

## DESIGN AND IMPLEMENT OF A STATE FEEDBACK POSITION OUTPUT CONTROLLER FOR A MAXON S-DC MOTOR WITH dSPACE

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### ABSTRACT

This paper presents design and implements the state feedback controller using Matlab/simulink for position control of DC motor. The controller is designed by pole placement is also introduced to the system. After observing the controller response in simulation, the overall control system is implemented on dSPACE DS1104 board to a real Maxon DC motor. The experimental results in testing the Maxon - 2332.968-51.236-200 15W 24V- DC motor show the effectiveness of the proposed control scheme. It is found that the motor position can be controlled over certain range.

**Keywords:** DC Motor, Position Control, State Feedback.

### 1. INTRODUCTION

Dc motor is always been an important instrument in industry and controlling of dc motor is a great challenge for control engineers [1]. This motor is getting popularity for long time because they are easier to be linear control [5]. Dc motor have been using in various application as it has simple mechanical structure and offers simple mechanism for accurate control of speed and position. But still today it has been an issue for proper controlling of Dc motor. The control of the angular position of these motors is an important challenge and requires accuracy. Different controllers for angular position control in continuous-time have been proposed, for example sliding mode controllers [6], [8], fuzzy sliding mode controllers [2], [4], PID combined with fuzzy sliding mode controllers [7]; in discrete time, for example the classic PID controllers [12], neural networks (NN) controllers [13], [14], among others. The authors in [9] made a comparison between a proportional control and the fuzzy control on a laser beam alignment system. It was shown that the fuzzy controller significantly reduced the overshoot and virtually eliminated limit cycling. Li and Lau [10] investigated the possibility of applying fuzzy algorithm in a microprocessor-based servomotor controller, which requires faster and more accurate response compared with other industrial processes. A set of simulation results on the performance of PI (proportional-integral) control, model reference adaptive control and fuzzy controllers are compared in terms of

steady-state error, settling time, and response time. According to the simulation results, the settling time of the fuzzy controller is only two-fifths that of the PI controller. It was concluded that the fuzzy controller is better than the PI controller. Smith and Comer [11] compared a fuzzy position controller with a PD controller using only the simulation result. Many of the applied controllers were successful to control dc motor. But one control technique may not be applicable for all application. Same control technique may have different performance in various applications. So controlling Dc motor remains a challenge. PID controller is widely used in many control applications because of its implicitly and effectiveness. Though the use of PID control has been a long history in the field of control engineering, the three controller gain parameters are usually fixed. The disadvantage of PID controller is poor capability of dealing with system uncertainty, i.e. parameter variations and external disturbance. In this paper a state feedback controller is proposed for position control of Dc servo motor. The objective of this controller in a position control system is to maintain a position set at a given value and be able to accept new set point value dynamically. The proposed PC based controller has several implementation advantages, such as reducing computational time, engineering efficiency, ease of implementation. Also the proposed controller is very simple and easy state feedback controller as it reduce the computational complexity. In the experiment part of dc

motor to implement our controller we used rapid control prototype software dSPACE. The dSPACE(Digital Signal Processing And Control Engineering ) is a software and hardware real-time control platform based on MATLAB/Simulink. It provides Rapid Control Prototype (RCP) and Hardware-in-the-Loop Simulation (HLS) ([15]-[17]) application platforms. After creating control system block diagram in Simulink, the control system frame can be compiled and downloaded to dSPACE real-time hardware system by RTW/RTI. The control system process can be monitored and the controller parameters can be adjusted online by ControlDesk software. At present, dSPACE has widely applied in some domains such as astronautics, aviation, engine, industrial control [3] and so on. In this paper, the online simulation is carried on. The most superior controller parameters can be obtained by adjusting online. The experiment shows that the real-time platform provided by dSPACE can construct the control system model and complete the system's debugging conveniently. The rest of the paper is organized as follows. Section 2 describes the model design of dc motor. Next section 3 briefly describes design of proposed state feedback controller. Section 4 contain the simulation and experimental response of the system for both open loop and close loop. Finally section 5 concludes the paper.

