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OPPONENT STATEMENT OF THE DOCTORAL DISSERTATION

Author:	Ing. Jaroslav TABAČEK
Title of thesis:	**STATE ESTIMATION AND FAULT DETECTION WITH REDUCED ERROR SENSITIVITY TO PARAMETERS**
Supervisor:	prof. Ing. Vladimír Havlena, CSc. Department of Control Engineering Faculty of Electrical Engineering Czech Technical University in Prague
Branch of study:	Control Engineering and Robotics
Scope of work:	95 pages, 10 chapters, 1 appendix, 33 images, 1 table

1. Timeliness of the topic

The synthesis of dynamic systems with the presence of noise and uncertain parameters, tied in the presented theoretical context to the principles of Kalman filtering, is currently a highly preferred field of control theory and robotics. Open theoretical problems of state estimation, especially of distributed systems with uncertain parameters and the detection of unacceptable changes (faults) of system parameters or their parts, potentially common theoretical starting points for describing the uncertainty of parameters and noises and the formalism of threshold detection of modes of decentralized structures with Kalman filtering, probably motivated the author the most when treatment of this topic. In the presented areas, he was able to accurately formulate and theoretically justify the existing problems. From this point of view, the proposed estimation and detection algorithms extend the theoretical basis of the scientific field, contribute to the algorithmic comfort of the considered class of methods, increasing the reliability of control, and are currently an undeniably topical topic.

2. Objective of the dissertation

I understand the objective of the dissertation as a solution to specific problems of distributed Kalman filtering with reduced sensitivity of system state estimation on uncertain system parameters with a considered degree of uncertainty about their expected values, while the final solution is adapted to the used class of control and the required distributed structure of Kalman filtering algorithms. Due to the fact that the work is connected with a set of the author's publications, the stated goal also reflects the selected description of the considered class of uncertain systems and the prescribed control structure, which mainly limit the framework of problem solving. The goal understood in this way is theoretically and algorithmically demanding and corresponds to the high level of criteria set for the dissertation. It can be concluded that the results of the dissertation accomplish the formulated sub-tasks and fulfilled the objective of the dissertation.

3. Methods of processing

The solution, as it follows from the title of the work and from the formulation of the goals of the work, is limited to the class of parametrizable linear, or of linearizable nonlinear systems with additive Gaussian noises of the system and measurements, for which it is possible to create a system description in the state area and estimation of the state can be realized based on the principle of Kalman filtering from the measured vector of system output variables. The proposed extension of the standard methodology of Kalman filtering consists in the derivation of filtering algorithms that have a reduced sensitivity to the uncertainty of the model parameters (desensitized filtering), or in the application of this type of algorithm, where the gain of the filter can be expressed explicitly. The obtained algorithms were verified on two structures of simulation models, where their distributed structures are stochastically correct.

The methodology follows the world trend of distributed state filtering algorithms, as well as of network control for systems with uncertainties; from a practical point of view these are interesting implementation procedures with appropriate algorithmic support, potentially also suitable for fault detection in distributed systems.

4. Work results and their characteristics

The results of the work are presented in Chap. 3-7 of the dissertation and their brief summary is given in Chap. 8. Because the text of the chapters is linked to the published results of the author, they present the theoretical starting points, the procedures used and the method of algorithmization for the chosen type of filtering algorithms, while the dominant is the strict separation of the levels of the algorithm, or the formulation of stability conditions with respect to the steady-state solution.

The author illustrates the algorithmic procedures in an acceptable way, and with a certain insight, the obtained results can also be understood as a qualitative contribution to the methodology of covering the parametric sensitivity of Kalman filtering, which is a certain generalization of the author's experience with the given type of algorithms and with the conservatism of desensitized Kalman filtering solutions in interacting local sub-models. The use of a desensitized Kalman filter for distributed estimation of the state of a system with a network control structure also appears promising, even though the uncertainty of the estimation in local nodes can be critical for the global estimation of the state.

In the Scopus database, there are 7 publications in which the doctoral student is a co-author, of which 2 are journal publications from the areas to which the topic of the dissertation is connected. There are 12 citations to these publications (without self-citations), the *h*-index of the author is equal to 2. Five of these publications are located in the Web of Science database, 9 citations are marked there for these contributions. The journal in which he published is indexed in the Science Citation Index Expanded, IF is 4.246, Quartile is Q1 and it is processed by the ISI Current Contents service.

5. Benefit for the further development of science and technology

With its results, the dissertation covers part of a set of basic procedures that expand the knowledge in the field of Kalman filtering for systems defined by state description with parametric uncertainties. At the same time, it offers modifications of the application of this principle for state estimation in predictive control application. In the sense of the above, it is possible to accept the conclusions of the fulfilment of the objectives of the dissertation as they are formulated in Chap. 8.

Of course, it is also necessary to draw attention to the fact that he worked with Kalman filtration methods that were and are being developed for a long time by top experts at his training workplace, and in this constellation to define himself in such an occupied theoretical field is worthy of appreciation.

6. Comments and topics for discussion

The work is written in English, with professionally acceptable style, appropriate explanatory characteristics of the obtained solutions and the clarity and coherence of the writing. The author provides a good overview of 74 publications related to the subject of the doctoral thesis. The presented bibliography has uniform format and is bibliographical complete. I have no formal or substantive comments on the work.

In the discussion, it would be desirable to add explanations to the following problems:

- It is a pity that the work does not include a list of abbreviations. I could not verify whether DMPC is not by chance an abbreviation from the following paper "Jafarzadeh, H., Fleming, C.: DMPC: A data-and model-driven approach to predictive control, Automatica, vol. 131, ID 109729, 2021. https://doi.org/10.1016/j.automatica.2021.109729."
Under what conditions (limitations) would the presented principle of desensitized filtration be applicable in such a DPMC context?
- In what way is the principle of desensitized Kalman filtering less conservative for uncertain linear systems with respect to the range of values of **Q** and **R** when changing the parameter v?
- The correction step of the Kalman filter can be critical for a short sampling period. Since the sensitivity to parameter changes is primarily tied to the prediction step, would it be possible to modify the desensitization for the Kalman predictor? Give some comments.

7. Conclusion

The dissertation "State estimation and fault detection with reduced error sensitivity to parameters" Ing. Jaroslav Tabaček fulfilled the set goals, brings new knowledge in the field, confirms the abilities and competence of the doctoral student for independent creative scientific work and accomplish the conditions for doctoral dissertations, therefore in terms of my position

I recommend

that the work was submitted for evaluation in the study program Control Engineering and Robotics. Subsequently, after a successful examination,

I recommend

awarding the academic title of philosophiae doctor – PhD.

Košice, 16.05.2023

prof. Ing. Dušan Krokavec, PhD.