Adaptive Sinusoidal Disturbance Cancellation Strategy for Pointing Applications

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Abstract

This paper combines an adaptive sinusoidal disturbance cancellation scheme with linear pointing control techniques. The approach utilizes a six–axis active platform to reject disturbances with a large sinusoidal component, which could be caused by a noisy host or target. Since often the frequency of the sinusoidal disturbance can not be precisely known, a Phase Locked Loop(PLL) algorithm is used to catch the frequency, and a method for PLL design is developed. Experimental results on the UW (University of Wyoming) hexapod demonstrate a 50–fold decrease in pointing errors due to the monotone disturbance.[1]

1 Introduction

Flexure jointed hexapods have become great candidates for precision pointing applications in which a large workspace is not required because they can perform both vibration isolation and pointing [1]. Precision pointing is limited by disturbance vibrations, which could be on–board or from a vibrating target. In many environments the source of noise is a rotating machine, so a large component of the disturbance is periodic with a fixed (or slowly changing) frequency. This paper proposes a strategy to reduce both low–frequency disturbances and high frequency dominant sinusoidal components. Low frequency disturbances can be eliminated using existing linear control techniques [1], but high frequency disturbances cannot. This paper achieves both low and high frequency disturbance rejection by augmenting the linear control with nonlinear adaptive control algorithms. For simplicity, we assume that the high frequency disturbance has a single dominant harmonic component. The real time experiments on UW hexapods have shown that this strategy works well, and demonstrates over 35 dB (magnitude) of monotone sinusoidal disturbance rejection (with PLL).

2 Cancellation of Sinusoidal Disturbance of Known Frequency

Adaptive feedforward cancellation (AFC) is used for rejection of sinusoidal disturbances with known frequencies. The problem of attenuating an output, $y(t)$, in the Laplace domain, is given by

$$y(s) = P(s)[u(s) - d(s)] \quad , \tag{1}$$

where $u(s)$ and $d(s)$ are the Laplace transforms of the controller output and sinusoidal disturbance signal respectively, and $P(s)$ is the transfer function of the plant. The plant is assumed to be linear, time–invariant, and stable. To cancel a sinusoidal disturbance, let

$$u(t) = \hat{a}\cos(\omega_1 t) + \hat{b}\sin(\omega_1 t) = \hat{A}\cos(\hat{\alpha}_d(t)) \quad , \tag{2}$$

where $\dot{\hat{\alpha}}_d(t) = \omega_1$. Bodson, Sacks and Khosla [2] have shown that the following update law (3) for the adaptive parameters $\hat{a}$ & $\hat{b}$ is effective when $P(s)$ is stable, $Re[P(j\omega_1)] > 0$, and the adaptive gain γ is positive and sufficiently small.

$$\dot{\hat{a}} = -\gamma y \cos(\omega_1 t) \quad \dot{\hat{b}} = -\gamma y \sin(\omega_1 t) \tag{3}$$

3 Cancellation of Sinusoidal Disturbance with Unknown Frequency

As proposed in [2], in the case that the period of the sinusoidal disturbance can not be precisely known, a phase–locked loop can be used to estimate the instantaneous frequency (& phase) of the sinusoidal disturbance, while the magnitude of sinusoidal disturbance can be estimated by an adaptive algorithm. In this paper a similar idea is used for hexapod pointing control, but with a different implementation shown in Figure 1. $P_e(s)$ is an estimate of $P(s)$. It is used to shift the $-\sin(\hat{\alpha}_d(t))$ signal to make sure that $\cos(\hat{\alpha}_d(t))$ is in phase with $d(t)$, rather than $y(t)$.

Under some assumptions (omitted to save space), a linearized PLL model can be obtained. Based on this linear model, conventional control system techniques are used for the PLL design. $C(s)$ is designed so that the closed-loop system is stable for all gains, and it is able to track ramp input with zero steady–state error. The

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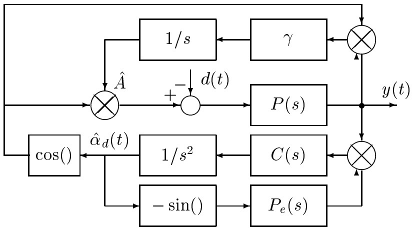

Figure 1: Combined scheme for cancellation of sinusoidal disturbance of unknown frequency.

bandwidth of the system is chosen according to the frequency of $y(t)$.

