Robust Estimation and Failure Detection: A Concise Treatment

Rami S. Mangoubi

Part of the "Advances in Industrial Control" series
published by Springer-Verlag

Dr. Mangoubi's monograph brings together two of the most exciting areas of advanced signal processing and control:

1. The development of optimal estimators for uncertain signal and noise models.
2. The subject of failure detection and isolation, which has considerable potential in a range of applications.

The solution of a robust estimation problem is crucial to solving the fault monitoring and detection problem effectively. That is, one of the primary difficulties is deciding whether an estimated fault condition is really due to a fault or is simply due to poor system models. Therefore, a robust estimation method is essential. The text provides a novel solution to a class of robust estimation problems. The solutions are presented in a suitable form to be applied to the failure detection and isolation problem considered in the later chapters. Also included are convincing application studies for both marine and aerospace applications. Extensive appendices cover related and relevant areas.

Generally speaking, the subjects of estimation and failure detection for dynamic systems are concerned with extracting information of interest about a dynamic plant or process. The objective is to estimate physical quantities related to the plant, as well as to determine whether any abrupt change or failure occurred. The approach consists of processing measurements obtained from sensors and combining the results with a priori information available from the plant's dynamic model. One possible application is the monitoring of dynamic plants, such as vehicles, in order to estimate their position and velocity, and to detect plant failures. Another application is target tracking, where the objective is to follow targets and detect their maneuvers.

The book provides a concise treatment of classical and current estimation and failure detection theory. Specifically, the book starts with the first linear least squares, or minimum variance, filter developed in the 1940s - the Wiener filter. This filter is applicable to linear time-invariant systems at steady state; its solution is based in the frequency domain. Next, the book introduces the Kalman filter, a recursive time domain filter shown to be a generalization of the Wiener filter. It is applicable to linear time-varying and transient systems, and is equivalent to the Wiener filter for linear time-invariant plants at steady state. These two classical filters have seen pervasive use in many applications. Their role in failure detection and isolation is illustrated. Specifically, the book derives the generalized likelihood ratio test (GLRT), which is shown to require the Kalman filter for its implementation and illustrates how estimation and detection are tightly coupled subjects.

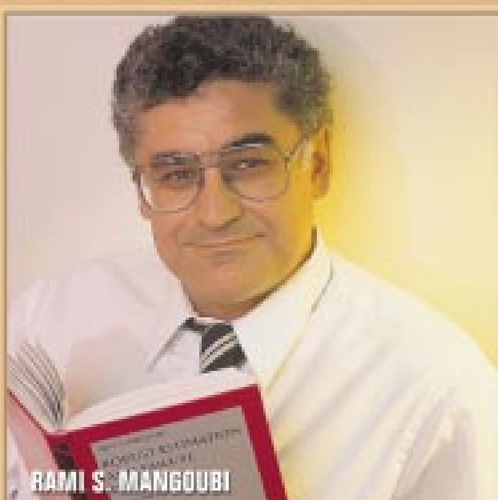
The Kalman and Wiener filters, as well as the likelihood ratio test, assume perfect knowledge of the plant dynamics and noise statistics. The book first expands that theory by introducing noise model uncertainty. In fact, a family of recursive estimators is derived, of which the Kalman and Wiener filters are members. These filters can trade off optimal minimum variance (or least-squares error) performance against noise robustness. The book discusses this generalization in both the deterministic and stochastic context, and later illustrates how the new analytical framework relates to the likelihood ratio tests.

Finally, the analytical basis for dealing with both noise and plant model uncertainties is developed, and the theory applied to derive robust filters. The filters, in turn, are used to develop failure detection and isolation algorithms that are sensitive to failures, but insensitive to the modeling errors. Draper Laboratory, which was the first to use Kalman filters in the early sixties for the Apollo navigation system, was also the first to pioneer the development of robust estimation theory. The development of this theory is more complex, and the filters require the solution to two matrix Riccati equations, as opposed to the previous filters, which need the solution to only one Riccati equation. In the absence of uncertainties, the robust filter reduces to the Kalman filter, and the associated robust detection algorithm reduces to the likelihood ratio test.

Robust Estimation and Failure Detection is of particular value to students, researchers, and engineers with an interest in filtering or failure detection. It offers classical and advanced theories and design methods and allows the readers to benefit from the robust control theoretic developments of the last fifteen years. Control researchers and engineers will also find the book relevant, as it demonstrates how development in their discipline affects these two neighboring fields.

BIOGRAPHY

Robust Estimation and Failure Detection: A Concise Treatment



Rami S. Mangoubi is currently a Senior Member of the Technical Staff in the Autonomous Control Group at Draper. Since joining Draper in 1983, Rami has been the technical lead of an IR&D project on the performance evaluation of computer systems. He has also worked in the areas of target discrimination, optimal control of transport aircraft during cruise flight, undersea target tracking, image processing, and simulated annealing for planning methods. He developed theory and algorithms for robust estimation, and introduced the use of these robust estimators in model-based failure detection where plant model uncertainties are an issue. He also developed adaptive filters for detecting shifts in flexible modes of space structures, such as the Russian MIR station, and is now applying these filters to turbopump vibration monitoring. Rami received an SB in mechanical engineering, an SM in operations research, and a PhD from the Department of Aeronautics and Astronautics, all from the Massachusetts Institute of Technology, in 1978, 1980, and 1994, respectively.

mangoubi@draper.com