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Dynamic Nonlinear Control for Electro-optical tracking system

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Abstract-- In a typical electro-optical tracking system, two or more types of controllers are used for seeking, acquisition and tracking modes. This leads to the problem of mode switching among these controllers. This paper proposes a nonlinear proportional integral derivative control scheme which can perform all the above functions to shorten the settling time by reducing the overshoot caused by the integrator, without degradation of other performance specifications. This control law not only increases the speed of closed-loop response, but also improves the settling performance.

Keywords-- electro-optical tracking； nonlinear control； Settling time

I. INTRODUCTION

Typical electro-optical tracking systems are designed to operate in two modes: acquisition mode when the error is initially large and gradually decrease; and tracking mode when the error is maintained small. Since optimizing of an LTI controller for the purpose of acquisition and for the purpose of tracking results in quite different systems, performance of LTI controllers cannot be best both for acquisition and tracking, and the controller design involves some compromises. The trade-offs can be better resolved in nonlinear controllers.

The major performance limitations are expressed in frequency-domain: the feedback bandwidth and the robust performance are limited by the Bode integrals in conjunction with, in the acquisition mode, the plant structural modes and the sampling frequency, and in the tracking mode, with the sensor noise and the jitter sources. The tracking response need not be compromised in order to meet the requirements for good acquisition, and vice versa; these responses are also not compromised by the requirement to the adaptation transient smoothness. The last requirement together with the requirements to the rate of adaptation to be fast is addressed by designing appropriate intermediate responses and specifying the rate for changing the responses.

In a typical servo implementation, an integral element is added into the compensator to improve the steady state error due to bias. For a proportional integral derivative (PID) compensation servo loop, although a small track error can be achieved, the settling time due to large overshoot caused by the integrator would usually be very long. Many effective methods were developed to improve the transient process in the past years, such as initial value compensation (IVC)[1-6]. In IVC, the integrator works after mode switching and the nonzero initial state such as velocity at the second mode is compensated. There was also a trend towards using nonlinear control schemes to improve the servo performance. Venkataramanan et al.[7, 8] presented a composite nonlinear controller made of a combination of linear and nonlinear feedback parts to overcome possible problems associated with mode-switching. Li et al. [9] proposed a nonlinear PID controller, where a combination of linear proportional and differential terms was used with an integrator term whose gain is tuned by a nonlinear Gaussian function. As a result, the settling time is shortened by reducing the overshoot caused by the integrator. Hawwa et al. [10] proposed a nonlinear PID scheme which is carried out by utilizing a derivative action tuned by a nonlinear function to provide the system with the needed level of damping.

In this paper, we put forward a nonlinear PID control scheme for acquisition and tracking control in a electro-optical tracking system. Since the proposed nonlinear factor makes integrator work continuously all the time, IVC is unnecessary any more.

II. LOOP RESPONSE

In acquisition regime illustrated in Fig 1 signal is large .In the case the controller should respond rapidly, i.e. the feedback bandwidth should be wide and the closed-loop response is close to that of a Bessel filter. In the acquisition mode it is not necessary however that the feedback be very large, since the error is big anyway. In contrast, in the tracking regime, the feedback bandwidth needs to be reduced to reduce the output effects of the sensor noise, but the value of the feedback at lower frequencies should be made large to reject the jitter and to make the tracking precise. The loop frequency responses for the two modes of operation are depicted in Fig. 2. We assume here that the feedback bandwidth in the system is limited by a structural mode with large phase uncertainty, and therefore the mode needs to be gain-stabilized. The shapes of the loop responses arc optimized under the Bode integral limitations.

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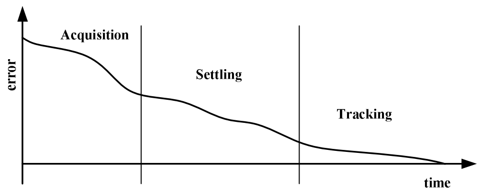

Figure 1. acquisition and tracking of an Electro optical tracking system.

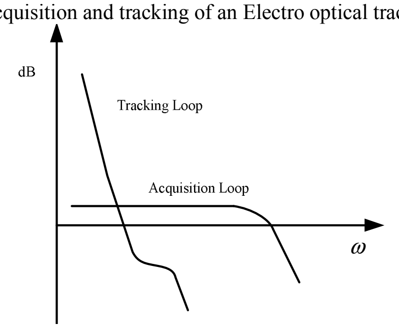

Figure 2. response of acquisition loop and tracking loop

III. NONLINEAR CONTROL SCHEME FOR FAST SETTLING

The design targets for the closed-loop control system are (i) to move the actuator fast from current position to target position, and (ii) to maintain tracking accuracy in presence of various disturbances. The PID controller has been the tool of choice for so many servo designers. In its linear from, a PID controller uses as an input the error (e) defined as the reference signal minus the actual output. It then operates on the error using a proportional gain, an integrator, and a derivative term to produce the control output, U:

$$U = K_P \cdot e + K_D \cdot \dot{e} + K_I \cdot \int edt \tag{1}$$

where K_P, K_I, K_D are the proportional, the integrator, and the derivative gains, respectively; and e is the regulation error.

