Friction parameters identification and compensation of LuGre model base on genetic algorithms

Yuqin Wen[a], Ming Chu[b] and Hanxu Sun[c]
School of Automation,
Beijing University of Posts and telecommunications
No.10 Xitucheng Road, Haidian District, Beijing, China
awyq_bupt@163.com

Abstract

According to the interference of the servo system, a method is proposed that identify the parameters of LuGre friction model and compensate the friction torque base on genetic algorithms. First, establish the LuGre friction model, on the basis of the model, identify the static parameters and the dynamic parameters in turn. Second, introduce the friction compensation to the feedback control of the servo system so that to eliminate the interference and improve the system tracking accuracy and robustness.

Keywords: LuGre friction model; genetic algorithms; servo system; friction compensation.

1 Introduction

Friction exists in almost all of the servo systems. In high precision servo system, friction usually has a strong nonlinear character and has impact on the position control accuracy and performance implications. There are lots of friction models including static models and dynamic models. Static models like Bingham model, Stribeck model, Kamopp model and dynamic model like Dahl model, Bliman-Sorine model, LuGre model, and so on. While Genetic Algorithms is a searching mechanism that mimics the natural biological evolution, searching the optimal solution in the global scope, can solve LuGre friction model parameters identification problem well. LuGre model can well explain crawling, pre-sliding displacement, friction memory, rising static friction. Therefore, we adopt this model to analyze. In this paper, two aspects are discussed aim at the interference problems originated from friction: parameters identification and control of friction compensation[1]. With the identification result, we can compensate the friction, now that to improve the stability and control accuracy of the servo system.

2 Friction model

The primary factor in measuring a friction model is whether it can describe the friction dynamic characters neighboring zero speed or not. Stribeck model handle the strong nonlinear problems well, hence, it can be considered an ideal model. As a result, LuGre model[2] applies Stribeck while solve the problems the nonlinear factors affect the friction near zero speed.

Stribeck model can be described as:

Static friction is,

$$F_f(t)=\begin{cases} F_m, F(t)>F_m \\ F(t), -F_m<F<F_m \\ -F_m, F(t)<-F_m \end{cases}. \tag{1}$$

Dynamic friction is,

$$F_f(t)=\left[F_c+\left(F_m-F_c\right)e^{-\alpha_1\left|\dot{\theta}(t)\right|}\right]\cdot \operatorname{sgn}\dot{\theta}(t)+k_v\dot{\theta}. \tag{2}$$

$$F(t)=J\dot{\theta}(t). \tag{3}$$

Where $F(t)$ is driving force; F_m is max static friction; F_c is coulomb friction; k_v is viscous friction torque coeddicient; $\dot{\theta}(t)$ is angular velocity of rotation; α and α_1 is small positive number.

It's schematic diagram as follows,

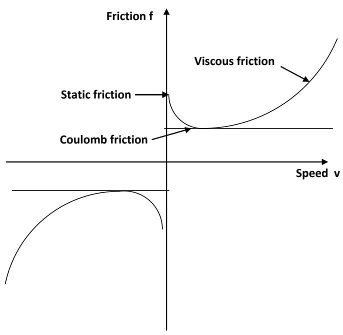

Fig. 1 Stribeck friction model diagram

The equation of the friction in servo system can be described as,

$$m\frac{d^2x}{dt^2}=u-F. \tag{4}$$

Among this, m is rotational inertia, x is the displacement, u presents the control torque and F is a friction torque.

LuGre model is built based on the average transformation of the bristle, presented by z, friction is F.

$$\frac{dz}{dt} = \dot{x} - \frac{\sigma_0 |\dot{x}|}{g(\dot{x})} z . \tag{5}$$

$$g(\dot{x}) = F_c + \left(F_s - F_c\right) e^{-(\dot{x}/v_s)^2} . \tag{6}$$

$$F = \sigma_0 z + \sigma_1 \frac{dz}{dt} + \sigma_2 \dot{x} . \tag{7}$$

Where σ_0 and σ_1 are two dynamic parameters; F_c , F_s , v_s , σ_2 are four static parameters.

