New Control for Two Mass Positioning System Using Nominal Characteristic Trajectory Following Controller

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ABSTRACT

In this study, a nominal characteristic trajectory following (NCTF) controller for point-to-point (PTP) positioning system is introduced for two mass systems and its performance is evaluated. The NCTF controller consists of a nominal characteristic trajectory (NCT) and a compensator. The objective of the NCTF controller is to make the object motion follow the NCT and end at its origin. Therefore, the NCT is used as an intended object motion and the compensator is used to make the motion of the controlled object follow the NCT. The NCTF controller is designed based on a simple open-loop experiment of the object and no information except the NCT is necessary for controller design. The effectiveness of the NCTF controller is evaluated and discussed through simulations. The effect of the design parameters on the robustness of the NCTF controller to inertia and friction variations is evaluated and the influence of saturation on the positioning performance is examined.

Keywords
Two mass system, NCTF, Simulation

1.0 INTRODUCTION

Positioning systems play an important role in industrial engineering applications such as advanced manufacturing systems, semiconductor manufacturing system and robot systems. A nominal characteristic trajectory following (NCTF) controller as practical controller for point-to-point positioning systems had been proposed. The NCTF controller consists of two elements namely a nominal characteristic trajectory (NCT) and a compensator. It had been reported that the NCTF had a good positioning performance and robustness to parameters variations (Wahyudi, 2002). However, the NCTF controller is designed based on assumption that the positioning system is a one-mass system. The positioning system can only be assumed as one-mass positioning system in the case a rigid coupling (a coupling with high stiffness) is used and there are no flexible elements. On the other hand, the systems should be modeled as multi-mass system when flexible couplings (couplings with low stiffness) or other flexible elements are used to connect the actuator to other elements. In multi-mass systems, low stiffness elements such as couplings cause mechanical resonance, which may reduce positioning accuracy. Therefore, the NCTF controller can not be used directly in the case there is a flexible connection between elements of the positioning systems. Improvements in the design of NCT and compensator are required to make the NCTF controller is suitable for multi-mass positioning system.

2.0 NCTF CONTROL CONCEPT

The structure of the NCTF control system is shown in Figure. 1. The NCTF controller consists of a NCT and a compensator. The NCTF controller works under the following two assumptions:

(1) A DC or an AC servo motor is used as an actuator of the object.
(2) PTP positioning systems are discussed, so θr is constant and θr' =0.

Here, the objective of the NCTF controller is to make the object motion follow the NCT and end at the origin of the phase plane (*e, e'*). Signal *u*p shown in Figure.1 represents the difference between the actual error rate *e'* and that of the NCT. The value of *u*p is zero if the object motion perfectly follows the NCT. The compensator is used to control the object so that the value of *u*p, which is used as an input to the compensator, is zero.

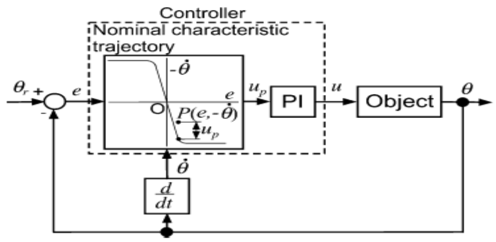


Figure 1. Structure of NCTF control system for PTP positioning.

Figure.2 shows an example of object motion controlled by the NCTF controller. The object motion comprises two phases: one is the reaching phase and the other, the following one. In the reaching phase, the compensator forces the object motion to reach the NCT as fast as possible. In the following phase, the compensator controls the object motion to follow the NCT and end at the origin. The object motion stops at the origin, which represents the end of the positioning motion. Thus, the NCT governs the positioning response performance.

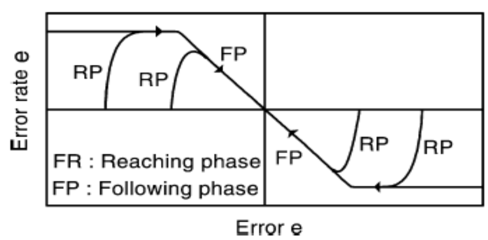


Figure 2. NCT and object motion.

