Self-Tuning Speed Control of Permanent Magnet DC Motor

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Abstract

In this study, speed control problem of a permanent magnet DC motor considered in the existence of disturbance and unknown plant parameters. Self-tuning adaptive control technique is used to solve the problem. Firstly, an ARX model of the plant is considered with recursive identification of its parameters then the parameters and predefined performance criteria is combined to design an adaptive controller. The effectiveness of the control method is tested via simulations.

1. Introduction

The area of adaptive control has been improved significantly in recent years. The goal of the approach is to find a solution to controller design for processes which are sufficiently known and change over time. Several approaches have been proposed in this field. Self-tuning controller (STC) is one of them and it has shown great potential and success.

The basic idea behind STCs is obtaining the estimates of the process parameter and updating them recursively and finally obtaining controller parameters from the solution of a design problem using estimated process parameters. This adaptive control scheme consists of the process and a feedback controller. As the name suggests the controller automatically tunes its parameters to obtain the desired properties of the closed loop system. STC scheme is very flexible with respect to the choice of the underlying design and estimation methods. A number of researchers studied on STC which is a member of adaptive control techniques [1-4].

On-line determination of process parameters is a key element in self-tuning control. A recursive parameter estimator is an important component of a self-tuning control system. Parameter estimation also occurs implicitly in a model-reference adaptive controller. Therefore system identification for self-tuning control has a great importance. A general structure of STC is given in Figure 1. In this study, speed control of a permanent magnet DC motor considered in the existence of disturbance and unknown plant parameters. Firstly, DC motor model structure and control method is chosen. An ARX model with recursive identification and pole placement control method is chosen for DC motor speed control. The effectiveness of the control method is tested via simulations.

2. General Structure of the Self Tuning Control System

Recursive least squares approach is used to estimate plant parameters since the method is reliable and simple. Recursive estimation gives the opportunity to monitor changes in the characteristics(parameters) of the process in real time and therefore form the basis for self-tuning controllers [2].

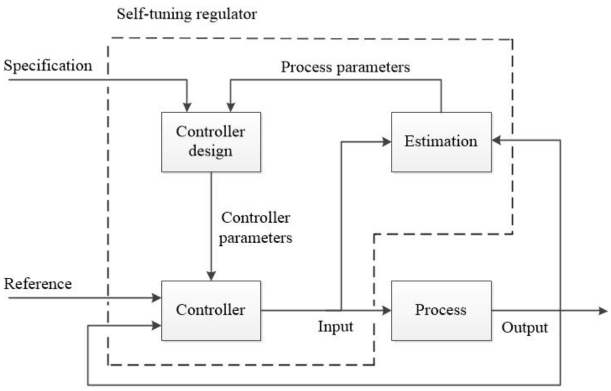

Fig. 1. Self-tuning controller general structure

In recursive least squares method regressor vector and output vector are respectively:

$$X(t+1)=\begin{bmatrix} X(t) \\ x^T(t+1) \end{bmatrix} \tag{1}$$

$$Y(t+1)=\begin{bmatrix} Y(t) \\ y^T(t+1) \end{bmatrix} \tag{2}$$

Parameter estimation algorithm in this case is defined by following expressions:

$$\hat{\theta}(t+1)=\hat{\theta}(t)+K(t+1)\left[y(t+1)-x^T(t+1)\hat{\theta}(t)\right] \tag{3}$$

$$K(t+1)=\frac{P(t)x(t+1)}{1+x^T(t+1)P(t)x(t+1)} \tag{4}$$

$$P(t+1)=P(t)-\frac{P(t)x(t+1)x^T P(t)}{1+x^T(t+1)P(t)x(t+1)} \tag{5}$$

where $P(t)$ is covariance matrix. In order to design pole placement control the system represented by noise free ARX model is considered:

$$A\left(q^{-1}\right)y\left(t\right) \; = \; q^{-d}B\left(q^{-1}\right)u\left(t\right) \tag{6}$$

The control law of the PPC (pole placement control) is defined as:

$$F\left(q^{-1}\right)u\left(t\right) \; = \; G\left(q^{-1}\right)y\left(t\right) \; + \; Mr\left(t\right) \tag{7}$$

Where the control polynomials F(q-1) and G(q-1) are respectively, defined as

$$F\left(q^{-1}\right) \; = \; f_0 + f_1q^{-1} + \; f_2q^{-1} + \; \ldots\ldots + \; f_nq^{-nf}\,,\, f_0 = 1 \tag{8}$$

$$G\left(q^{-1}\right) \; = \; g_0 + g_1q^{-1} + \; g_2q^{-1} + \; \ldots\ldots + \; g_{ng}q^{-ng}\,, g_0 \neq 1 \tag{9}$$

Recommended orders of polynomials are respectively nf=nb+d – 1 and ng = na-1.