When the system is in stable motion, $\frac{dz}{dt} = 0$. At this time, F is,

$$F = \left[F_c + \left(F_s - F_c\right)^{-(\dot{x}/v_s)^2} \right] \cdot \operatorname{sgn}(\dot{x}) + \sigma_2 \dot{x} . \tag{8}$$

From the equation, we can see that LuGre friction model uses Stribeck model in solving the problem strong nonlinear near zero speed. Meanwhile, it describes other static and dynamic characteristics accurately.

3 Parameters identification

The identification of LuGre friction model is divided in two steps[3], static parameters and dynamic parameters. First, we identify four static parameters using the Stribeck curve. Second, dynamic parameters identification is proceeded based on the static parameters identification[4、5].

4 Static parameters identification

The closed-loop system moves at a grope of invariable speeds $\{\omega\}_{i=1}^{N}$, and the corresponding sequences of the control torque are $\{u\}_{i=1}^{N}$. From Eq. 4, we can see that, when $\frac{d^2 x}{dt^2}$ =0, u=F. Hence, the two sequences above determine the stable corresponding relations between the frictions torque and the velocity, which is known as the Stribeck curve. Supposed the parameter vector to be identified is $x_s = \left[x_s^+, x_s^- \right]$, then,

$$x_s^+ = \left[\hat{F}_C^+, \hat{F}_S^+, \hat{v}_s^+, \hat{\sigma}_2^+ \right] \ (\dot{x} > 0), \ x_s^+ = \left[\hat{F}_C^-, \hat{F}_S^-, \hat{v}_s^-, \hat{\sigma}_2^- \right] \ (\dot{x} < 0). \tag{9}$$

We define the error of the identification is,

$$e(x_s, \dot{x}_i) = u_i - F(x_s, \dot{x}_i). \tag{10}$$

$$F(x_s, \dot{x}_i) = \begin{cases} \left[\hat{F}_c^+ + (\hat{F}_s^+ - \hat{F}_c^+) e^{-(\dot{x}/\hat{v}_s^+)^2} \right] \mathrm{sgn}(\dot{x}) + \hat{\sigma}_2^+ \dot{x} (\dot{x} > 0) \\ \left[\hat{F}_c^- + (\hat{F}_s^- - \hat{F}_c^-) e^{-(\dot{x}/\hat{v}_s^-)^2} \right] \mathrm{sgn}(\dot{x}) + \hat{\sigma}_2^- \dot{x} (\dot{x} < 0) \end{cases}. \tag{11}$$

The objective function is,

$$J = \frac{1}{2} \sum_i^N e^2(x_s, \dot{x}_i). \tag{12}$$

To identify the static parameters is to minimize the objective Eq. 12.

5 Dynamic parameters identify

When we identify the dynamic parameters, we use the output displacement or accelerate velocity and the output control torque. Supposed the parameters is $x_d = \left[\hat{\sigma}_0, \hat{\sigma}_1 \right]$, we define the error,

$$e(x_d, t_i) = u(t_i) - u(x_d, t_i). \tag{13}$$

In the equation, $u(t_i)$ is the control torque of the servo system, $u(x_d, t_i)$ is the identified output control torque. Form Eq. 4, we can see,

$$u(x_d, t_i) = F + m \frac{d^2 x_i}{dt_i^2}. \tag{14}$$

$$F = \hat{\sigma}_0 z + \hat{\sigma}_1 \dot{z} + \hat{\sigma}_2 \dot{x}. \tag{15}$$

$$\dot{z} = \dot{x} - \frac{\hat{\sigma}_0 |\dot{x}|}{g(\dot{x})} z .$$

(16)

We define the objective function,

$$J = \frac{1}{2} \sum_{i}^{N} e^2 (x_d, t_i) .$$

(17)

To identify the dynamic parameters is to minimize the objective Eq. 17.

