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Our Ref.: MF/otta

Subject: Review of Dissertation Thesis

Multiple-Domain Optimal Control
Ing. Pavel Otta
FEL ČVUT in Prague

Contents of the Thesis

The dissertation thesis contains 82 pages including 4 chapters and bibliography. It is written in English. Some occasional errors and typos occurring in the text did not decrease its quality.

There are two main parts of the work in Chapters 2 and 3 with only a loose connection between them. The goals of the work concentrate on the solution of optimal control of double integrator with a novel formulation that is not parameterised in time but in distance from the origin. This formulation aims to solve challenges with long optimisation horizons, affine constraints, state-variable constraints, nonlinear model, and singularities. It has to be noted, however, that some of these challenges were actually introduced by the proposed formulation.

Chapter 2 proposes spatial domain formulation of vehicle dynamics and was proposed in journal paper [1]. For the purposes of numerical solution, discrete-time/space model is used. Efficient transformations are proposed to obtain the solution as quadratic programming. Long horizons are solved using distributed optimisation of consecutive profiles. Finally, the chapter deals with optimisation including traffic lights.

Chapter 3 builds on the cooperation of the author with O. Šantin that resulted in PhD thesis of Šantin, 2016. This resulted in 2 journal publications [2], [3]. It describes in much detail efficient solution of quadratic problems with affine constraints. I enjoyed reading this chapter as it exposes comprehensibly individual parts of the procedure in general and Newton projection with proportioning in particular. Special care is taken for affine constraints that represents improvements and novelty of the method.

Chapter 4 could have been part of the previous chapter as it only deals with numerical benchmarks for quadratic programming and to my surprise did not deal with concrete results from Chapter 2.

Aims and New Results

The thesis solves some of actual problems in car optimisation in an original way. This can be especially seen in [1] where this approach was successfully compared to other five. The problem is presented using reformulation of the time representation to space. The structure of this problem is exploited and solved using new efficient quadratic programming solver with affine constraints. The thesis level could be enhanced if better connection betwen these topics were elaborated in

more detail. I can state that the thesis fulfilled the aims, used appropriate methodology, and produced new results. These have both theoretical value, but can also be used in practice.

Other Remarks

Publication record includes one paper in Control Engineering Practice, one paper in Optimization Methods and Software (another one conditionally accepted), and several papers at high quality international conferences including MED, ECC. I find these results satisfactory for the submission of the thesis.

Questions and Comments

- Chapter 2: Could the optimised problem be adapted for the case with recuperation of the braking energy?
- p. 19. Can you explain the behaviour at the distance $s = 55$?
- Although bang-bang control is indeed time-optimal for the double integrator, the real conditions do not favour such a strategy. What kind of reformulation would be needed to overcome it?
- p. 26. What are in your opinion issues with the convergence of the subgradient method?
- p. 25. Chapter 2.6 is difficult to read, many new symbols and variables without proper explanation.
- p. 29, Figure 2.9. Is the division between the segments arbitrary? I would expect that speed should be zero at their boundaries to account for traffic lights.
- p. 30, Chapter 2.7. The proposed algorithm only assumes a single car on the road. Will it stay optimal if this assumption is not satisfied?
- p. 31. If there is the time-optimal unconstrained strategy and there is a red light then the car cannot drive faster, only slower. Therefore, there would be no need to construct the tree.
- p. 42, Chapter 3.1. What are the unique preprocessing strategies of NPPro compared to other active-set QP solvers?
- As Chapter 3 serves as a computational block for Chapter 2, I would prefer their reverse ordering. The present layout gives me an impression of two separate topics in one work.
- Chapter 4: I am missing comprehensive results from the Chapter 2 where I had opinion that the examples serve for illustration only.

Formal issues:

- Typos: p. 48: expansive, p. 60 Dowdate, p. 63: observer, server, affect
- missing list of symbols and abbreviations
- half empty pages (p. 29)

Concluding Remarks

The author of the thesis showed to have ability to formulate and treat scientific problems, and to achieve new results. The thesis fulfils all proposed aims and complies with minimal requirements of committee for scientific degrees. He has worked in the area of optimisation and automatic control. Several of his results have already been reviewed by international community, published in prestigious conferences and journals, cited, and even patented. Therefore, I **recommend** it in the current form for defence for PhD degree.

Miroslav Fikar

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