## 2. DC MOTOR MODELING

The differential equations describing DC motor dynamics are:

$$L \frac{di_a}{dt} + Ri_a + k_w w = v_m \quad (1)$$

$$J \frac{dw}{dt} + Bw = k_a i_a \quad (2)$$

$$\frac{d\theta}{dt} = w \quad (3)$$

where  $v_m$  is the input motor voltage,  $w$ ,  $\theta$ ,  $i_a$  are the motor angular velocity, angular position, and armature current respectively. The data sheet for the Maxon - 2332.968-51.236-200 15W 24V Smotor - DC motor has the following values of the parameters:

Armature inductance  $L = 1.54 \times 10^{-3}$  H, armature resistance  $R = 7.94 \Omega$  velocity constant  $k_w = (2\pi 243 / 60)^{-1}$  V/(rad/s), motor inertia  $J = 27.8 \times 10^{-3} \times 10^{-4} \text{ kgm}^{-2}$  and torque constant  $k_a = 39.3 \times 10^{-3}$  Nm/A.

There are three sensors attached to the DC motor (3604.040-0500.00-100 DC- Tacho/Encoder) (a) a tachometer with 0.52 V output for 1000 rpm, (b) an encoder with 500 pulses per revolution and (c) an armature current sensor.

The sensor outputs can be written as:

$$y_\theta = c_\theta \theta \quad (4)$$

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$$y_w = c_w w \quad (5)$$

$$y_{i_a} = c_{i_a} i_a \quad (6)$$

Where  $c_\theta$ ,  $c_w$  and  $c_{i_a}$  are sensor gain.

The internal interconnection of the DC Motor is shown in Fig. 1.

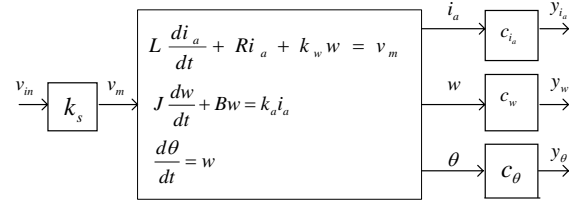


Fig 1. DC motor with actuator and sensor

The state space representation of (1), (2), (3) is as follows

$$\begin{bmatrix} \dot{I}_a \\ \dot{\omega} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -\frac{K_w}{L} & 0 \\ \frac{K_a}{J} & -\frac{B}{J} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} I_a \\ \omega \\ \theta \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \end{bmatrix} [v_m] \quad (7)$$

$$y = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ \omega \\ \theta \end{bmatrix} \quad (8)$$

$$\text{Hence } A = \begin{bmatrix} -\frac{R}{L} & -\frac{K_w}{L} & 0 \\ \frac{K_a}{J} & -\frac{B}{J} & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$D = [0]$$

Taking the Laplace transform of (1), (2), (3) and rearranging the equations

$$\frac{\theta(s)}{v_m(s)} = \frac{K_a}{s[(sL + R)(sJ + B) + K_a K_w]} \quad (9)$$

It is clear that position output got a third order system in the denominator Which gives a clear idea about the nature of the system and it is helpful for designing controller.

### 3. STATE FEEDBACK CONTROLLER DESIGN

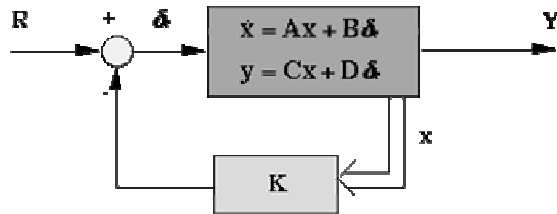


Fig 2. State feedback block diagram

The fig:2 given above shows a basic state feedback control technique used in many control issues where  $K$ = Control Matrix,  $x$ = state matrix,  $R$ = Reference. For full state feedback  $R=0$ . State-space models allow us to use a very powerful design method state feedback. First assume that we can measure the entire state vector. We will address the case where this cannot be done later.

