Control Theory of Networked Systems

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Communication technology makes it increasingly easy to connect sensors, controllers and actuators of controlled dynamical systems whenever an information exchange may improve the system performance. This current trend is associated with the notion of *cyberphysical systems* that describes systems connecting the physical world to be controlled with the virtual world of computers and data networks.

For control theory, this technological development raises important questions. Given a network of physically interconnected systems that are controlled by local control stations, how should one design the corresponding data network among these stations in terms of topology and capacity? Which information needs to be transmitted in order to solve a given control task? How can we model and deal with technical limitations of the actually implemented network? Which new functions can be implemented by using this global network that connects the local controllers?

These and other questions have been dealt with in the Priority Programme 1305 on *Control Theory of Digitally Networked Dynamic Systems* that the German Research Foundation (DFG) has financially supported between 2007 and 2013. Evidently, in order to find fundamental, yet applicable answers to these questions, various disciplines had to be integrated, ranging from more theoretical areas in mathematical systems theory all the way to fields dealing with software development and actual implementations. It is this interdisciplinary spirit which drove the collaborative effort in this Programme and made the engineers benefit from recent mathematical findings as much as the mathematicians from recent new concepts and possibilities of the new technology.

The results of 17 PhD students working in departments of Control, Mathematics, and Communication at German universities are summarized in the monograph [1]. Further reports can be found in the special issues [2] and [3] of this journal and in the current issue. The papers of this special issue describe recent results along the mentioned lines and point to important open problems that should be tackled by control theory in the near future.

Dominic Gross, Martin Jilg and Olaf Stursberg propose a new method of **Event-based communication in distributed model predictive control**, where the data network connecting the local controllers of the subsystems of the plant is used only if an event signals that the local controllers need information about the behavior of the other subsystems in order to improve its performance. The method tries to balance the communication load and the performance of the overall closed-loop system.

Jörg Fischer, Marc Reinhardt and Uwe D. Hanebeck develop a method for reducing the effect of transmission delay and data loss, which may be introduced by communication networks in the closed-loop system. Their paper entitled **Optimal sequence-based control and estimation of networked linear systems** proposes a new control scheme, in which sequences of control inputs rather than the current input value only are sent from the controller towards the actuators. The basis for this method is an extension of the ideas of the hypothesizing distributed Kalman filter.

The control of multi-agent systems has attracted considerable interest in the networked control community. In the standard setting, autonomous dynamic systems are considered that have to be controlled such that they satisfy common goals. Consequently, the networked controller has to introduce couplings among all agents and the used communication topology needs to be chosen in dependence upon the design task to be solved. Anna von Heusinger and Uwe Helmke consider the synchronization problem, where the controller should give linear identical subsystems a coherent behavior. In their paper on **Synchronizing subspaces of networks of homogenous linear control systems** they characterize the synchronizability of the agents for controllers with fixed interconnection structure and they solve the stabilization problem of networked systems by reformulating it as a linear matrix inequality problem.

In the current status of networked control, the digital communication network is primarily used for sending sampled state or output information from sensors towards the controller or the input signal from the controller towards the actuators. However, data networks can be used for higher-level tasks like the modification or adaptation of control algorithms as well and this purpose opens the door to much more general questions of networked control systems. Sven Bodenburg and Jan Lunze describe in the paper on **Plug-and-play control: Definition and realisation in MATLAB**, how a control algorithm can be replaced by another algorithm that is sent by a supervisor of the overall system over the digital communication network to the corresponding subsystem. The MATLAB implementation described takes care of an automatic inclusion of the new control algorithm into the control system of the corresponding subsystem and its embedding into the physical environment of this subsystem. In comparison to its common use for data exchange, in plug-and-play control the digital network is used to modify the control algorithm as a whole rather than for updating the online information about the plant state.

Real-time control over communication networks relies on a reliable and timely transmission of process data over the network. If data is lost, a re-transmission of this data may increase the success of the transmission and, hence, the performance of the closed-loop system. Rainer Blind and Frank Allgöwer investigate in their paper **On the optimization of the transport layer for networked control systems** combinations of TCP-like and UDP-like protocols, which are applied for sending sensor information towards the controller or for sending control information from the controller towards the actuators, respectively. By determining the maximum data rate for specified loss probabilities of the network, they can answer the question under what conditions an increase of the sampling time, which allows to send more information packets over the network, improves the performance of the closed loop.

Frederik Deroo and Sandra Hirche describe **MTIDS: A MATLAB toolbox for large-scale networked systems**, which allows to analyse a network of dynamical systems both from a graph-theoretic viewpoint and from a dynamical systems perspective. The toolbox helps to easily create the model of the networked system and to simulate the overall system behavior.

References

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Received: 15. April 2013

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