16-4.

Ph.D. Thesis Review Report

PhD student: Ing. Radek Beňo

Thesis title: Distributed Identification of nonlinear Systems

Reviewer: Ing. Jaroslav Pekař, Ph.D., Honeywell spol. s r.o., Connected Vehicle, Transportation Systems

Introduction

This thesis introduces a novel approach for identification of unknown parameters of a nonlinear system. The approach is suitable namely in cases when the system can be decomposed to several smaller interconnected subsystems with highly nonlinear behavior. The thesis has standard structure, including introduction, state-of-art review of algorithms for nonlinear systems parameter identification and pointing out specific convergence issues related to numerical optimizations, introduction of modeling for internal combustion engines, description of novel approach and its brief validation using the combustion engine model. The original results, per the list of publication, were published in one journal with impact factor (Control Engineering Practice), and two conference papers (indexed in Web of Science).

The thesis is introduced by a brief general discussion about modeling for optimal control and issues related to calibrating the models. It includes related literature references and is concluded by the problem statement. The goals of the thesis are also clearly stated in this section. Chapter 2 goes deeper into the nonlinear system modeling and calibration. The calibration process is formulated as optimization problem that has to be solved by a suitable numerical method. The chapter also describes the standard numerical approaches, and introduces standard distributed optimization techniques. Chapter 3 is a brief introduction to combustion engine modeling which is used later as a validation example. Chapter 4 introduces the original concept of regularized components and Chapter 5 contains formal definition of the proposed algorithm. Chapters 6 and 7 describes validation of the proposed approach.

Overall, the thesis is well written with good clarity. However, I would appreciate better description of the novel algorithm in Chapter 6, which I see as a key result of the thesis.

The Topicality of the Thesis

The PhD student demonstrated reasonable knowledge of domain (combustion engines) and of theory related to state-of-art numerical optimization algorithms. The topic of the thesis is current and relevant to state-of-art in the nonlinear system parameter calibration field.

Approach and Achieved Results

I would like to emphasize several most important benefits of the work:

- A brief summary of mean value modeling for combustion engines, including discussion on calibration process. It is used as a validation system for the novel calibration algorithm.
- Introduction of a regularized approach for subsystem parameters calibration to make the optimization process numerically stable.
- Formulation of a novel algorithm for distributed calibration of nonlinear systems composed of several subsystems. The objective is to reduce the nonlinearity and to ensure better convergence properties of the calibration process.

The key result of the thesis is a distributed calibration algorithm described in Chapter 5, and its validation using mean value model of a combustion engine in Chapter 7. To my best knowledge, the approach taken is original. The idea is to use information about the structure of the calibrated system and decompose it to several subsystems, which are connected by calibration parameters, and then to solve the resulting optimization problem using distributed approach. Furthermore, numerical properties of individual subsystems are improved by introducing suitable auxiliary optimization variables, for example to avoid division by zero (or going close to it) during the numerical optimization process. As already mentioned in the introductory section, the core algorithm should be introduced in a more formal way, and with better clarity.

In summary, the aims and used methods are clearly described. The aims were fulfilled, the selected methods related to numerical optimization for distributed calibration process (key achievement) are appropriate.

Specific Comments and Question for Discussion

1. In general, the ratio of text split between the description of combustion engines (Chapter 3, 6 and 7) and novel algorithm (Chapter 4 and 6) could be better balanced towards the algorithm. However, I recognize necessity to fully explain the motivation and an example. This is comment rather than question.
2. I would appreciate more clear explanation of the key algorithm, and especially to put it into the framework of standard distributed optimization methods, as described in Section 2.5. Can you please explain in a better way how the novel algorithm (related optimization problem is (5.5)) is related to the standard distributed optimization approach (related optimization problem is (2.20)), e.g. by comparing the novel approach with Figure 2.5.1? Please, show for the novel algorithm, if possible, related master problem and subproblems.
3. In Section 5.3.3., please explain the "step" in graph 5.3.6 for "decomposed" line.
4. On page 32, there is a reference to equation (1.4), however that equation does not exist in Chapter 1.

Final evaluation statement

The thesis introduces a novel approach for distributed calibration of parameters of nonlinear system. I see the benefits of the proposed method and can imagine its practical impact. I would say that the thesis

fulfils the requirements for a doctoral degree. Therefore, I recommend the thesis of PhD student Ing. Radek Beno for defense.

Prague, 1. 7. 2018

Ing. Jaroslav Pekař, Ph.D.