State feedback control law:  $u(k) = -Kx(k)$  or, equivalently,  $u(s) = -Kx(s)$  (10)

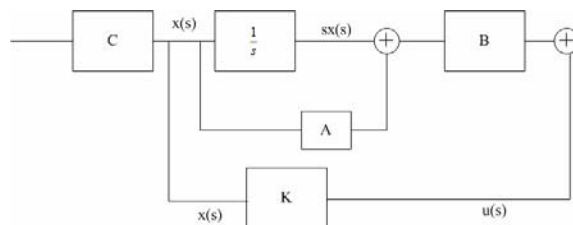


Fig 3. State feedback technique

Consider following Continuous time domain state space

$$\dot{x} = Ax + Bu \quad (11)$$

$$y = Cx \quad (12)$$

Given a discrete-time state-space system,

$$x(K+1) = Ax(k) + Bu(k) \quad (13)$$

Recall that the poles of the system are the eigen values of  $A$ .

State feedback law:  $u(k) = -Kx(k)$

This gives,

$$x(k+1) = Ax(k) - BKx(k) = (A - BK)x(k) \quad (14)$$

The closed-loop poles are given by the eigenvalues of  $(A - BK)$ .

### 3.1 Structure Of The State Feedback Control Gains

$$u(k) = -kx(x) = -[K_1 \quad K_2 \quad \dots \quad K_n] \begin{bmatrix} x_1(k) \\ x_2(k) \\ \dots \\ x_n(k) \end{bmatrix}$$

Where  $K$  is a static  $nu \times nx$  matrix

Determination of the value of gain  $K$  is a key task in state feedback control design technique. To determine it we assign some close loop pole for the system.

Start by specifying the desired closed-loop poles. Say they have positions in the  $z$ -plane:

$$z = \beta_1, \beta_2, \dots, \beta_n$$

Root-locus arguments, or knowledge of “nice” pole positions, can often be used to come up with suitable closed-loop pole locations.

The closed-loop pole locations can also be specified as the roots of the polynomial,

$$(z - \beta_1)(z - \beta_2) \dots (z - \beta_n) = 0$$

Now, under state feedback, the closed-loop poles are the roots of,

$$\det(zI - (A - Bk)) = \det(zI - A + BK) = 0 \quad (15)$$

Another easy approach to calculate gain is Ackermann’s formula.

Given state equation  $(A, B)$  and desired close loop positions, Ackermann’s formula calculates  $K$ .

At first we have to form “controllability matrix”

$$C = [B \quad AB \quad A^2B \quad \dots \quad A^{n-1}B]$$

Which is  $n \times n$  matrix.

If the desired closed-loop pole positions are given by

$$z^n + \gamma_1 z^{n-1} + \gamma_2 z^{n-2} + \dots + \gamma_n = 0 \quad (16)$$

Then define

$$\gamma_c(A) := A^n + \gamma_1 A^{n-1} + \dots + \gamma_n I$$

$$K = [0 \quad \dots \quad 0 \quad 1] C^{-1} \gamma_c(A)$$

But it will not work if  $C^{-1}$  does not exist.

So a system is “controllable” if and only if  $C$  is invertible (equivalently,  $\text{rank}(C) = n$ )

For our controller design we propose the following assumption.

$$x_1 = i_a, x_2 = \omega, x_3 = \theta - \theta_{ref}$$

$$v_{in} = -k_1 x_1 - k_2 x_2 - k_3 x_3 \quad (17)$$

Hence the new  $A, B, C, D$  matrix for state space representation is as follows:

$$\text{Hence } A = \begin{bmatrix} -\frac{R}{L} & -\frac{k_1}{L} & -\frac{K_w}{L} & -\frac{k_2}{L} & \frac{k_3}{L} \\ \frac{K_a}{J} & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{k_3}{L} \\ 0 \\ 0 \end{bmatrix}, \quad C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$D = [0]$$

#### 4. EXPERIMENTAL SETUP

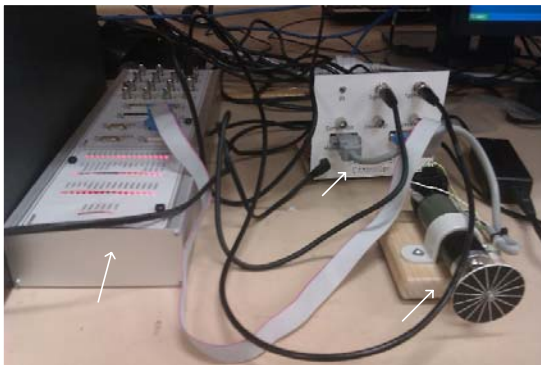


Fig 3. Experimental Setup for Motor position Control

The figure given above has shown the experimental setup for controlling DC motor position. The setup consists of a rapid prototype system dSPACE (Digital Signal Processing and Control Engineering) which is used to implement the state feedback controller in real time. Setup also consists of motor controller circuit and Maxon-S DC motor which should be used for position control. Before implementing the controller in a real DC motor, simulation work has been performed using matlab simulink for open loop and close loop .