The system closed loop transfer function is given by

$$\frac{Y\left(q^{-1}\right)}{R\left(q^{-1}\right)} = \left[\frac{MB\left(q^{-1}\right)}{F\left(q^{-1}\right)A\left(q^{-1}\right)}q^{-d}\right]\left[\frac{MB\left(q^{-1}\right)}{F\left(q^{-1}\right)A\left(q^{-1}\right)}q^{-d}\right]^{-1} \tag{10}$$

$$= q^{-d}\,\frac{B\left(q^{-1}\right)M}{F\left(q^{-1}\right)A\left(q^{-1}\right) - q^{-d}G\left(q^{-1}\right)B\left(q^{-1}\right)} \tag{11}$$

The aim is to design the closed loop poles to a specified location by letting the characteristic equation of 2 to a predefined design polynomial Γ(q-1)

$$F(q^{-1})A(q^{-1}) - q^{-d}G(q^{-1})B(q^{-1}) = \Gamma\left(q^{-1}\right) \tag{12}$$

The desired transient response is designed by using the Diophantine equation 12

$$\Gamma\left(q^{-1}\right) \; = \; \gamma_0 + \; \gamma_1q^{-1} + \; \gamma_2q^{-1} + \; \ldots\ldots + \; \gamma_{n\gamma}q^{-n\gamma}\,,\; \gamma_0 = 1 \tag{13}$$

By assigning poles for the closed loop system the steady state gain will be affected. Using the final values theorem the closed loop steady state gain is computed as

$$SSG = \left[\frac{B\left(q^{-1}\right)M}{\Gamma\left(q^{-1}\right)}q^{-d}\right]_{q^{-1}=1} = \frac{B\left(1\right)M}{\Gamma\left(1\right)} \tag{14}$$

The idea is to design M such that SSG =1, hence the compensator for such a SSG is then

$$M = \frac{B\left(1\right)}{\Gamma\left(1\right)} \tag{15}$$

This approach cancels the offset due to Γ(q-1) on the closed loop SSG so that there is no model mismatch, the steady state output match the reference signal r(t) [1]. The block diagram of the STC with pole placement approach is given in Figure 2.

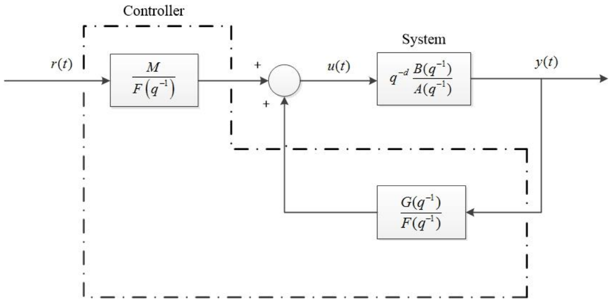

Fig. 2. Pole-placement controller with compensator

3. Self-Tuning Control for DC Motor

The knowledge of the plant order is an important step thus we use here a generic transfer function of the plant desired to control:

$$\frac{\omega}{E} = \frac{K}{\left(R + Ls\right)\left(Js + b\right) + K^2} \tag{16}$$

In order to apply recursive least squares approach an ARX DC motor model is obtained as given below:

$$G\left(q,\theta\right) = \frac{B\left(q\right)}{A\left(q\right)} = \frac{b_2q^{-2}}{1 + a_1q^{-1} + a_2q^{-2}} \tag{17}$$

and parameter vector is as the follows:

$$\theta \; = \; \left[a_1 \quad a_2 \quad b_0 \quad b_1 \quad b_2\right] \tag{18}$$

Using the approximated model of DC motor discrete time transfer function in equation 17, DC motor system has $n_a = 2$, $n_b = 1$ and d = 1 is given by

$$\left(1 + a_1q^{-1} + a_2q^{-2}\right)y\left(t\right) \; = \; q^{-1}\left(b_2q^{-1}\right)u\left(t\right) \tag{20}$$

The open-loop poles of the system are unknown at the beginning. The aim is to achieve a critically damped response such that repeated closed-loop poles are defined to be 0.5 and 0.5, so that

$$T(q^{-1}) = 1.000 - 1.000q^{-1} + 0.2500q^{-2} \tag{21}$$

The Diophantine equation for nf =1 and ng =1 becomes

$$(1 + \; f_1q^{-1})(1 + a_1q^1 + a_2q^{-1}) - q^{-1}(g_0 + g_1q^{-1})(b_0 + b_1q^1) = (1 + \gamma_1q^{-1} + \gamma_2q^{-2}) \tag{22}$$

