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Review of the dissertation thesis

Consensus and Synchronization in Distributed Estimation and Adaptive Control

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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, in which no central coordinator is available, neither for the design of the controller nor for the implementation of the estimation and control algorithms.

The development of modelling, analysis and control methods for such systems is a hot topic in control theory nowadays. Many problems to be solved result from the fact that no part of a networked system has a complete knowledge about the model of the overall system and of the measurement signals. The thesis considers two of such problems. The state reconstruction problem considered in Chapter 3 should be accomplished by the individual agents separately based on their local information and the information communicated among the agents in a connected graph. The control problem tackled in Chapter 4 uses a networked controller in which the agents communicate their current state and use the received data to implement feedback loops based on state differences of neighbouring agents. The complexity of such systems make this topic suitable for research on a PhD level.

2 Contents

The main contributions of the thesis are presented in chapters 3 and 4 and can be summarised as follows. **Chapter 3** on „Distributed estimation on sensor networks" deals with the situation that a linear system has several outputs $y_i(t)$ that are used by several agents to estimate the state vector $x(t)$ of the overall system. As every agent has only access to a part of the measurement signals, communication among the agents improves the estimation result. An important aspect, which has been emphasised in the thesis, is the fact that the overall system may not be completely observable from the viewpoint of any of the agents, but, nevertheless, it may be observable through the overall output vector, which, however, is not available to any of the agents. Hence, communication among the agents does not only improve the estimation result, but this communication is necessa-

ry to get a valid estimation at all. The main result presented in Theorem 6 shows that the local estimators together with the communication links used lead to an estimation result that converges towards the true state vector.

Chapter 4 on „Distributed adaptive consensus protocol" considers the synchronisation problem in which the state of identical agents should approach the state of a leader agent. This problem has been solved in literature mainly for communication protocols (networked controllers) with constant gains and it is considered here for protocols with variable gains. The protocol is defined such that is provides a diffusive coupling among the agents and by an adaptation law that shows how the controller gains are changed in dependence upon the control errors. The main idea of the thesis is to introduce a new adaptation law, which makes it possible that the controller gains increase or decrease in dependence upon the state differences of the agents. Similar methods from literature only allow to increase the controller gains with the result that the gains usually become very large.

Chapters 1 and 2 introduce the two scientific problems tackled in the two later chapters, give a survey of the available literature and summarise preliminary results on networked control systems. The thesis ends with a concluding chapter and a bibliography.

3 Evaluation of the results and the presentation

The thesis considers two interesting problems in the field of networked control systems. Whereas the first problem is concerned with the reconstruction of the state vector $x(t)$ of the overall system from the local measurements, the second problem deals with the structure and the parameters of a networked controller that should bring the agents towards the same trajectory. While these two problems are considered separately, the main idea that connects them is on a more abstract level. Networked systems are usually considered with the constraint that they do not have any coordinating unit and this aspect is emphasised in the thesis by requiring that the whole process of designing and implementing the state reconstruction algorithms and the control algorithms should be possible from the viewpoint of the agents and by using local information only. The thesis shows that this constraint has severe consequences and that some decisions concerning the structure or the parameters of the state observers or the local controllers have to be made that may be suboptimal from the viewpoint of the overall system, but are unavoidable due to the restriction to local information. For example, Theorem 6 states the convergence of the distributed estimation scheme proposed in this thesis with the only global parameter γ to be chosen „sufficiently large". All further calculations can be made by using local model and sensor information. Similarly, Theorem 12 says that under the assumptions made the synchronisation problem is solved by the protocol and the adaptation rule for the controller gains given in the thesis provided that the parameters β_i are chosen appropriately in dependence upon the global parameters P and Q, but that for all P and Q this choice is possible.

These main results are obtained in a way that is rather similar to earlier results in literature. The estimation method developed in Chapter 3 is an extension of reference [79] and the control method in Chapter 4 has used preliminary results of several papers, in particular of [46] and [75]. However, the author has clearly stated what the extensions of these methods are and which assumptions have been released in comparison to literature. In this sense, the main objectives of the thesis have been fulfilled.

The results are illustrated by simulation studies. Whereas the situation in Chapter 4 concerns the standard set of double-integrator agents, which has been used in literature very often, the example used in Chapter 3 is more interesting. A clamped beam has been considered, which, after

several model simplifications and the concentration to selected behavioural modes, lead to a linear system that is not completely observable from every single measurement $y_i(t)$ and, hence, needs the communication among the agents for ensuring asymptotically correct state estimates.

The thesis is clearly structured and written in good technical English. The first two chapters are missing some illustrations like block diagrams or graphs illustrating the character of networked systems. The introductory parts of the main chapters give extensive surveys of the relevant literature and state clearly the aim and the main ideas of the methods to be developed. Analytical results are accompanied by intuitive explanations the improve the readability of some lengthy proofs.

4 Conclusions

The thesis shows the author's deep knowledge of systems and control theory and his abilities to solve interesting theoretical problems and to verify the solutions by simulation. The results have been published in two journal paper and three papers at international conferences.

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 a Ph.D. degree.

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