6 The overall identity process

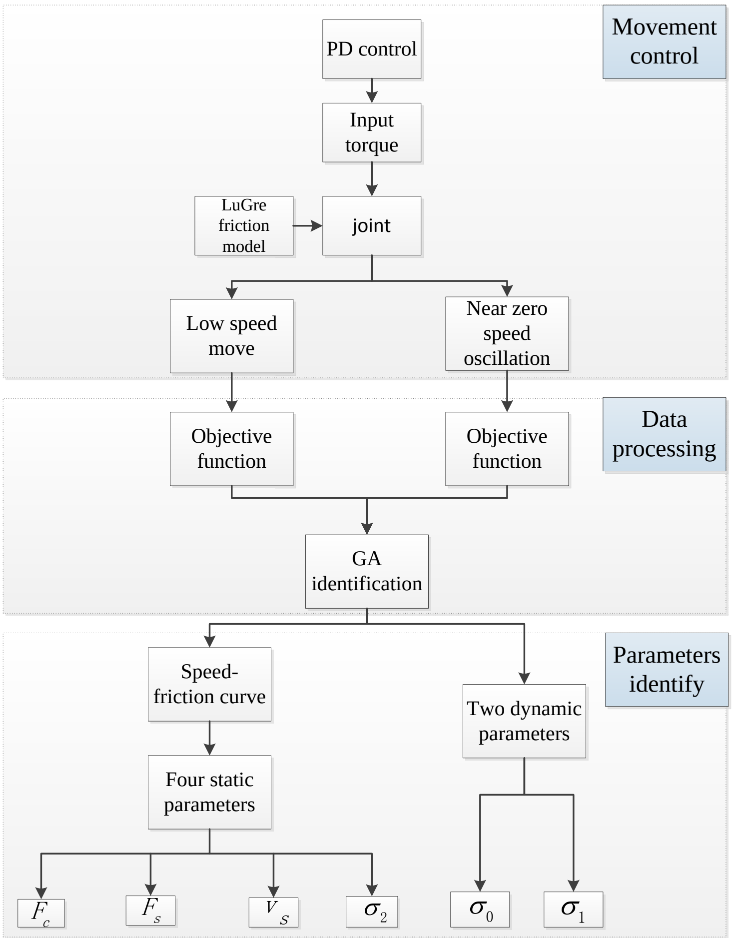

Figure. 2 GA identification process

7 Simulation and the results analysis

Static friction curve's test and identify

From Eq. 4, we can see that, input a constant speed, we get u=F. Eq. 11 is adapted in practical system friction $F_c^+ = 0.1503, F_s^+ = 0.631, \alpha^+ = 0.019, V_s^+ = 0.051$.

$F_c^- = 0.201, F_s^- = 0.72, \alpha^- = 0.029, V_s^- = 0.051$, speed signal is $\{\dot{x}_i\}_{i=1}^{N} = [-1.0 : 0.05 : 1.0]$. There are 41 signals in all. Using PD control to the signals, while $k_p = 200$, $k_d = 200$. When we are tracking the speed signal, all the signals corresponds to a tracking result.

Fig. 2 is the tracking curve when the speed is one, and the result comes fairly well. Fig. 3 is the tracking error. We can tell that the error is quite little, and is approaching to zero. Fig. 4 is the curve error between practical and identified curve.

When we do the simulation by using genetic algorithms, determine population size M=100, largest evolution algebra G=1000. The searching area of parameters are, $F_c \in [0,1], F_s \in [0,1], V_s \in [0, 0.1]$, $\alpha \in [0, 0.1]$. Fig. 5 shows the practical curve and the identified curve. Contrast them, we can see they are closed. The result is ideal. Identification results are,