While the PID action is considered to be an effective controller, which is easy to implement and to tune, the increasing restrictions, put by the ever increasing areal density, are putting limitations on its capabilities. Hence, we believe that the use of nonlinear gains should provide us with more tuning capabilities of the PID gains. The proposed control action is:

$$U = K_P \cdot f_P(e) \cdot e + K_D \cdot \dot{e} + K_I \cdot f_I(e) \cdot \int edt \tag{2}$$

Where $f_P(e)$ and $f_I(e)$ are functions used to modulate the proportion gain and derivative gain and have the forms:

$$f_P(e) = k_P + k_1 |e| \tag{3}$$

$$f_I(e) = k_i \cdot \exp(-k_2 |e|) \tag{4}$$

Where k_1 k_2 are tunable parameters to shape the proportion and integrator state, the selection of k_1 k_2 is determined by the proportion and integrator gain K_P K_I in (1) and "exp" means the common exponential function.

When the error is large, would be so small that the integrator is almost deactivated, and the main control task is executed by an approximate PD type controller to achieve fast response. With the decrease of error, would increase exponentially so that the integrator strengthens its work gradually to deal with the system steady performance. Thus, the closed-loop performance is determined by a dynamic PID controller continuously varying with error. By the appropriate selection of the parameters k_2 and k_I, we can take advantages of both the PD controller for the dynamic performance and the PID controller for the steady-state performance while alleviating their respective adverse effects.

From (4), the parameter k_2 will affect the shaping degree of Gaussian function in the integrator gain and thus determine whether the NPID controller can work perfectly or not to coordinate the fast response and the improved settling process. It can be determined by the following equation:

$$k_2 = \ln k_I / (\Delta r) \tag{5}$$

Where Δ is the percentage width of the settling belt in the step response, it is usually acceptable for 10%–15% in tracking systems, and r is the step size in degree. The formula (5) is selected such that the integrator gain at the settling boundary is the same as in (1).

IV. EXPERIMENT RESULTS AND ANALYSIS

A. *Electro-optical tracking systems Modeling and Controller Design*

We have developed a software dynamic signal analyzer (SDSA) using dSPACE 1103. The electro-optical tracking system model is obtained by using the SDSA injects a swept sine signal into the driver IC, and read the position information from the resolver, then generates the frequency response by the fast Fourier transform (FFT). The electro-optical tracking system model we obtained is

$$\frac{1154s^2 + 1895s + 1.355e8s + 6.24e05}{3.865e-6s^5 + 0.001236s^4 + 1.439s^3 + 271.5s^2 + 9.459e04} \tag{5}$$

The control law is experimented on dSPACE 1103 and then implemented on TI's DSP TMS320LF2812 with a sampling frequency of 1kHz.

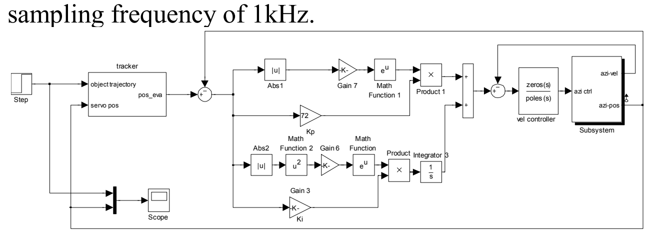

Figure 3. NPID control scheme simulation using Matlab

$$f_P(e) = 30 + 10|e| \quad f_I(e) = 200 \cdot \exp(-40|e|). \tag{6}$$

Then

$$U = (30 + 10|e|) \cdot e + 0.1 \cdot \dot{e} + 200 \cdot \exp(-40|e|) \int edt \tag{7}$$

