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Evaluation Report for the Ph.D. Thesis "Scaling in vehicle platoons" by Ivo Herman

It is my great pleasure to write this evaluation report for the Ph.D. Thesis "Scaling in vehicle platoons" by Ivo Herman. I recommend that the thesis is accepted without reservation. I believe that the thesis has made important fundamental contributions to the development of the state of the art in the area of distributed control of vehicle platoons. Therefore I recommend the continuation of the promotion procedure. I detail my argument in the following text.

The thesis presents a theoretical framework for the analysis and design of distributed controllers for vehicle platoons. The focus is on linear vehicle models with particular feedback and inter-vehicle communication structures. Depending on how information from the vehicles in front and behind is taken into account, the author shows that the gain of the platoon transfer function scales in different ways with the number of vehicles in the platoon. In particular, it is shown that symmetry plays an essential role for the considered model and that position and velocity state information is important. The underlying idea platoon control based on leader-follower strategy together with the foundational tools mainly from robust control theory and algebraic graph theory are described in detail. Challenges with string stability are introduced in a pedagogical way and the considered problems are motivated from important practical systems. A variety of suitable theoretical tools are developed to treat the problems in new ways. The relevant literature is well covered. Pedagogic examples are used throughout the thesis to illustrate the results and to explain the proof techniques. The thesis results have been presented at several major conferences and have appeared or are soon to appear also in leading archival journals (including one paper in IEEE Transactions of Automatic Control and one in Systems & Control Letters already published and three journal papers under review).

The thesis consists of three core chapters plus an introductory chapter, a background chapter, and a summary chapter with conclusions. Chapter 1 presents some motivation and then the overall structure of the thesis. A pedagogical example is given to illustrate that a collision can happen in a vehicle platoon if the controllers are not designed in a suitable way. The chapter contains a section where the author highlights the fact that the results of the thesis have some limitations when it comes to their applicability in practice, but is merely a theoretical investigation to understand some of the fundamental properties of distributed control of vehicle platoons. Chapter 2 introduces the required notions from graph theory and distributred control. Some of the literature in this vast area is reviewed, particularly with a focus on distributed control for vehicle platoons and other highly structured networked control systems. The core chapters (Chapters 3-5) all deal with novel methods to analyze platoon control schemes, but in different settings. Chapter 3 develops a transfer function model for interconnected systems. Both low-order models, such as single-integrator dynamics, and general linear dynamics are considered. Particular studies are made on the transfer function from reference and disturbance inputs to various outputs for a networked control system over a general graph but with identical node dynamics. Chapter 4 deals with the achievable performance limits and how they scale in the number of vehicles in the platoon. A particular distributed controller with bidirectional communication is considered with both symmetric and asymmetric interactions between the vehicles. It is shown that for the case with identical vehicles symmetric bidirectional control poses severe limitations that in some cases can be circumvent with asymmetric bidirectional control. Some discussions on open problems about how to handle platoons with non-identical vehicles are included. Chapter 5 presents some ideas of how to utilize different coupling in position and velocity. From a co-design of the communication weights and the controller parameters, it is shown how the overall performance of the vehicle platoon can be improved. Chapter 6 concludes the thesis with a short summary, a discussion on the author's contributions, and how the goals of the thesis have been fulfilled.

My overall impression of the thesis is that the author makes an outstanding contribution in introducing the novel techniques to analyze the control of vehicle platoons. The considered problems are very well motivated and of high interest to the scientific community. Vehicle platooning has been studied for more than fifty years, but the thesis is still able to develop some important new results. The author specifies some ambitious goals of the thesis, which seem to all have been fulfilled. I believe that the results of the thesis provide significant new insignt into how vehicle platoon systems should be analyzed and designed. In addition, the thesis is written in a clear and pedagogical way with several examples illustrating the new theory.

The author of the thesis proved to have an abilitity 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.

Yours sincerely,

Karl H. Johansson

Professor