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Review of the dissertation thesis entitled
"Travelling Waves in Distributed Control"
by Dan Martinec

Contents of the thesis

The thesis comprises 7 chapters on 171 pages. It is written in English with a very good command of the language. The thesis is written in a comprehensive and elaborate style, it is easy to read and reports novel, original, and interesting results.

Chapter 1 introduces the reader to the problem and cites relevant literature. Prior results are put into perspective and their respective pros/cons are elaborated. I appreciate that the literature review is deep and covers import early works as well. The main aims of the thesis are stated in clear terms. The general problem statement is supported by illustrative examples which immediately engage the reader into the topic. The questions posed in Section 1.3 serve as a kind of a checklist for further chapters.

Chapter 2 is devoted to Path-graph topology of vehicle platoons that are controlled by wave-absorbing controllers. The results reported in the chapter extend and generalize the concept to wave-based control by additionally considering distances between vehicles. The controllers are synthesized in the transfer function domain with a suitable approximation of the nonlinear impulse response. The main results of this chapter include, but are not limited to derivation of front-, rear- and two-sided wave-absorbing controllers for which asymptotic and string stability can be shown. Theoretical results are supported by persuasive numerical simulations.

Chapter 3 considers control of heterogeneous agents that have either different dynamics or are controlled by different local controllers. The chapter introduces the mathematical definition of boundaries and shows how to synthesize controllers for them. It elaborates on conditions under which such controllers provide stability. The numerical case study discusses local effects of the tuning as well as the combination of soft and hard boundaries.

Chapter 4 addresses the problem of the design of asymmetric control laws for a network of agents. To solve this problem, the thesis proposes the concept of wave transfer functions for asymmetric bidirectional connections. Such transfer functions are derived constructively, along with the corresponding reflections of the wave from the leader and the rear-end agent. The chapter elaborates of the properties of the transfer functions and draws implications for complex graphs with asymmetric coupling.

Chapter 5 discusses general graph topologies. It can be viewed as a natural (but non-trivial) extension of previous chapters. The concept of waves under general topology is first stated in rigorous mathematical terms before establishing properties of the waves. Conditions under which the gains of the transfer functions depend only on the number of neighbors are derived and related to the number of integrators in the system. The proposed technical concepts are illustrated, and their effectiveness is verified, on a numerical simulation involving ten agents.

Chapter 6 wraps up the thesis and offers comprehensive conclusions. It states in clear terms where the author's main contributions are and discusses their advantages and disadvantages. I highly appreciate Section 6.3 where the applicant envisions open problems and sets out the directions for future research.

Chapter 7 describes WaveBox, a toolbox-like set of functions are routines that implement some of the results presented in the thesis.

Goals and their significance for the field

The thesis has four central goals: (i) the design of bi-directional wave-absorbing controllers for homogeneous agents; (ii) the extension to heterogeneous agents; (iii) the design of asymmetric control laws; and (iv) the support for general graph topologies. The goals are demanding and the contribution to the field is clear. Conditions are presented under which the proposed controllers provide string stability allow the designer to verify important control properties. The methodological contributions address questions that are both difficult from a theoretical point of view and immediately relevant in practical applications. The goals have been achieved in my opinion.

Publications

At the time of the submission of the thesis, the defendant has coauthored seven journal papers (three of which are currently under review) and 12 conference paper. All the journal papers are either published in, or submitted to, high-quality peer-reviewed journals with high impact on the community (Automatica, IEEE Tr. on Aut. Control, Systems and Control Letters, Europ. J. of Control). The selection of conference outlets with a strict review process (ACC, ECC, IFAC WC, MSC) also ensure a high quality of the reported publications. The publications clearly corroborate that the defendant's work is appreciated in the control community.

Other remarks

Although the results presented in the thesis are linked to the applicant's scientific papers in Sections 1.4 and 6.2, the thesis would benefit from a more prominent linking directly when individual results are stated. Take Theorems 1 and 2 on pages 18 and 30, respectively, as representative examples - they are neither accompanied with the corresponding proofs, nor is their source referenced. This leaves the reader in doubt about the actual source of some of the result. In certain places (e.g. Corollary 5 on page no. 124), the reader would benefit from the author linking symbols (e.g. T_{t,N}, T_{r, N}) to actual equations.

Questions

- In the defendant's judgment and opinion, what are the limits of the presented methodology in terms of number of agents and type of topologies that can be handled? Are these limits more on the theoretical or more on the computational side?
- The rear-sided wave-absorbing controller of Chapter 2 requires that the last vehicle knowns the reference velocity of the whole platoon. In the author's own admission, this may not always be

feasible. Which practical scenarios can the applicant envision that would be compatible with such an assumption?

- The effect of noise on the control quality is discussed in Section 2.5.3. Would it be possible to account for the noise characteristics directly in the controller design?
- In the context of heterogeneous agents discussed in Chapter 3, how does the applicant envision the possible inclusion of other types of local controllers? For instance, could MPC-like controller or local feedback laws based on heuristically designed switching rules be used?
- Relating to the results of Chapter 5, can the proposed approach handle time-varying topologies? For example, one could consider platoon control where vehicles are disconnecting from/connecting to the platoon on-the-fly. How could this scenario be tackled in the context of the presented results?

Concluding remarks and recommendation

By his thesis and his original scientific papers, the candidate has clearly demonstrated his ability to state, treat and solve demanding scientific problems in the field of control theory tailored to traveling waves in distributed control. I am impressed by the scope of the thesis and the technical elegance with which the reported results are derived, presented, and discussed. After a thorough reading of the thesis, it is my opinion that the applicant has achieved all anticipated aims and goals. Without hesitation I **recommend to accept** the thesis for the defense of the PhD degree.

Bratislava, 22.8.2016

Michal Kvasnica