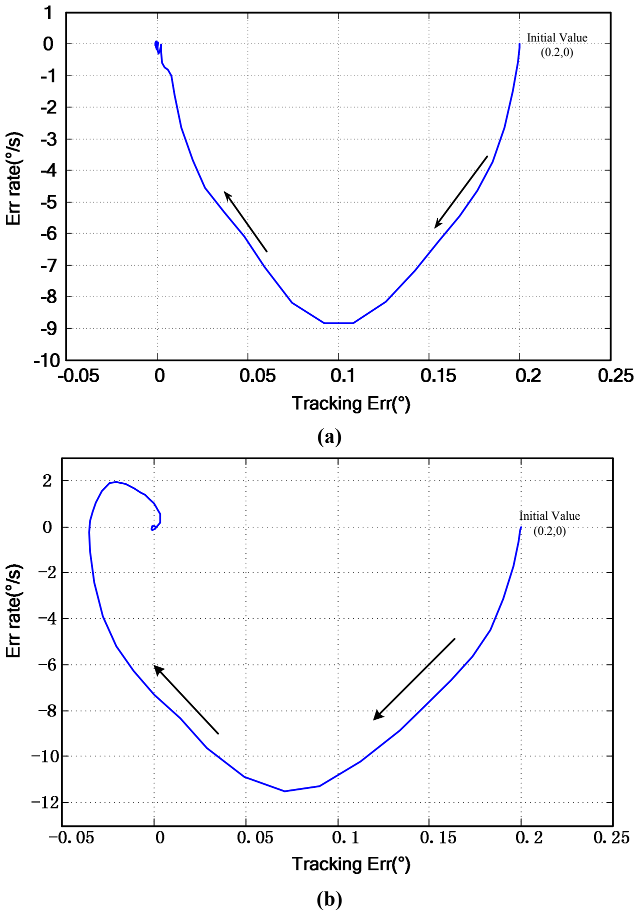

Figure 4. Phase-plane trajectory plot (a) in NPID control system and (b) in PID control system

B. *Phase-Plane Analysis of System Performances*

The phase-plane analysis technique is to show the system state trajectory accurately with time to be a parameter. Since the effect of high frequency resonance can be eliminated by a notch filter, we use a second-order plant model, to calculate the system state equations for simplicity. The two-dimensional phase-plane trajectories then can be easily drawn in the Matlab package, as shown in Fig. 4.

The initial error and error rate correspond to, which mean the step size is 0.2 degree and zero initial states in both systems. As time increases, the trajectories move clockwise about the origin and reach, the maximal negative excursion beyond the final steady state, so that it indicates the maximal overshoot. In PID control system, it is about 20% with undershoot of 5%, and 1.5% without undershoot with NPID controller. Therefore, the step response in NPID case can be regarded to have entered the settling belt of 10%–15% directly, and thus, the settling time can be shortened greatly.

V. CONCLUSION

In this paper, a NPID control scheme is proposed to improve settling process of electro-optical tracking systems in mode-switching and tracking control. The NPID scheme is a combination of linear scheduled proportional gain terms and an integrator term whose gain is tuned by a nonlinear Gaussian function.

Experiment results show it is robust against different bias and step sizes. The use of nonlinear PID scheme was found to significantly shorten the settling time and reduce the overshoot caused by the integrator when compared to the corresponding classical linear PID controller. It has been utilized in an IR tracking system and got good performances.

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REFERENCES

[1] Yunfeng, L., et al., *Optimization of initial value compensation for settle control in hard disk drives.* Magnetics, IEEE Transactions on, 2005. **41**(2): p. 797_801.

[2] Iwasaki, M., et al., *Residual vibration suppression using initial value compensation for repetitive positioning.* Advanced Motion Control, 2004. AMC '04. The 8th IEEE International Workshop on, 2004: p. 571_576.

[3] Oboe, R. and M. Federico, *Initial value compensation applied to disturbance observer-based servo control in HDD.* Advanced Motion Control, 2002. 7th International Workshop on, 2002: p. 34_39.

[4] Johansson, M. *Optimal initial value compensation for fast settling times in mode-switching control systems*. in *Decision and Control, 2000. Proceedings of the 39th IEEE Conference on*. 2000.

[5] Okuyama, A. and T. Yamaguchi, *Controller switching strategy for constrained systems and its application to hard disk drives.* Advanced Motion Control, 2006. 9th IEEE International Workshop on, 2006: p. 143-148.

[6] Li, Y. and M. Tomizuka. *Short seeking by multi-rate digital controllers for computation saving with initial value adjustment*. in *Control Applications, 2004. Proceedings of the 2004 IEEE International Conference on*. 2004.

[7] Venkataramanan, V., et al., *Discrete-time composite nonlinear feedback control with an application in design of a hard disk drive servo system.* Control Systems Technology, IEEE Transactions on, 2003. **11**(1): p. 16_23.

[8] Venkataramanan, V., et al. *Design and implementation of discrete-time composite nonlinear feedback law for a hard disk drive*. in *Decision and Control, 2001. Proceedings of the 40th IEEE Conference on*. 2001.

[9] Ying, L., G. Guoxiao, and W. Youyi, *A nonlinear control scheme for fast settling in hard disk drives.* Magnetics, IEEE Transactions on, 2004. **40**(4 part:2): p. 2086_2088.

[10] Hawwa, M.A. and A.A. Masoud. *A nonlinear PID servo controller for computer hard disk drives*. in *Advanced Motion Control, 2006. 9th IEEE International Workshop on*. 2006.