

**Modeling and Control of Closed Loop
Networked PLC-Systems**

Modellierung und Regelung von vernetzten
SPS-Regelungssystemen

Dissertation

zur Erlangung des Grades

des Doktors der Ingenieurwissenschaften

der Naturwissenschaftlich-Technischen Fakultät II

- Physik und Mechatronik -

der Universität des Saarlandes

von

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Saarbrücken

2011

Tag des Kolloquiums: 29.09.2011

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Berichte aus der Automatisierungstechnik

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Shaker Verlag
Aachen 2011

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Saarbrücken, Univ., Diss., 2011

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Printed in Germany.

ISBN 978-3-8440-0520-2

ISSN 0945-4659

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen

Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9

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Acknowledgment

I am heartily thankful to my supervisor, Prof. Dr. Georg Frey, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

Lastly, I offer my regards and blessings to my parents, my family and to all of those who supported me in any respect during the completion of my dissertation.

Abouelabbas, 2011

Abstract

The term Networked Control Systems (NCS) in recent literature refers to the interdisciplinary research area, combining both network and control theory, in order to guarantee the stability and performance of an NCS. In contrast response time estimation in Networked Automation Systems (NAS) combines network and formal modeling tools to guarantee certain time performance for time critical automation tasks. The two research areas seem to be independent, despite both of them work rather in studying delays in networked automation and control systems. Networked closed loop systems that use Programmable Logic Controllers (PLC) play an important role in recent manufacturing. PLC-based networked control systems (PLC-based NCS) constitute a well-known category of industrial automation and control systems that use time-based execution platforms. In this dissertation, we present a unified formal modeling and control design of PLC-based NCS. The modeling phase proposes a two-step approach for modeling and simulation of delays in Networked Automation and Control Systems (NAS/NCS). In the first modeling step, a detailed parametric structure-conserving hierarchical timed model for the whole NAS/NCS is built and simulated using Colored Petri Nets (CPN). The detailed parametric model aims to understand the key parameters that affect delay performance and to generate extensive time-stamped delay data records. NAS/NCS CPN-based models use PLC as a system controller and Ethernet as a control network. The models capture the most important features of such time-driven systems, such as client/server input/output scanning and cyclical execution of the control algorithm on the system controller. The second modeling step introduces a new concept of direct and hidden Markov modeling in the area of response time estimation in NAS, instead of the assumption of independent and identically distributed (iid) random delays. The dissertation enhances the use of Markov models in NCS delay modeling by introducing the concept of mutual Markov modeling to analyze interaction between the two types of induced delays, namely, the sensor-to-controller time delay τ_{sc} or S-C link delay and the controller-to-actuator time delay τ_{ca} or C-A link delay. The results of mutual Markov models is used in the control phase to design a novel two-mode-dependent NCS control scheme, in which the controller depends on mutual Markov models for both S-C and C-A delays, instead of previous designs that use independent Markov models for each delay. The resulting closed-loop system can be represented as Markovian Jump Linear System (MJLS). The dissertation concludes with proposing a modified algorithm for solving the Linear/Bilinear Matrix Inequalities (BMIs/LMIs) stability conditions with non-convex constraints using the new mutual Markov models.

Kurzfassung

Bei vernetzten Regelungssystemen (VRS) sind Sensoren, Aktuatoren und Regler durch Echtzeit-Kommunikationsnetze miteinander verbunden sind. Beim Reglerentwurf und der Analyse sind die, durch die Kommunikation entstehenden, Verzögerungen im geschlossenen Regelkreis zu berücksichtigen. Man unterscheidet hier gemeinhin die Sensor-Regler-Verzögerung (sensor-to-controller time delay, τ_{sc}) und die Regler-Aktuator-Verzögerung (controller-to-actuator time delay, τ_{ca}). Diese Zeiten sind i.A. nicht fest sondern unterliegen stochastischen Schwankungen.

Speicherprogrammierbare Steuerungen (SPS) sind die in der Industrie am häufigsten eingesetzten Hardwareplattformen zur Implementierung von Regelungs- und Steuerungsaufgaben. SPS-basierte VRS bilden deshalb eine bekannte und im industriellen Einsatz wichtige Untergruppe der VRS, die sich dadurch auszeichnet, dass zeitbasierte Ausführungsplattformen verwendet werden. In der vorliegenden Arbeit wird ein neues Verfahren zur Modellierung und zum Reglerentwurf für SPS-basierte VRS vorgestellt.

Zur Modellierung wird ein zweistufiger Ansatz vorgeschlagen. Im ersten Schritt wird ein Modell des VRS auf Basis dessen Hardware-Struktur mittels farbiger Petri-Netz strukturerhaltend komponentenbasiert aufgebaut. Dieses Modell kann einfach parametrisiert werden und wird zur Gewinnung umfangreicher Verzögerungsdatensätze simuliert.

Die in der Simulation gewonnenen Daten dienen im zweiten Schritt zur Erstellung eines kompakten Markov-Modells, das seinerseits zum Reglerentwurf und -analyse eingesetzt werden kann. Neben bekannten Formen der Markov-Modelle für Verzögerungen in VRS, stellt die Arbeit hierzu einen neuen Ansatz vor, bei dem die beiden Verzögerungen (τ_{sc} und τ_{ca}) zusammen in einem Markov-Modell betrachtet werden.

Für dieses neue Modell wird schließlich ein Reglerentwurfsverfahren vorgestellt. Hierzu wird ein modifizierter Algorithmus zur Lösung der Stabilitätsbedingungen für Markov Jump Linear Systems (MJLS) vorgeschlagen. Das Verfahren wird schließlich an einem Referenzbeispiel evaluiert.

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