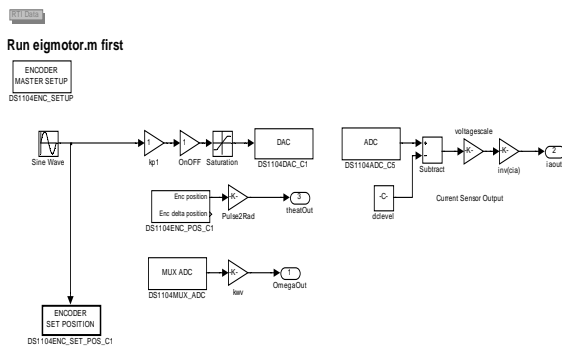


Fig 4: Open loop experimental block diagram

Figure given above has shown the open loop block which was drawn in Matlab Simulink, after that it was loaded into dSPACE by real time build command in simulink. Then we measure the open loop armature current, angular velocity and angular position of DC motor. The following figures shows a comparison between simulated and experimental response of DC motor.

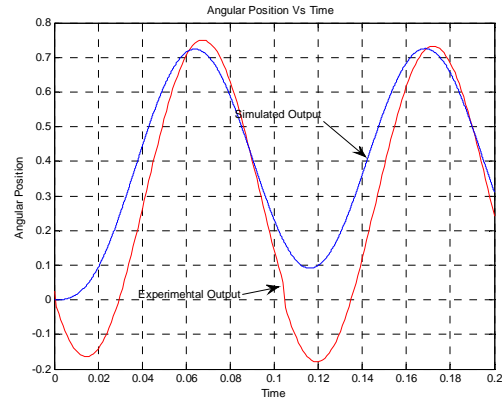


Fig 5. Comparison of simulated and experimental angular position output response for sinusoidal input

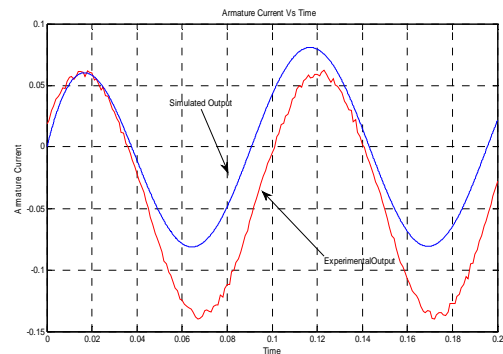


Fig 6. Comparison of simulated and experimental armature current output response for sinusoidal input

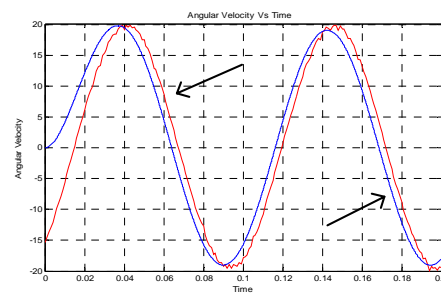


Fig 7. Comparison of simulated and experimental angular velocity output response for sinusoidal input

The above fig. shows the comparison between simulated and experimental responses of angular position, armature current and angular velocity. From the above two comparison it clear that proposed model suits the nature and behavior of DC motor. Using this model at first we simulate the system for open loop and close loop. After observing the simulated response we implement

state feedback control technique in experiment.

