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Review on the Doctoral Thesis of Ing. Matej Pčolka titled

„Numerical Aspects of Optimal Control Design for Nonlinear Systems "

Content of the Thesis

The dissertation investigates the problem of optimal control design for some nonlinear systems. This very general topic is mostly dedicated to the system of penicillin batch production although also building models and a hybrid car model are also considered as applications. The Thesis covers a rather wide area of aspects, all of which are relevant for practical implementation: Effects of adaptive search step size, influence of different horizon concepts for predictive control, optimal control of discontinuous models (either in the input or with hybrid dynamics), and last but not least an overall production process optimization are treated.

Core part of the Thesis are seven peer reviewed publications in either renown journals or international conferences. Mr. Pčolka is first author of these publications with at least 50% authorship as shown in the publication list of the Thesis.

The Thesis is structured in seven Chapters, the first one being an introduction and motivation, the second one summarizing the contributions of the author, the third one describing the state of the art, the fourth containing the treatment of horizon lengths on the predictive optimization of nonlinear systems, the fifth dealing with the robustification against discontinuities, the sixth presenting an overall optimization of a production process, and the seventh being the conclusion.

Both the theoretical aspects of the nonlinear optimization as well as the necessary extensions and modifications for obtaining a real-world solution have been extensively treated. Overall, the scientific contributions form a sound foundation for the further development of nonlinear optimization.

Appraisal and Discussion of the Thesis

The topic of the thesis of Mr. Pčolka is of high interest for the scientific community. Especially in batch processing of bioreactors the strongly coupled and nonlinear process behavior together with strict constraints on almost all variables form a difficult problem. The contributions of the Thesis to

overcome the associated problems are substantial, and it is no question that the Thesis and the publications therein represent an important means for the further development of Science.

The main results and contributions of the Thesis are listed in Chapter 2:

1. The optimization step size has a strong influence on the convergence speed of nonlinear optimization algorithms. Various alternative formulations to constant steps are investigated and adaptive size computations are also considered Computer simulations of the penicillin batch process serve as a means for comparing the respective results.
2. The choice of the optimization horizon is investigated for fixed length moving horizon and for a horizon with fixed end time. Additionally, the effects of feedback introduction, effectiveness maximization, and minimization of computational complexity are treated.
3. The effect of discontinuities is an important problem in many nonlinear control tasks. Here, two variants of the Hamiltonian-based gradient method are presented. The first one covers discrete input values while the second one deals with hybrid plant dynamics.
4. An overall optimization of a batch production process is presented, where in several stages a re-parametrization of the input profile as well as an optimization of the initial conditions and of the input profile parameters are performed.

The scientific work conducted in the Thesis consists of a wide area of methods and ideas that greatly contribute to the optimal control of nonlinear processes. Specifically for batch processing the work of Mr. Pčolka represents a substantial contribution which will improve the future production processes in bio-fermentation. Nevertheless, the application examples in building automation and for control of autonomous cars also demonstrate the versatility of the underlying principles. Several solutions of different problems have been provided, all of which are necessary to be solved on a high scientific level.

The main goals and contributions of the work have been stated in the thesis (both Chapter 2 and the Conclusion); correspondingly, the scientific publications of Mr. Pčolka are listed, and his individual contributions are detailed. All objectives have been completely fulfilled, the solutions to all of the outlined tasks have been presented, and the resulting performance is illustrated by simulation results and comparisons to state-of-the-art control and optimization algorithms.

The work has been conducted in a methodically correct and adequate way; citations of references are extensive and up to date. The theoretical treatment of the practical problems shows a high level of scientific work with excellent mathematical skills. The list of Mr. Pčolka's publications is extensive: Four Journal papers (all of them first authorship), and 16 other publications in quality journals and international conferences demonstrate a prolific scientific work. Overall, the publications in peer reviewed quality journals and conferences prove that the scientific quality of the work meets international standards.

Mr. Pčolka has clearly proven that he is capable of applying existing methods to new and challenging control and optimization problems, and that he can adapt and extend state-of-the-art results where necessary.

All elements of creative scientific work are contained within the thesis. Additionally, Mr. Pčolka has proved that he is able to master different complex methods and tools to investigate a given optimization and control problem, and to cover thus all aspects of a sound theoretical foundation for the development of a functional application solution.

Some specific questions related to the contents would be of additional interest:

- In many technical problems with fixed end time (or position) some state constraints at the end apply: A robot arm must be placed in a specific coordinate, or an electric car must have a battery state of charge larger than zero. How can such constraints be incorporated in a shrinking horizon or in a receding horizon formulation, respectively?
- Do you consider the robustness of the smart car nonlinear MPC sufficient for all possible road conditions? Which additional adaptations could be made to cover extreme deviations of the nominal model (e.g. high load and icy road).?

The author of the thesis proved to have an ability to perform research and to achieve scientific results.
I do recommend the thesis for presentation with the aim of receiving the Degree of Ph.D.

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