$F_c^+ = 0.1503, F_s^+ = 0.631, \alpha^+ = 0.019, V_s^+ = 0.051$,

$F_c^- = 0.201, F_s^- = 0.72, \alpha^- = 0.029, V_s^- = 0.051$

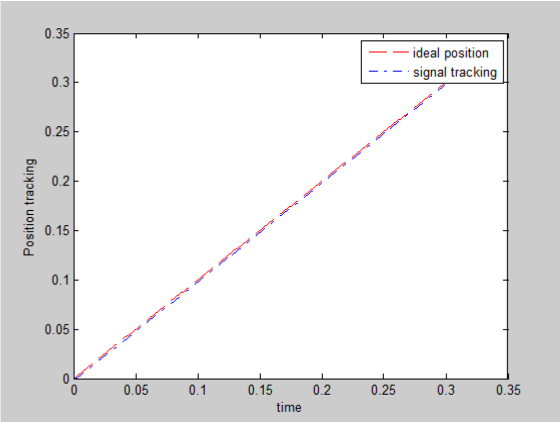

Fig. 2 speed tracking

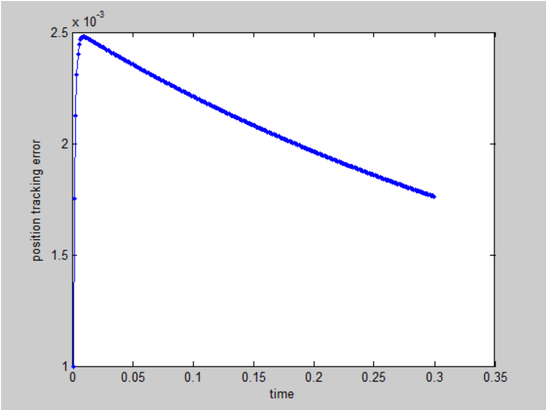

Fig. 3 speed tracking error

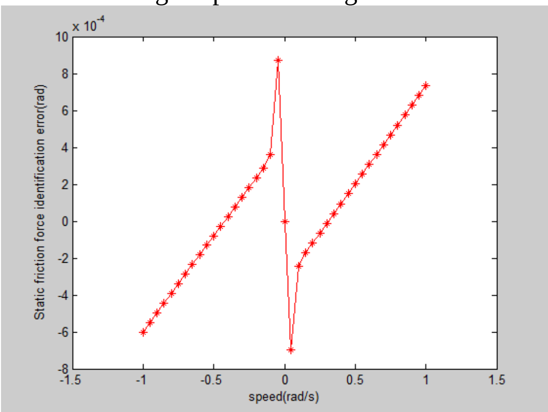

Fig. 4 friction curve error

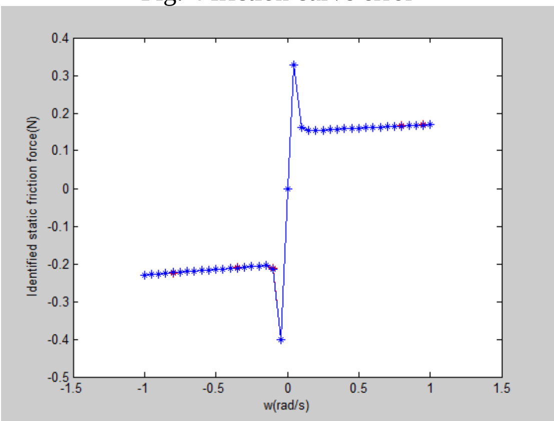

Fig. 5 practical and ideal curve

8 PD control of LuGre model

According to Eq. 5-7, make $J = 1, \sigma_0 = 260, \sigma_1 = 2.5, F_c = 0.28, F_s = 0.34, V_s = 0.01$, make the input signal sine wave $y_d = 0.1\sin(2\pi t)$.

Describe the control algorithm and the system by using Simulink.

Choosing PD control, $k_p = 20, k_d = 5$, Fig. 4 and 5 show the tracking result of position and speed,it can obviously figure out the ceiling phenomenon. While in Fig. 6-7, we can see the serious deformation when the speed cross zero, and tracking dead zone is appeared.