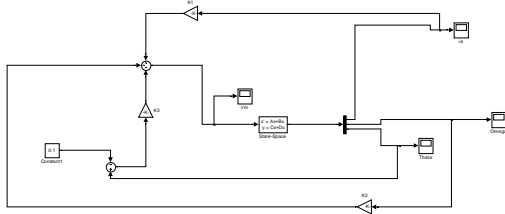


Fig 8. Simulation block with State feedback technique

The figure given above shows the state feedback of DC motor in simulation. Each state feedback with a gain multiplication. Gain value was chosen by using pole placement technique. Assuming that the pair (A, B) is controllable, there exists a feedback matrix K such that the closed-loop system eigenvalues can be placed in arbitrary locations. To have this K we chose pole location at  $-65+10i$ ,  $-65-10i$  and  $-5000$ . Then we use matlab code to generate K using acker command. After observing eigen value of new state matrix (A-BK) is in the left half plane we implement our controller in a real system. Following few lines shows matlab code that was used to generate gain K.

```
L = 1.54e-3; R = 7.94; k_w = inv(2*pi*243/60);
J = 27.8e-7;
k_a = 39.3e-3;
B = 15e-6;
k_s = 0.96;
AA = [-R/L -k_w/L 0; k_a/J -B/J 0; 0 1 0];
BB = [1/L; 0; 0];
CC = [1 0 0; 0 1 0; 0 0 1];
DD = zeros(3,1);
pole = [-65+10i -65-10i -5000];
k = acker(AA, BB, pole);
Ac = AA - BB*k;
eig(Ac)
```

which gives following eigen value of matrix Ac.

```
1.0e+003 *
-5.0000
-0.0650 + 0.0100i
-0.0650 - 0.0100i
```

From the above code it is seen that we chose three pole at location  $-65+10i$ ,  $-65-10i$  and  $-5000$  from which we get three value of gain K. Then we check eigen value of new vector matrix Ac and that confirmed that close loop system is stable which led to design simulation.

Figure 9 shows the experimental block diagram used in our experiment. Since a scaling of 10 in both ADC and DAC of dSPACE, ADC divides by 10 and DAC multiplies by 10, that's why we add suitable gain block in the system to overcome this issue. Also as DC motor has its own sensor gain, we also introduce gain block to overcome this issue. After implementing it we saw the responses through control desk software. The control

system process was monitored and the controller parameters was adjusted online by Control Desk software. The most superior controller parameters can be obtained by adjusting online. The experiment shows that the real-time platform provided by dSPACE can construct the control system model and complete the system's debugging conveniently. After monitoring responses we save data as a mat file and we plot data in matlab using proper matlab command.

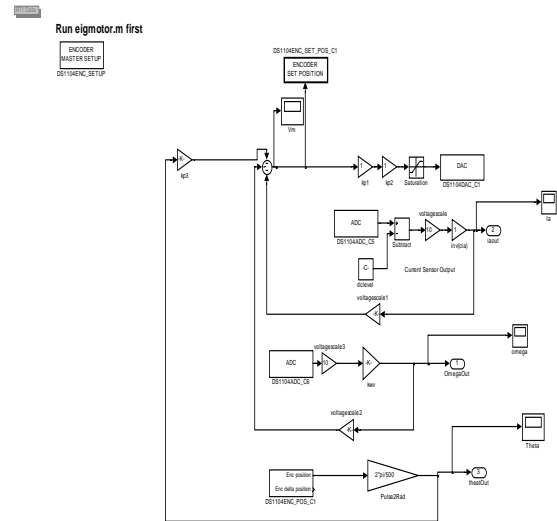


Fig 9. Experimental block with State feedback technique

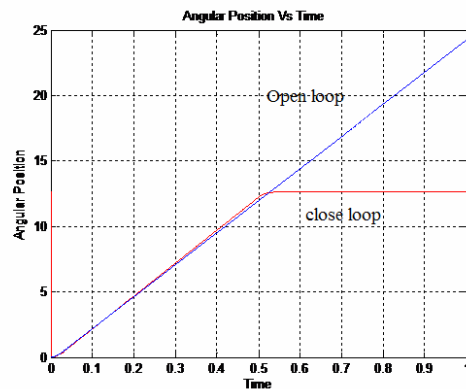


Fig 10. Movement from  $0^0$  to  $180^0$

Figure given above shows that the proposed control technique has been successfully implemented on a PC based controller using dSPACE and have been shown to perform well regardless of how the desired position trajectory and load are changed.

## 5. CONCLUSION

This paper has presented the simulation and experimental identification of state feedback control scheme for a DC motor position control. Based on the simulink control block it is possible to develop position tracking for this motor. The experiment was performed

online using control desk software. Results shows the stability of the proposed control methodology with respect to parameter variation. Due to limit of space, we do not present the robustness analysis. We will proceed with the robustness analysis of the controlled system as well as the real implementation.

