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Our Ref.: MF/santin

Subject: Review of Dissertation Thesis

Numerical Algorithms of Quadratic Programming for Model Predictive Control
Ondřej Šantin
FEE CTU in Prague

Contents of the Thesis

The dissertation thesis contains 129 pages including 9 chapters, 2 appendices, and bibliography. It is written in English. Some occasional errors and typos occurring in the text did not decrease its quality.

The thesis can be divided into three parts. The first one is introductory and covers Chapters 1 and 2 – motivation, goals and state-of-the-art in the domain. I enjoyed especially Chapter 2.2 (previous results and related work) written very concisely.

The theoretical core of the work is spread in Chapters 5 to 7 with basic building blocks listed in Chapter 4. The material in these chapters belongs to the field of applied mathematics – optimisation and it is also presented in this manner. Every chapter proposes a variation of QP algorithm, calculates its computational complexity, compares it to existing ones in the literature as well as to preceding proposed ones, and finally proves its convergence properties. QP formulation is not general in the sense that it only assumes box constraints on optimised variables. Although this might be considered as a drawback, it makes possible to derive more specialised solvers with improved convergence and computational complexity features.

Three algorithms proposed in the thesis are called (i) combined gradient and Newton projection (CGNP), (ii) proportioning with Newton directions (PND), and (iii) Newton projection with proportioning (NPP). The main issue of CGNP method is that it does not take into account the values of Lagrange multipliers and thus it is not always optimal in the cost function decrease. PND resolves this issue using proportioning step. Finally NPP improves the proportioning step and removes the need for convergent step-size (Hessian matrix norm evaluation). This is important in nonlinear MPC applications when Hessian changes between sampling times.

The third part employs the algorithms and compares them with the existing methods and toolboxes. This chapter provides links between the optimisation domain, automation, and control. The chapter deals first with standard QP examples and shows that the proposed method outperform well established toolboxes FiOrdOs, qpOASSES, and FORCES. Then, in the second half, diesel engine MPC control is solved with both linear and nonlinear controllers. Only simulation results are presented, but the model was fitted to real turbocharged diesel engine data.

Aims and New Results

The thesis aims to achieve the following goals:

1. Development and improvement of the solver for box constrained QP programs suitable for MPC.
2. Comparison of the proposed algorithms to existing state-of-the-art solvers on selected benchmark problems.

In my opinion, both goals were fulfilled. Scientific results are achieved in the domains of optimisation and automatic control. Moreover, the proposed QP solvers can be used not only in automotive application domain and are of great interest of industrial sector. It is a pity that the solvers were not included in existing open-source solvers (for example box constrained solver of qpOASES) – the dissemination and outreach would be much larger.

Other Remarks

Publication record includes one published in journal Optimization methods and Software, 2 patents, and several papers at high quality international conferences including IFAC WC, CDC, ECC, MED. Some of them are already cited internationally which documents quality of the results. I find these results satisfactory for the submission of the thesis.

Questions and Comments

- p.12: why do we need to constrain slack variables?
- References in the thesis on explicit MPC end at 2011. Discuss recent improvements, actual limits on the maximum number of state variables and relations between complexity of implicit and explicit methods.
- Discuss sensitivity of convergence speed to various tuning parameters of the proposed methods.
- Nonlinear MPC: with 3 inputs, why is λ not controlled? Could you provide/compare control of the engine with existing methods?
- Nonlinear MPC: Explain, how setpoint functions Γ, Δ were generated.

Formal issues:

- Typos: p.18 (it is showed), p.29 (than based on the active set, than return the upper).
- P.11, (2.4) typo in the cost function indices.
- Reference [71] not complete, reference [C.8] wrong.
- It would be nice if all mathematical equations would be numbered.
- Footnote referenced at page 43 is shown at page 44.

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 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 patented. Therefore, I **recommend** it in the current form for defence for PhD degree.