Preface

As a practical way to achieve robust motion control and state estimation (Kalman filtering), a promising approach in terms of the perturbation compensator (or perturbation observer equivalently) is investigated in this book, where the *perturbation* means lumped uncertainty not considered in the nominal plant model based on which the feedback controller and state estimator are designed. The perturbation compensator can be regarded as a kind of model regulator which drives the physical plant with uncertainty to the nominal model. Specifically, in mechanical systems where the nonlinear friction is regarded as a dominant disturbance, the perturbation observer actually operates as an adaptive friction compensator. Fundamentally, it is a decoupling control approach in contrast to the multivariable control method based on the linear optimal control solutions. Above all, the perturbation observers are physically intuitive, structurally simple, and easily implementable. Hence, these can be readily accepted by industry to increase the performance of many control systems. Based on a unified view on the existing class of perturbation observers, some novel approaches for design and analysis of perturbation observer are investigated in this book and they are extended to robust motion control and robust state estimation (Kalman filtering also). The stability and sensitivity characteristics of the perturbation observer loop is made clear through discrete-time analysis. Here, the main results are given chapter by chapter.

In Chapter 2, a robust tracking control method is proposed by combining the perturbation compensator which effectively attenuates plant perturbations including model uncertainty and external disturbance with the nominal tracking controller designed using the sliding surface. This approach enables a smooth sliding mode in tracking control loop without chattering problem. An unified view is given on a class of perturbation observers and three kinds of equivalent expressions for the perturbation of a plant is described. In terms of the equivalents, we propose the feedfoward perturbation observer (FFPO), the feedback perturbation observer (FBPO), and the sliding mode perturbation observer (SMPO). Successively, by hierarchically adopting these three observers to attenuate the *residual perturbation*, the hierarchical perturbation compensator (HPC) is constructed. The stability and robustness property of HPC is clarified through the analysis of error dynamics. Adaptive and integral property of HPC greatly enhances the tracking performance with minimal control effort. The issue of actuator saturation is also considered.

In Chapter 3, the concept of residual perturbation and hierarchical perturbation compensation in Chapter 2 is extended to general n-loop case. As a result, the multiloop perturbation compensator (MPEC) is formulated. A robust stability condition with respect to the inertia variation is derived as a function of the number of compensation loops. In MPEC, as the number of compensation loops increases, the external disturbance condition for system stability is gradually relaxed and the perturbation attenuation performance is remarkably enhanced but the robust stability margin on the modeling error becomes more strict. By combining MPEC with nominal feedback controller, a robust motion controller is synthesized and it is applied to XY positioner and robot manipulator.

In Chapter 4, the perturbation observer (compensator equivalently) is investigated in discrete-time viewpoint. In fact, the design of the low pass filter has been a central issue in the class of perturbation observers, for example, disturbance observer (DOB). However, the effect of the low pass filter (so-called Q-filter) on the performance and robustness of the perturbation observer has not been clarified yet, specifically in discrete-time domain. In this chapter, this problem is answered considering the general order of discrete Q-filter and the inertia perturbation as a structured model uncertainty. The results illustrate well how the performance and robustness of the perturbation observer involved compensation loop is changed in discrete-time domain according to the parameter variation of Q-filter and plant. Accordingly, some guidelines on the Q-filter selection for the trade-off between performance and robustness are suggested.

In Chapter 5, a combined state estimator–perturbation observer is synthesized by unifying standard linear state estimator (Luenberger observer) and perturbation observer. It enables robust state estimation for uncertain dynamical systems and simultaneously provides full-state to the perturbation observer under output feedback condition. The combined observer can be regarded as a practical state estimator to overcome the limit of the imperfectness of plant model. It has the merit that it is given as a recursive discrete-time form and above all it requires no knowledge of plant uncertainty. A coupled estimation error dynamics is derived and the related technical issues such as stability and noise sensitivity are addressed. The combined observer setting is also extended to stochastic systems and the discrete Kalman filter is reformulated by including the perturbation estimate update process. Numerical examples and experimental results validate the practicality of the combined observer and the modified Kalman filter.

In Chapter 6, some control problems related to the coarse/fine dual-stage are included. First, a dual-stage control architecture is suggested, where the perturbation compensator is necessitated to guarantee a good tracking performance in spite of plant uncertainty. Also, the minimum-time control using the coarse/fine dual-stage is discussed. The fast and fine positioning capability of the coarse/fine dual-stage is shown through the microteleoperation issue.

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