N91-13342

# REDUCED-ORDER FILTERING FOR FLEXIBLE SPACE STRUCTURES

By

Craig S. Sims
Professor
Department of Electrical and Computer Engineering
West Virginia University
Morgantown, WV 26506

There is a need for feedback control of the large flexible space structures which are going to be increasingly important in the future of the space program. These structures are very lightly damped, and vibrations may persist for a long time when the system is disturbed unless an active feedback control strategy is used to damp out the vibrations. The system is best described by a partial differential equation description, but the more common approach is to use a large set of second order differential equations, where a large number of modes must be retained if the mathematics is to provide an adequate description of the dynamical process. Sensors, such as accelerometers and rate gyros, may provide data to the feedback controller so that it may respond appropriately to control the system. The data from the sensors is not perfect, but is subject to noise, called measurement noise, and the dynamical process itself is subject to disturbances referred to as process noise. This research is concerned with filtering the sensor signals to remove the measurement noise, and using the resulting state estimates to control the system.

Since the equations are linear, and the objectives are more or less standard, it would seem that the problem mentioned above could be solved using the standard state space techniques known as Kalman Filtering and Linear Quadratic Regulator Design [1]. The two difficulties with this approach are that the system order is very high, and that some system parameters are not known with any precision. In particular, the damping terms are not well known. Furthermore, a filter and control which worked satisfactorily on earth might not work as well in space under the micro-gravity conditions. We are proposing ways of dealing with the two problems mentioned. The problem of high dimensionality leads to a Kalman filter which may be so computationally burdensome that it cannot be implemented in real time, and so is not useful for control purposes. Typically, one tries to overcome this problem by reducing the order of the model until it is possible to process the filter equations in real time. But the model may then not represent the physical system with much accuracy. Instead, our approach is to constrain the order of the filter prior to optimization, but not reduce the model order more than necessary, so that we do not introduce modeling errors beyond those which occur naturally. The filter designed is then of smaller dimension than the model, and is consequently called a reduced-order filter. But its design is based on the higher order model of the dynamical structure and the noise processes. In the course of designing these reduced-order filters, we noticed that they were sometimes very robust and insensitive to modeling errors when compared to the Kalman Filter. We were able to identify just what it was that caused this lack of sensitivity to variable parameters, and developed a procedure for designing filters which would be completely insensitive to certain system parameters such as damping coefficients.

The author and his students have worked on the design of various types of reduced order filters in the past [2,3,4,5], but never applied any of the techniques to flexible space structures. The techniques we applied during the course of the current research on structures was based on the work reported in [4] and [5] where the reduced-order filter is forced to have an observer structure [6]. The design reported in [4] and [5] had to be modified in such a way that it allowed for and took advantage of correlated process and measurement noise, a feature which resulted from the presence of accelerometer measurements. The design of the new filters was straight forward and computer code was written to demonstrate how they compared with Kalman Filters. These filters, while simpler to implement than a Kalman Filter, had performance loss relative to a Kalman Filter's performance when all model parameters were known. But when false parameters were assumed, the reduced-order filters could perform better than the Kalman Filters under some circumstances.

We found that the ability to be insensitive to certain system parameters was a property that was linked to how one made use of the accelerometer measurements, and we were able to develop a procedure for designing both full and reduced-order filters which were insensitive to parameter variations. The key to the procedure was that certain of the filter gains had to be set at specific values to achieve the insensitivity of performance desired. The remaining gains could then be optimized. The price paid was the fact that more traditional designs gave better performance when system parameters were at their nominal values. Ways of trading off robustness and peak performance are currently being investigated. Computer code was prepared to test the ideas suggested here, and it seems that the procedure of using the insensitive design might be a good idea when parameters are apt to be far from their nominal values, but there are probably better procedures when parameters are fairly close to their nominal values. One outstanding feature of the proposed filters is that Luenberger's Separation Principle [6] is always true for them regardless of how parameters may change. This makes eigenvalue analysis for the closed loop system very easy.

Other research that is under way and could be important for flexible space structure control is concerned with observer based stochastic control, and reduced-order filters that only use accelerometer data.

REFERENCES:

[1] Lewis, Frank L., Optimal Estimation with an Introduction to Stochastic Control, Wiley - Interscience, New York, 1986.

[2] Sims, Craig S., "Reduced-Order Modeling and Filtering," In Advances in Control and Dynamic Systems, Vol. 18, C. T. Leondes, Editor, Academic Press, San Diego, CA., 1982.

[3] Sims, C. S., and Asher R. B., "Optimal and Suboptimal Results in Full and Reduced-Order Linear Filtering," IEEE Trans. Aut. Cont.,Vol. AC-23, June 1978.

[4] Nagpal, K., Helmick, R., and Sims, C. S., "Reduced-Order Estimation, Parts 1 and 2," International Journal of Control, Vol, 45, No. 6, June 1987.

[5] Nagpal, K., Helmick, R., and Sims, C. S., "Reduced-Order Estimation of Complementary States, Parts 1 and 2, " International Journal of Systems Science, Vol. 20, No. 7, 1989.

[6] Luenberger, D. G., "Observers for Multivariable Systems," IEEE Trans. Aut. Cont., Vol. AC-11, April 1966.