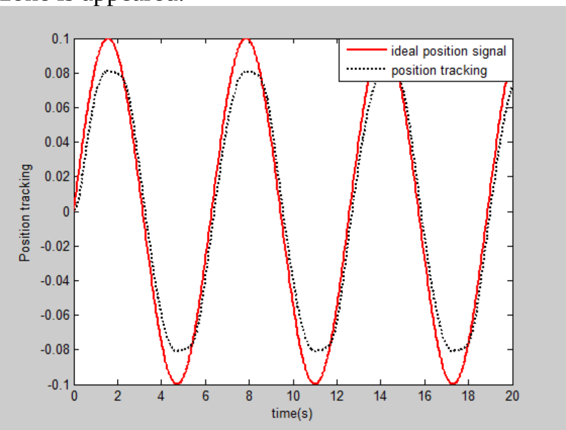

Fig. 6 position tracking

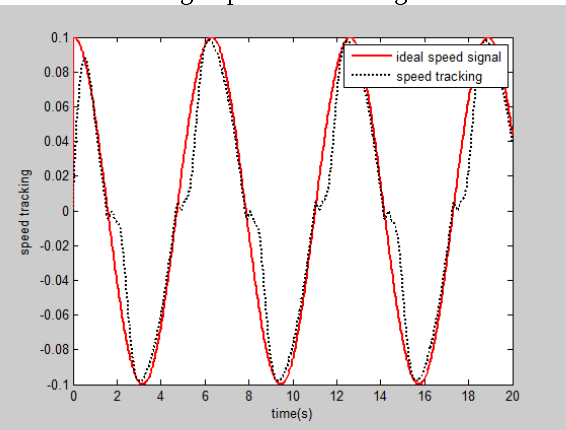

Fig. 7 speed tracking

9 Servo system friction compensation

To offset the influence brought by friction, we compensate the friction according to the identification result, introducing the compensation to servo system, making it approaching the actual friction interference continuously.

Among the simulation, step signal is adopted, choosing LuGre friction model and adding in friction compensation. Using real number coding, we determine the size of sample is 30, $P_c = 0.99$, $P_m = 0.10 - [1:1:Size] \times 0.01 / Size$.

During dynamic identifying, supposed the practical parameter σ_0=0.3, σ_1=0.15, while identify results σ_0=0.36, σ_1=0.147. Fig. 9 and10 are the position and speed tracking of compensation system. We can see that the speed cross zero and tracking dead zone are disappeared obviously.

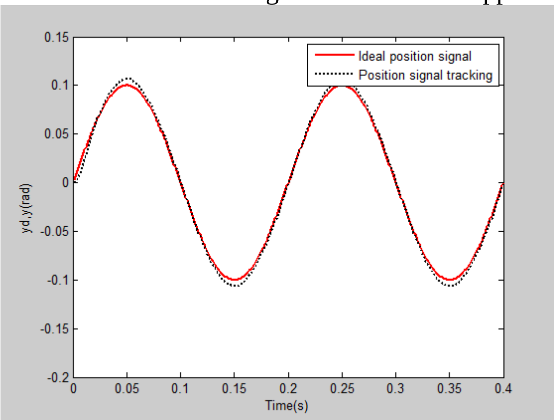

Fig. 9 position tracking with compensation

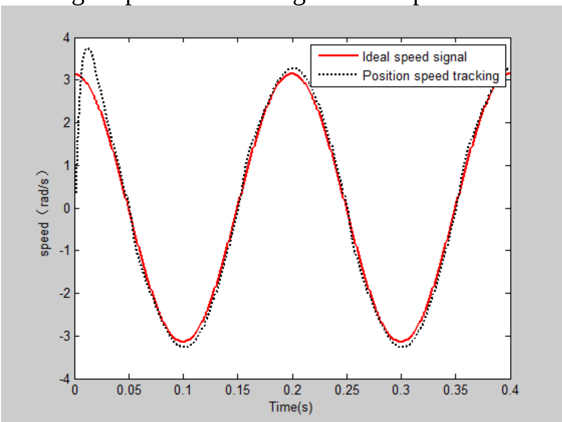

Fig. 10 speed tracking with compensation

10 Conclusion

Friction is a phenomenon that cannot be avoided. It can reduce the accuracy of tracking and stability. Through the tracking result of servo system that contains friction, we can observe the effect that brought by friction. Using genetic algorithms in identifying friction parameters, can remove the effect brought by friction and making the system rapidly response thus improve the stability and tracking accuracy of the system.

Acknowledgements

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