By equating coefficients of like powers, the above expression may be reformulated in the convenient form:

$$\begin{bmatrix} 1 & -b_0 & 0 \\ a_1 & -b_1 & -b_1 \\ a_2 & 0 & -b_1 \end{bmatrix} \begin{bmatrix} f_1 \\ g_0 \\ g_1 \end{bmatrix} = \begin{bmatrix} \gamma_1 - a_1 \\ \gamma_2 - a_2 \\ 0 \end{bmatrix} \tag{23}$$

The unknown controller parameters may be computed directly from the equation via matrix inversion or using Cramer's rule:

$$f_1 = b_1(b_1 s_1 - b_0 s_2) / p \tag{24}$$

$$g_0 = ((a_1 b_1 - a_2 b_0) s_1 - b_1 s_2) / p \tag{25}$$

$$g_1 = a_2(b_1 s_2 - b_0 s_2) / p \tag{26}$$

$$p = b_1^2 + a_2 b_0^2 - a_1 b_0 b_1 \tag{27}$$

$$s_1 = \gamma_1 - a_1 \tag{28}$$

$$s_2 = \gamma_2 - a_2 \tag{29}$$

p is the determinant of the matrix and γ represents desired pole locations. In order to compensate for the steady-state error, which occurs by relocating the original open-loop poles, the compensator M is introduced;

$$M = \frac{T(1)}{B(1)} = \frac{1 + \gamma_1 + \gamma_2}{b_0 + b_1} \tag{30}$$

The control action can then be determined from Equation 6 which may be expressed in the difference equation form as

$$u(t) = -f_1 u(t-1) + g_0 y(t) + g_1 y(t-1) + Mr(t) \tag{31}$$

4. Simulation and Experimental Results

An approximated model of the real system discrete time transfer function is given in the following form:

$$G(q) = \frac{1.6922 q^{-2}}{1 + 0.1042 q^{-1} - 0.0823 q^{-2}} \tag{32}$$

DC motor system has na = 2, nb =1 and d = 1 is given by

$$(1 + 0.104 q^{-1} - 0.0823 q^{-2}) y(t) = q^{-1}(1.6922 q^{-1}) u(t) + e(t) \tag{33}$$

The open-loop poles of the system are -0.3372 and 0.2372. The aim is to achieve a fast critically damped response such that repeated closed-loop poles are defined to be 0.05 and 0.05, so that

$$T(q^{-1}) = 1.0000 - 0.1000 q^{-1} + 0.0025 q^{-2} \tag{34}$$

The Diophantine equation for nf =1 and ng =1 becomes

$$\begin{aligned} T(q^{-1}) &= (1 + f_1 q^{-1})(1 + a_1 q^{1} + a_2 q^{-1}) - q^{-1}(g_0 + g_1 q^{-1})(b_0 + b_1 q^{1}) \\ &= (1 + \gamma_1 q^{-1} + \gamma_2 q^{-2}) \end{aligned} \tag{35}$$

Firstly, discrete time DC motor model is placed into simulation block in the presence of noise. Then RLS algorithm and pole placement controller is adapted to the model by using embedded code blocks. System parameters are updated and then updated parameters are used in the control system algorithm to generate control signal so that DC motor follows desired speed set point. In real applications we do not have the knowledge about real system parameters. Here, a system with exactly known parameters is used in order to check RLS algorithm works properly. It can be seen from Figure 3 that tuned parameters of DC motor converge to actual values.

