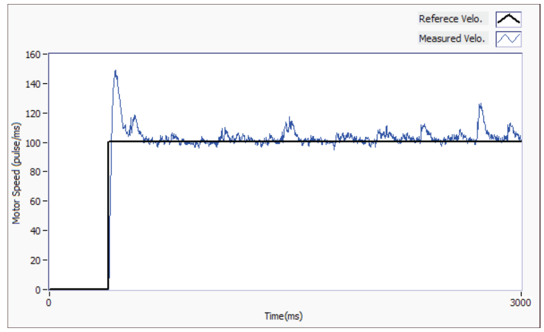

Fig. 7. Experimental result of conventional PID control

The second experiment was carried out based on the proposed robust control algorithm. The system damping is found to be 41.4. The gain Kp_robust was set to be equal 23. Therefore, m was calculated as follows:

$$m = \frac{K_{p\_roboust} + B}{K_{p\_roboust}} = \frac{23 + 41.4}{23} = 2.8.$$

The detail of how to calculate B is provided in [9]. With a certain value of Kp, m will have approximate value. The result of this experiment is shown in Fig. 8.

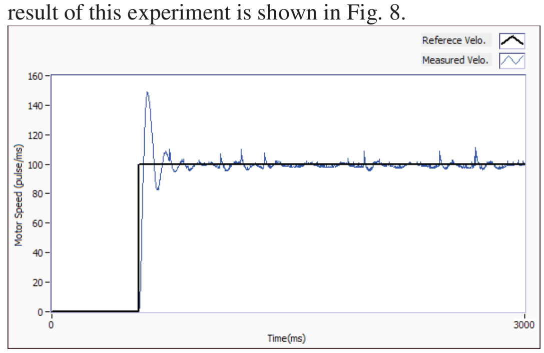

Fig. 8. Experimental result of proposed control method with $Kp = 23$, and m=2.8.

To demonstrate the tuning technique, the experiment was conducted with the second set of Kp and m, and the result is shown in Fig. 9. The steady state speed can follow the reference speed set.

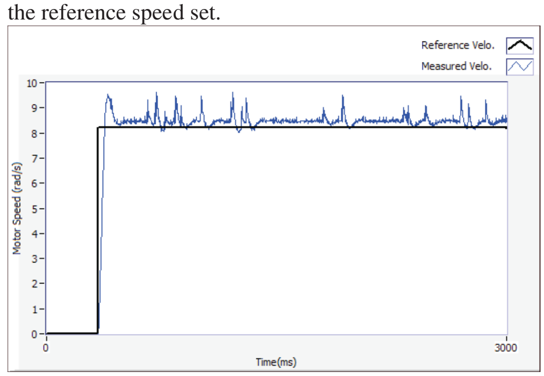

Fig. 9. Experimental result of proposed control method with $Kp = 15$, and m=3.76.

Figure 10 shows the experimental result of varying reference speed. The measured speed follows reference speed with error 4%, and setting time is 30 ms.

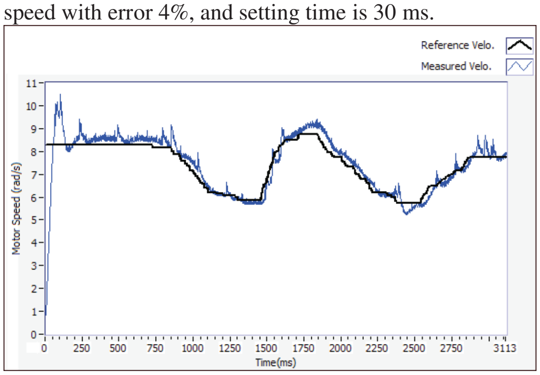

Fig. 10. Experimental result of proposed control method with $Kp = 15$, and m=3.76.

Figure 11 shows the comparison of the noise behaviour of the conventional PID controller and the proposed controller. With the proposed control algorithm, the noise was reduced about 25% compared with the PID controller. During the experiment, it was evaluated that the proposed controller made the motor run smoother and more quite.

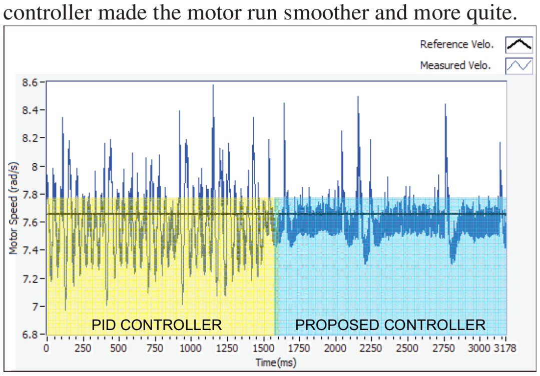

Fig. 11. Comparison of noise in PID controller and proposed controller.

The comparison of the conventional PID control and the proposed robust control algorithm is provided in [Table 1]. With the proposed method, noise behavior can be reduced and the tuning technique is very simple because there is no requirement of finding Ki and Kd.

Table 1 Comparison of conventional PID controller and the proposed robust controller

FACTORS TO BE COMPARED	PID SPEED CONTROLLER	ROBUST SPEED CONTROLLER
PERFORMANCE	Noise	Less Noise
IMPLEMENTATION	Complex Tuning Technique	Easy Tuning technique

5. CONCLUSION

In this research, a novel and simple robust control algorithm of motor's speed was proposed. The proposed method has an advantage in both noise reduction and simple tuning method. Moreover, this controller does not require an inner loop current control. The feasibility of the proposed method was demonstrated with mathematical analysis and experimental results.

ACKNOWLEDGEMENT

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