## 6. REFERENCES

1. Su, W.-C.; Drakunov, S.V.; Ozguner, U.; 1992 "Sliding mode brushless DC motor current and torque control algorithms," *Control Applications, First IEEE Conference on* , pp.910-915 vol.2, doi: 10.1109/CCA.1992.269800
2. Hailong Song; Yong Yu; Ming Yang; Dianguo Xu; Feb 2003 , "A novel SMC-fuzzy speed controller for permanent magnet brushless DC motor," *Applied Power Electronics Conference and Exposition, 2003. APEC '03. Eighteenth Annual IEEE* , vol.1, no., pp. 281-285 vol.1, doi: 10.1109/APEC.2003.1179227
3. Katsuhiko Ogata, *Modern Control Engineering*, Prentice Hall International, 2002.
4. Yan Xiaojuan; Liu Jinglin; , March 2010 "BLDCM Fuzzy Sliding Mode Control based on network control system," *Advanced Computer Control (ICACC), 2010 2nd International Conference on* , vol.5, pp.332-335, doi:10.1109/ICACC.2010.5487067
5. Satar, M.N.A.; Ishak, D.2011, "Application of Proteus VSM in modelling brushless DC motor drives" *Mechatronics (ICOM), 4th International Conference On*, pp.1-7
6. Ch, U.M.; Babu, Y.S.K.; Amaresh, K., June 2011 "Sliding Mode Speed Control of a DC Motor," *Communication Systems and Network Technologies (CSNT), International Conference on* , pp.387-391, doi: 10.1109/CSNT.2011.86
7. Paul-I-Hai Lin; Sentai Hwang; Chou, J.;Oct 1994, "Comparison on fuzzy logic and PID controls for a DC motor position controller," *Industry Applications Society Annual Meeting, 1994., Conference Record of the 1994 IEEE* , pp.1930-1935 vol.3, doi: 10.1109/IAS.1994.377695
8. Cheng-Yi Chen; Cheng, M.H.-M.; Cheng-Fu Yang; Dec 2009 "Modified Sliding Mode Speed Control of Brushless DC Motor Using Quantized Current Regulator," *Innovative Computing, Information and Control (ICICIC) Fourth International Conference* pp.926-929 doi: 10.1109/ICICIC.2009.267
9. R.D. Marchbanks and M. Jamshidi, 1993, "A Fuzzy Control Approach to a Two Axis Mirror Laser Beam Alignment system" *Engng Applic. Arcif. Intel*, vol. 6, No. 2, pp.117-122
10. Y.F.Li and C.C. Lau, 1989, " Development of fuzzy algorithms for servo system", *IEEE control Systems*, pp. 65-72
11. S.M. Smith and D.J. Comer, 1991, "Automated Calibration of a Fuzzy Logic Controller using a Cell State Space Algorithm", *IEEE control Systems*, pp. 18-28.
12. Fallahi, M.; Azadi, S.; April 2009 , "Fuzzy PID Sliding Mode Controller Design for the Position Control of a DC Motor," *Education Technology and Computer, 2009. ICETC '09. International Conference on* , pp. 73-77, doi:10.1109/ICETC.2009.12
13. Jianbo Cao; Binggang Cao; Wenzhi Chen; Peng Xu; Xiaolan Wu; 2007, "Neural network control of electric vehicle based on position-sensorless brushless DC motor," *Robotics and Biomimetics.IEEE International Conference on* , pp.1900-1905 doi: 10.1109/ROBIO.2007.4522457
14. Yen,V.;Liu, T.Z.; Liu, D.Y.; Sep 1995, "Neural-network-based near-time-optimal position control method for DC motor servosystems," *Control Theory and Applications, IEEE Proceedings - vol.142, no.5*, pp.493-500, doi: 10.1049/ip-cta:19952021
15. MATLAB/Simulink User's Guide, *The Math Works, Inc,Natick,MA,1998*.
16. dSPACE User's Guide, *Digital Signal Processing and Control Engineering*, dSPACE, Paderborn, Germany, 2003
17. Control Desk Experimental Guide, May 2002

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