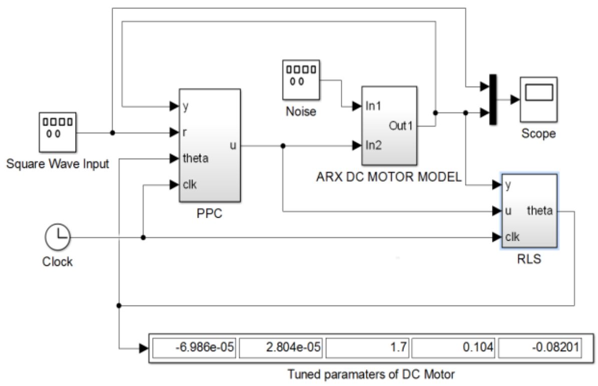

Fig. 3. Self-tuning control of DC motor speed simulation block structure

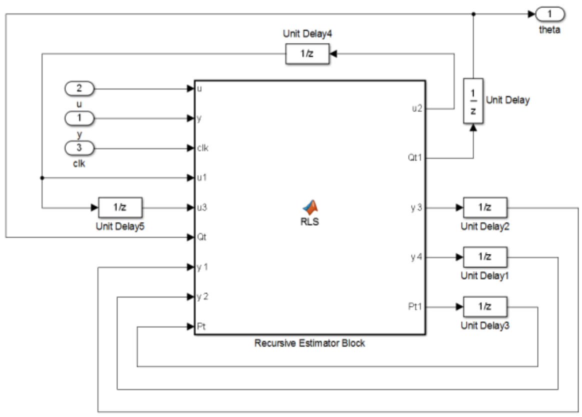

Fig. 4. RLS Parameter Estimator Block Structure

Pole placement control (PPC) algorithm is used to control online parameter estimated system. Block structure of PPC is shown in Figure 5.

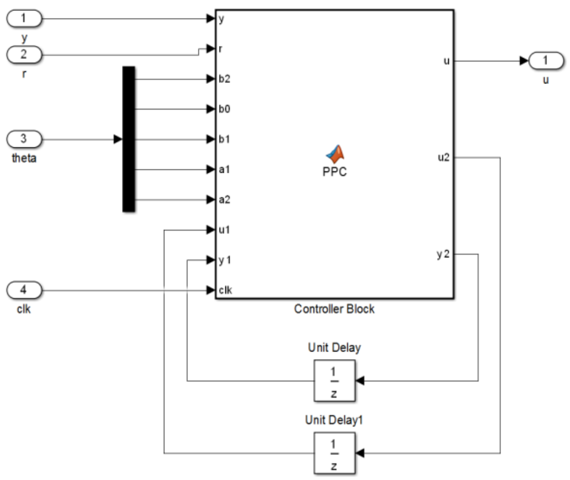

Fig. 5. Pole-placement control block structure

In the simulations, simulation step time is chosen as 0.001 s controlled system is run 100 s and we see that in the presence of the noise system parameters updated and after 5 s parameters are almost settled to their exact values we use this parameters in the PPS and generate desired control input. Controlled system response to a square wave and sawtooth inputs with 1s periods can be seen in Figure 6 and Figure 7.

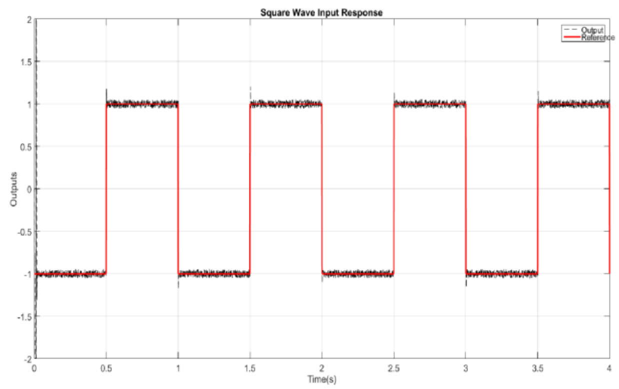

Fig. 6. Square wave input response

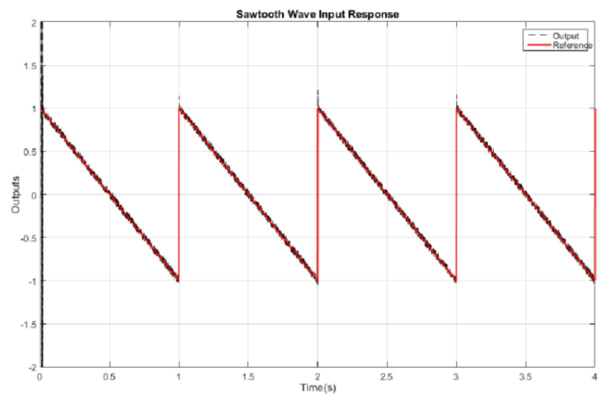

Fig. 7. Sawtooth wave input response

6. Conclusions

Speed control problem of a permanent magnet DC motor considered in the existence of disturbance and unknown plant parameters. Self-tuning adaptive control technique is used to solve the problem. Different types of reference input are applied to see the performance of the controller. It can be seen from the simulations that RLS estimator calculates the plant parameters accurately and PPC controller regulates the speed in the presence of noise. Furthermore speed of response of controller is satisfactory.

7. References

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