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Review of the dissertation

Scaling in vehicle platoons

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1 Motivation and Scope

The great current interest in the field of multi-agent systems and networked control systems results from the fact that a large variety of digital networks are becoming available everywhere and can be used for the implementation of feedback loops without additional installation cost. The structure of such systems is characterised by a flat hierarchy, which for vehicle platoons is visible as a leader-follower structure in which no central coordinator is available. Hence, the properties of the subsystems and their interactions determine the behaviour of the overall system.

The thesis considers vehicle platoons as a particular and practically important and interesting case of multi-agent systems and aims at elaborating new methods for the analysis of such systems. Although relatively simple models of second, third or fourth order are used to describe the vehicles, the dynamics of the overall system becomes rather involved if the number N of the vehicle grows. Even the case $N \to \infty$ is considered. The complexity of such systems make this topic suitable for research on a PhD level.

The thesis deals with vehicle platoons with nearest-neighbour interactions. That is, the controller of the i-th vehicle has the measurements of the position and the velocity of the preceding and the succeeding vehicle available. The aim is to find properties of the overall platoon that is independent of the behaviour of the vehicle. The thesis shows that results can be obtained, which depend mainly on the number of integrators present in the vehicle model and the kind of couplings of the vehicles introduced by the local controllers, which are classified as symmetric and asymmetric.

2 Contents

The main contributions of the thesis are presented in chapters 3 through 5 and can be summarised as follows. **Chapter 3** shows how the transfer function of the overall system with respect to an input to the c-th subsystem and the output from the o-th subsystem depends upon the model of the subsystems and the interactions, which are described by the graph Laplacian matrix. **Chapter 4** deals with platoons with proportional asymmetry, which means that the information obtained from the predecessor and the successor vehicle can be scaled differently, but where both pieces of information have the same weights. The results concern the stability and the string stability of

the overall system, the steady-state gain and the H_∞ norm of the overall system all of which are important characteristics of vehicle platoons. **Chapter 5** extends the results to platoons in which the weights of the position and the velocity may be different. The additional difficulty that arises from this set-up comes from the fact that in this situation two different Laplacian matrices have to be used for the presentation of the overall system structure and that these matrices are not simultaneously diagonalisable. The author uses an idea of PETER VEERMAN to approximate the vehicle string by a circular vehicle coupling, which simplifies the analysis considerably.

Chapters 1 and 2 introduce the scientific problems, give a survey of the available literature on distributed control and summarise the main ideas. Chapter 6 presents the conclusions and highlights the author's contributions to the results presented.

3 Evaluation of the results and the presentation

With this thesis, the author has extended the knowledge about the complex dynamics of vehicle platoons in several ways. First, the representation of the transfer functions appearing in vehicle chains in dependence upon the vehicle models and the interconnection structure shows the systems theoretic components that appear in any of these transfer functions and the dependencies of these components upon the interconnection structure used. As the vehicles are assumed to have identical dynamics, the behaviour of the overall system can be decomposed into N artificial subsystems of the size of a single vehicle but with different dynamical properties. The interaction structure determines how these artificial subsystems enter into the overall system representation.

For the asymmetric vehicle platoons, the author has derived several interesting results that show how the platoon properties depend upon the number of integrators that are present in the subsystem models. The most important result concerns the way how these properties depend upon the number N of subsystem, i. e., how these properties „scale".

For the extension of these results to platoons with different asymmetries in the position and velocity feedback, the author had to circumvent the difficulty of dealing with two Laplacian matrices that are not simultaneously diagonalisable. His idea to follow the approach of approximating a vehicle string by a circular vehicle, for which the Laplacian matrices are circulant and, hence, can be brought with the same transformation into a diagonal form, is interesting and, as the thesis shows, successful. The only problem that remains to be solved in a general way is an evaluation of the approximation error, which has been characterised in the thesis only by simulation examples.

The thesis shows a profound knowledge of the author in the literature on networked systems, distributed control and the modelling and analysis of vehicle platoons. He has worked and published together with several other researchers of this field, which shows his acceptance by the control community.

The thesis is clearly structured and written in good technical English. Many illustrations accompany the analytical derivation of the results and make the main ideas clear. The combination of theoretical results with illustrations obtained by simulation demonstrate the progress obtained by the author. The author's idea to shift the proofs of the theorems and lemmas into the final parts of each chapter has considerably contributed to a good readability of the thesis.

4 Conclusions

The thesis shows the author's deep knowledge of systems and control theory and his well-developed abilities to solve important theoretical problems and to verify the solutions by simulation.

The results have been published in several ways including two journal paper and five papers at international conferences. Further publications are submitted. Altogether, this outcome leads to a very solid dissertation.

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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