Tutorial Proposal for 2023 FUSION Conference

Systematic Filter Design for Tracking Maneuvering Targets: Getting Guaranteed Performance Out of Your Sensors

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Introduction and Motivation

Although the Kalman filter has been widely applied to target tracking applications since its introduction in the early 1960s, until recently, no systematic design methodology was available to predict tracking performance for maneuvering targets and optimize filter parameter selection. When tracking maneuvering targets with a nearly constant velocity (NCV) Kalman filter, the selection of the process noise (i.e., acceleration errors) variance is complicated by the fact that the motion modeling errors are represented as white Gaussian, while target maneuvers are deterministic or highly correlated in time. In recent years, the relationship between the maximum acceleration of the target and the variance of the acceleration errors was developed to minimize the maximum mean squared error (MMSE) in position. A lower bound on the variance of the motion modeling errors was also expressed in terms of the maximum acceleration. This tutorial presents a rigorous procedures for selecting the optimal process noise variance for the Kalman filter based on a particular sensor and target motion model. Design methods for NCV Kalman filters with discrete white noise acceleration (DWNA) or exponentially-correlated acceleration errors (ECAE) and nearly constant acceleration (NCA) Kalman filters with Discrete Wiener Process Acceleration (DWPA) are presented. Filter design for tracking maneuvering targets with linear frequency modulated (LFM) waveforms are addressed and tracking with LFM waveforms is shown to be significantly better than tracking with an monotone waveform. The application of the design methods to radar tracking is addressed and numerous tracking examples are given. Guidelines on the use acceleration in your track filter are provided.   In other words, guidelines on the use of an NCV Kalman filter versus an NCA Kalman filter are given. The design methods are applied to the Interacting Multiple Model (IMM) estimator and numerous radar tracking examples are used to illustrate the validity of the design methods. The benefit of tracking with LFM waveforms for mode estimation is also demonstrated via simulation examples.

Intended Audience

Engineering designing track filters for radar systems and other sensors, researchers involved in multitarget-multisesor tracking, and radar system engineers who want an understanding of the value of track filters to system performance and the processes for getting that performance.

Expected Outcomes

Ability to select the best motion model for one's radar tracking problem and the corresponding design parameters that will achieved the desired performance.

Prerequisites

Background in linear systems, probability, target tracking, and Kalman filtering, and an understanding of the radar measurement process.

Four Hour Course Outline

I. Introduction
II. Background
III. Design of NCV Kalman Filters for Tracking Maneuvering Targets
    a. NCV Kalman Filters with DWNA
    b. NCV Kalman Filters with CWNA
    c. NCV Kalman Filters for Tracking with LFM Waveforms
    d. NCA Kalman Filters for Radar Tracking of Maneuvering Targets
IV. Design of NCA Kalman Filters for Tracking Maneuvering Targets
    a. NCA Kalman Filters with DWPA
    b. NCA Kalman Filters for Tracking with LFM Waveforms
    c. NCA Kalman Filters for Radar Tracking of Maneuvering Targets
V. NCV Versus NCA Kalman Filters for Tracking Maneuvering Targets
VI. Design of NCV Kalman Filters with ECAE for Tracking
VII. Design of Interacting Multiple Model (IMM) Estimators for Tracking Maneuvering Targets
    a. CV-CV IMM Estimator
    b. CV-CA IMM Estimator
VIII. Concluding Remarks and Future Directions

Biography of the Instructor

Dr. Dale Blair is native of Jamestown, Tennessee and received the BS and MS degrees in Electrical Engineering from Tennessee Technological University in 1985 and 1987, respectively. Currently, he is a Principal Research Engineer with the Georgia Tech Research Institute (GTRI) and GTRI Fellow. He received the Ph.D. degree in Electrical Engineering from the University of Virginia in 1998. He is senior member of the Sensors & Electromagnetic Applications Laboratory (SEAL) staff and supports the lab as a subject matter expert in multisensor-multitarget tracking, radar data processing, data fusion, modeling and simulation, and algorithm assessment. Prior to joining GTRI, he was with the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) in Dahlgren, Virginia. At NSWCDD, he conducted research in the area of target tracking and supported upgrades and new developments for the Aegis weapons system. While at NSWCDD, Dr. Blair originated two benchmark problems for target tracking and radar resource allocation. He also led a project that demonstrated through a real-time tracking experiment that modern tracking algorithms

can be utilized to reduce the radar time and energy required by a phased array radar to support surveillance tracking by as much as 60%. He joined GTRI in 1997. From 1998 until 2010, he led multiorganizational teams in the development of multiplatform-multisensor-multitarget tracking benchmarks for both air defense and ballistic missile defense. From 2003-2010, he was the original technical lead for the FFRDC/UARC team responsible for independent assessment of the Command Control Battle Management Communications (C2BMC) algorithms for the United States (US) Ballistic Missile Defense System (BMDS). From 2010-2013, he served as Technical Director, C2BMC Knowledge Center in the Missile Defense Agency (MDA).

Dr. Blair is a recognized expert in the area of multitarget-multisensor tracking that includes optimal estimation, statistical signal processing, decision theory, radar resource allocation, radar signal processing, and radar systems modeling and simulation. He is internationally recognized for his contributions to radar resource allocation for single and multiple sensor systems. He is also internationally recognized for his technical contributions to monopulse processing for unresolved measurements of closely-spaced objects and a target in the presence of sea-surface induced multipath. In 2001, he was selected for the IEEE Fred Nathanson Award for Outstanding Young Radar Engineer for advancement of multitarget-multisensor tracking and radar resource allocation. In 2002, he was elected to the grade of IEEE Fellow for technical leadership and contributions to developing multitarget-multisensor tracking technology and applications. In 2008, Dr. Blair published his first paper on the design of Kalman filters for tracking maneuvering targets, a problem that had been open since the 1960s. His first paper addressed the design of nearly constant velocity (NCV) Kalman filters for tracking maneuvering targets. His publications since that time have enhanced the design methods for NCV Kalman filters and extended those methods to nearly constant acceleration Kalman filters and Kalman filters with exponentially-correlated acceleration errors.

Dr. Blair's publications include coeditor and coauthor of *Multitarget-Multisensor Tracking: Applications and Advances III* (ARTECH House, 2000); two chapters in *Principles of Modern Radar: Vol I* (SciTech Publishing, 2010); a chapter in *Modeling and Simulation Support for System of Systems Engineering Applications (Wiley, 2015);* 34 refereed journal articles, more than 42 refereed conference papers; and more than 150 other technical papers and reports. His editorial accomplishments include Editor for Radar Systems of the *IEEE Transactions on Aerospace and Electronic Systems (T-AES),* 1996-1999; Editor-In-Chief (EIC) of the T-AES, 1999-2005; and founding EIC for the *Journal for Advances in Information Fusion*, 2005-2013. Dr. Blair served as VP for Publications for the IEEE Aerospace and Electronic Systems Society (AESS) and continues to serve as VP for publications for the International Society for Information Fusion (ISIF). Dr. Blair has been a technical expert in panel discussions related to target tracking and information fusion at various conferences, guest speaker at numerous universities and professional events, and technical consultant to the more than seven organizations that include research laboratories and small and large businesses.

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