4 Sinusoidal disturbance cancellation in pointing control using a hexapod

By careful design of the θ_x & θ_y linear compensators, the noise below 1 Hz can be reduced by over 25 dB. However, the bandwidth (less than 10 Hz for UW hexapod) of the system can not be made big enough to suppress all disturbances. In this case, by combining the adaptive sinusoidal disturbance cancellation scheme with the linear pointing control, both the low frequency disturbances and a dominant sinusoidal component which appears outside the bandwidth of the linear system can be rejected.

5 Results

Two stacked hexapods are used. The combined pointing control algorithm is implemented on the top hexapod, while the bottom hexapod is used as a repetitive disturbance generator.

5.1 Cancellation of sinusoidal disturbance of known frequency

For contrast, the pointing errors are measured in three cases. First, no control effort is applied and the pointing loop is open. Then, linear compensators are designed and the pointing loop is closed. Finally, the known frequency adaptive cancellation scheme is added. In each case, the bottom hexapod is used to generate the same repetitive disturbance with a dominant fundamental harmonic of 10 Hz. Figure 2 plots θ_x vs θ_y for each of the above experiments. The experiments show that conventional linear control alone does not do a good job of rejecting the 10 Hz sinusoidal disturbance, though it reduces low frequency disturbance (below 6 Hz) very well. Compared with linear control alone, the adaptive cancellation method reduces the sinusoidal disturbance by over 20 dB (magnitude). However, the adaptation parameters $\hat{a}$ & $\hat{b}$ for channel θ_x, for example, do not converge to constants due to the frequency estimate error resulting in a degenerated performance.

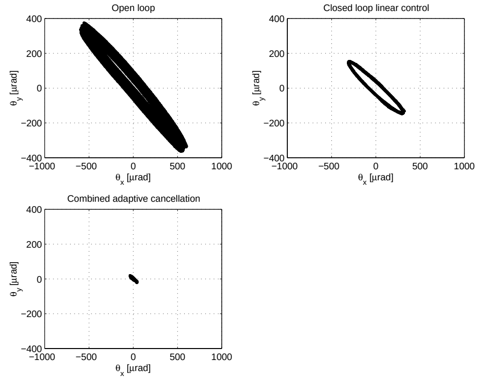

Figure 2: Plots of pointing error θ_x vs θ_y.

5.2 Cancellation of sinusoidal disturbances with unknown frequency

Denote Cancellation of Sinusoidal Disturbance with Unkown Frequency by CSDUF, and Cancellation of Sinusoidal Disturbance with Known Frequency by CSDKF. In the PLL design for both channels, $C(s) = (s+2)/(s+10)$. It can be shown that CSDUF rejects the dominant sinusoidal disturbance by 30 dB more than CSDKF method. In addition, the frequency and magnitude estimates $\hat{A}$ converge to constants as expected.

6 Conclusion

In this paper, we show that adaptive sinusoidal disturbance cancellation methods can be combined with conventional linear control schemes for hexapod pointing. The conventional linear control scheme can reduce the low frequency disturbances greatly, while the higher frequency dominant sinusoidal component can be rejected by combining an adaptive cancellation algorithm. Since usually the frequency of the sinusoidal disturbance can not be exactly known, the CSDUF method shows better performance in most cases. Further research has shown that this strategy can be used even when actuator failures occur, as long as appropriate reconfiguration algorithms for failed struts are used.

References

[1] J. E. McInroy and J. C. Hamann, "Design and control of flexure jointed hexapods," *IEEE Transactions on Robotics and Automation*, August 2000.

[2] M. Bodson and S. C. Douglas, "Adaptive algorithm for rejection of sinusoidal distanbance with unknown frequency," *Automatica*, vol. 33, no. 12, pp. 2213–2221, 1997.