Estimation of Noise Parameters in State Space Models

Ondřej Straka* **Jindřich Duník**

Organizers

Name: Ondřej Straka and Jindřich Duník

Affiliation: University of West Bohemia

Address: Univerzitní 8, 30100 Plzeň, Czech Republic

Email: {straka30,dunikj}@kky.zcu.cz

Type and Duration

Proposal type: tutorial

Tutorial duration: half-day

Motivation

Knowledge of a system model is a crucial prerequisite for many state estimation, signal processing, fault detection, and optimal control problems. The model is often designed to be consistent with the random behavior of the system quantities and properties of the measurements. While the deterministic part of the model often arises from mathematical modeling based on physical, chemical, or biological laws governing the system's behavior, the stochastic part's statistics are often challenging to find by the modeling and have to be identified using the measured data. Incorrect description of the noise statistics may result in a significant worsening of estimation, signal processing, detection, control quality, or even failure of the underlying algorithms.

Outline of the tutorial

The tutorial introduces a more than six decades-long history as well as recent advances and state-of-the-art methods for estimating the properties of the stochastic part of the model. In particular, the estimation of state-space model noise means, covariance matrices, and other parameters are treated. The tutorial covers all major groups of noise statistics estimation methods, including correlation methods, maximum likelihood methods, covariance matching methods, and Bayesian methods. The methods are introduced in the unified framework highlighting their basic ideas, key properties, and assumptions. Algorithms of individual methods will be described and analyzed to provide a basic understanding of their nature and similarities. The performance of the methods will also be compared using a numerical illustration.

Materials: The participant will be provided with *course notes* and *sample implementations (in MATLAB)* of the selected methods.
Prerequisites: Basic knowledge of probability theory, statistics, and linear algebra; elementary experience in MATLAB (for the interactive demonstration)

*main contact

Intended audience and expected outcome

Intended audience: researchers in academia and industry, engineers, and graduate students. A similar tutorial has been organized during the FUSION conferences since 2017 and was attended by participants in all career stages working in technical areas such as state estimation, target tracking and navigation, decision making, stochastic systems, and system identification, but also in non-technical areas.

Expected outcome: On completion of the tutorial, participants will be:

- aware of the importance of appropriate dynamic model noise description,
- familiar with approaches to estimating covariance matrices, their pros, and cons,
- able to utilize noise parameter estimation methods to estimate moments or parameters of state-space model noises,
- experienced with the provided noise identification method implementation in MATLAB.

Tentative schedule

Part I: Introduction, Motivation, and Basic Design Procedures (40 mins)

Part II: Correlation Methods (40 mins)

Part III: Maximum Likelihood, Covariance Matching, and Bayesian Methods (40 mins)

Part IV: Numerical Comparison and Illustration (40 mins)

Part V: Estimation of Means and Parameters (40 mins)

Part VI: Showcase of noise parameter application in real-world problems (20 mins)

Part VII: Implementation, interactive demonstration of the provided code (30 mins)

Brief biographies

Ondřej Straka

Ondřej Straka received his M.Sc. and Ph.D.degrees in cybernetics from the University of West Bohemia, Pilsen, Czech Republic, in 1998 and 2004, respectively. Since 2015, he has been an Associate Professor with the Department of Cybernetics, University of West Bohemia. He has seventeen years of teaching experience at the UWB. Currently, he is a lecturer for graduate and post-graduate courses on estimation theory, stochastic systems and processes, and mathematical control theory. He has published over 140 journal and conference papers and was involved in the development of several software frameworks for nonlinear state estimation and system identification. He has participated in several projects of fundamental research and in several projects of applied research (e.g., GNSS-based safe train localization and attitude and heading reference system). His current research interests include local and global nonlinear state estimation methods, system identification, noise covariance matrix estimation in state-space models, performance evaluation, and fault detection in navigation systems. Dr. Straka was a recipient of the Werner von Siemens Excellence Award in 2014 for the most important result in basic research.

Jindřich Duník

Jindřich Duník is an Associate Professor at the Department of Cybernetics, University of West Bohemia (UWB), Czech Republic and at the Aerospace Advanced Technology Europe, Honeywell International. He received his Ing.(M.Sc.) and Ph.D. degrees in Automatic Control in 2003 and 2008, respectively, both from the UWB. Until 2010, he was with the UWB. From 2010 he is with Honeywell and from 2013 again with the UWB working in the areas of state estimation and navigation system design and integration. Since 2020, he has been an Associate

Professor with the Department of Cybernetics, UWB. He is the author or co-author of more than 70 technical papers (both journal and conference) and granted patents. He has 8 years of teaching experience at the UWB and, currently, he is teaching graduate courses on "System Identification and Filtering" and "Adaptive Systems". Dr. Dunik is an IEEE Senior Member and was a recipient of the Werner von Siemens Excellence Award in 2014 for the most important result in basic research and Honeywell Aerospace Technology Achievement Award in 2016, 2019 for the navigation system design.

Previous experience

Publications related to the tutorial topic

The authors have a long record of publications related to noise parameter estimation in state-space models which includes the following journal papers

- KOST, O. DUNÍK, J. STRAKA, O. DANIEL, O. Identification of GNSS Measurement Error: From Time to Elevation Dependency. IEEE Transactions on Aerospace and Electronic Systems, 2023, vol. 59, no. 6, pp. 8931 - 8943. ISSN 0018-9251.
- KOST, O. DUNÍK, J. STRAKA, O. Measurement Difference Method: A Universal Tool for Noise Identification. IEEE Transactions on Automatic Control, 2022, ISSN: 0018-9286
- DUNÍK, J. KOST, O. STRAKA, O. BLASCH, E. Covariance Estimation and Gaussianity Assessment for State and Measurement Noise. Journal of Guidance, Control, and Dynamics, 2019, vol. 43, no. 1, pp. 132-139. ISSN: 0731-5090
- DUNÍK, J. KOST, O. STRAKA, O. Design of measurement difference autocovariance method for estimation of process and measurement noise covariances. AUTOMATICA, 2018, vol. 90, no. April 2018, pp. 16-24. ISSN: 0005-1098
- DUNÍK, J. STRAKA, O. ŠIMANDL, M. On Autocovariance Least-Squares Method for Noise Covariance Matrices Estimation. IEEE Transactions on Automatic Control, 2017, vol. 62, no. 2, pp. 967-972. ISSN: 0018-9286
- DUNÍK, J. STRAKA, O. KOST, O. HAVLÍK, J. Noise covariance matrices in state-space models: A survey and comparison of estimation methods—Part I. International Journal of Adaptive Control and Signal Processing, 2017, vol. 31, no. 11, pp. 1505-1543. ISSN: 0890-6327

Previously organized tutorials

The presenters organized the tutorial during conferences FUSION 2017, FUSION 2018, FUSION 2020, FUSION 2021, FUSION 2022, FUSION 2023, and 2023 IFAC World Congress with approx. 110 participants in total.