The NCTF controller is designed based on a simple open-loop experiment of the object as follows (Wahyudi & Albagul A, 2004):

(1) Open-loop-drive the object with a stepwise input and measure the displacement and velocity responses of the object.
(2) Construct the NCT by using the object responses. Since the NCT is constructed based on the actual responses of the object, the NCT includes effects of nonlinear characteristics such as friction and saturation.
(3) Design the compensator by using the NCT information. The NCT includes information of the actual object parameters. Therefore, the compensator can be designed by using only the NCT information.

Due to the fact that the NCT and the compensator are constructed from a simple open-loop experiment of the object, the exact model including the friction characteristic and the conscious identification task of the object parameters are not required to design the NCTF controller. The controller adjustment is easy and the aims of its control parameters are simple and clear.

3.0 CONTROLLER DESIGN

3.1 NCT Construction

In order to construct the NCT, a simple open-loop experiment has to be conducted. In the experiment, an actuator of the object is driven with a stepwise input and, displacement and velocity responses of the object are measured. Figure.3 shows the stepwise input and, the velocity and displacement responses of the object. In this case, the object vibrates due to its mechanical resonance (Ellis G, 2000). In order to eliminate the influence of the vibration on the NCT, the object response must be averaged. The exact model of the object used only for making simulation is shown in Table 1.

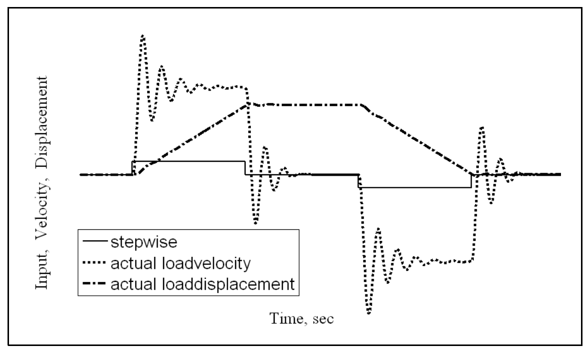


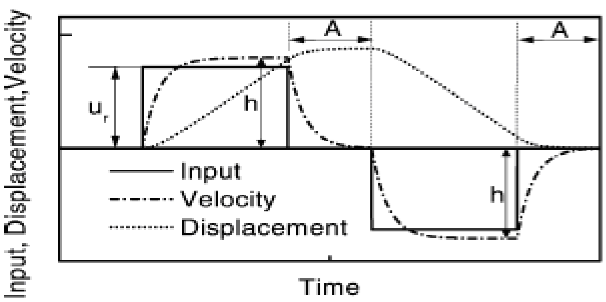
Figure 3. Input and actual object response

Table 1: *Nominal object parameters*

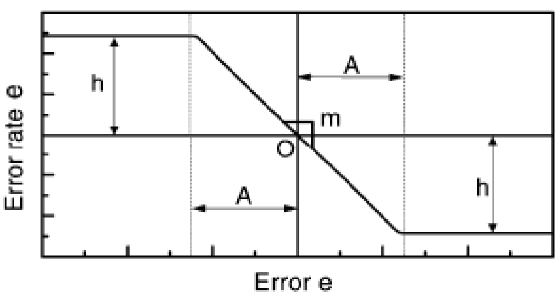
Parameter	Value	Unit
Motor inertia, J_m	20.43e-6	Kgm^2
Inertia load, J_l	19.58e-6	Kgm^2
Stiffness, K_c	0.04	Nm/rad
Motor resistance, R	5.5	Ω
Motor inductance, L	0.85e-3	H
Torque constant of the motor, K_t	0.041	Nm/A
Motor voltage constant, K_b	0.041	Vs/rad
Frictional torque, T_f	0.0027	Nm
Motor viscous friction, B_m	8.35e-4	Nms/rad
Load viscous friction, B_l	8.35e-4	Nms/rad
Gear reduction ratio, K_b	3.71	
Motor efficiency motor, n_m	78	%
Gear head efficiency, n_g	88	%

In Figure 4, moving average filter is used because of its simplicity (Oppenheim A.V. & Schafer R.W, 1999). The moving average filter operates by averaging a number of points from the object response to produces each point in the averaged response. The averaged velocity and displacement responses are used to determine the NCT. Since the main problem of the PTP motion control is to stop an object at a certain position, a deceleration process (curve in area *A* of Figure. 4) is used. Variable *h* in Figure.4 is the maximum velocity, which depends on the input step height. From the curve in area *A* and *h* in Figure.4 (a), the NCT in Figure.4 (b) is determined.

There are two important parameters in the NCT as shown in Figure. 4(b): the maximum error rate indicated by *h*, and the inclination of the NCT near the origin indicated by *m*. As discussed in the following section, these parameters are related to the dynamic parameters of the object. Therefore, the parameters are used to design the compensator.



a) Stepwise input and response



b) Nominal characteristic trajectory

Figure 4. Construction of the NCT.

An exact modeling including friction and conscious identification processes are not required in the NCTF controller design. The compensator is derived from the parameter m and h of the NCT. Since the DC motor is used as the actuator, the simplified object can be presented as a following fourth order system:

$$G_o(s) = \frac{\Theta(s)}{U(s)} = K \frac{\alpha_2}{s(s+\alpha_2)} \frac{\omega_f^2}{s+2\zeta_f \omega_f s + \omega_f^2} \quad (1)$$

Where $\theta(s)$ represents the displacement of the object, U(s), the input to the actuator and K, ζ_f, α_2 and w_f are simplified object parameters.

3.2 Compensator Design

The following PI compensator is proposed for two mass systems:

$$G_c(s) = \frac{(K_p s + K_i)(s + 2\zeta_f \omega_f s + \omega_f^2)}{s} \quad (2)$$

The compensator is used so that the poles of simplified object model which cause the vibration was canceled. The compensator parameters K_i and K_p are designed by using w_n and ζ as the design parameters. A higher w_n and a larger ζ are preferable in the compensator design. However they are constrained by the slew rate of the power amplifier and sampling time of the systems. The compensator and the simplified object model of the NCTF control system is constructed as shown in Figure 4.

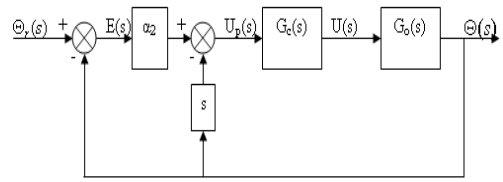


Figure 4. Simplified NCTF control system

4.0 EXPECTED RESULTS

The detailed model of the object used only for making simulations is shown in Figure.5. In the detailed model of the object, friction and saturation are taken into consideration (Cheok K.C.,Hu H., & Loh N.K, 1988). The significance of this research lies in the fact that the simple and ease control design for high precision positioning system is required in practical application. By improving the NCTF controller, it will be more reliable and practical for realizing high precision positioning systems not only for one-mass but also for two-mass positioning systems.

The expected outputs of the research are

1. An enhanced NCTF controller for two-mass positioning systems.
2. An experimental positioning system which can be used for further research as well as teaching of control systems.

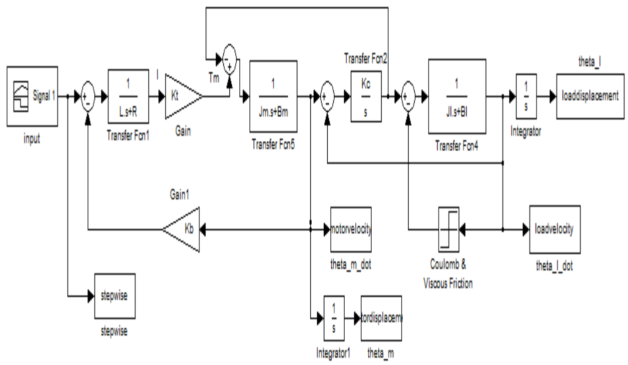


Figure 5. Dynamic model of the object.

5.0 SUMMARY

The NCTF controller as a new practical control for positioning systems has been introduced and discussed. The NCTF controller consists of the NCT and the PI compensator. The NCT is constructed using the object response data in a simple open-loop experiment and the compensator parameters are designed based on the NCT.

In this paper, NCTF control of two-mass positioning mechanisms has been discussed. However, mechanisms that have masses are also used for positioning. Therefore, the application of NCTF control to these mechanisms is left for future study.

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