Conceptualization of Temporal Specifications for Application to Distributed Real-Time Control Systems

This Thesis is presented for a degree of

Doctor of Philosophy (PhD) in Engineering

By

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Dedicated to my son

Arnav Seth

&

my husband

Amit Seth

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Declaration

I declare that this thesis is my own account of research and contains, as its main content, work which has not been submitted before for a degree at any tertiary educational institution.

Rachna Dhand

Abstract

The main consideration in the design of any control system is the intensive use of sensor equipment and its integration with a real-time computing environment. The degree of integration determines the efficacy and complexity of the control artefact. This research aims at investigating the use of Real-Time Languages as a generic paradigm for designing distributed automation systems. A challenging problem in control of any networked industrial plant is minimization and variance of delay within its control-loop. The time delay in executing the control algorithm originates from:

1. The computation giving rise to the control decision;
2. The sampling time chosen if a discrete-time controller is used;
3. Communication delays due to network characteristics like the application protocol in use, the topology, or the type of physical communication hardware used;
4. Physical transport delays as an integral part of plant operation.

A distributed real-time control system, linked through a communication network, is bound to be affected by the randomness of communication delay patterns. The research focuses on optimizing the controller to account for communication and computation delays. The computational delay can be bounded by the application of Real Time (RT)-languages such as the Timing Definition Language (TDL). Real-time programming methodologies like RT-Java or TDL have evolved in the last decade to address the increasing complexity of control systems and scalability of equipment in the industrial automation domain. Different temporal execution models are analysed and their execution is explored using RT-languages.

Communication networks like Ethernet have unbounded delays. Statistical modelling techniques, like Auto-regressive Integrated Moving Average (ARIMA), may be used to model the network traffic. The case study for Ethernet traffic modelling serves as a benchmark for modelling communication delays that are random in nature. Comprehensive coverage is provided for network traffic modelling through the stochastic approach ARIMA, with a case study of National Instruments (NI) DataSocket Transport Protocol (DSTP), based on high bandwidth Ethernet.

In real-time control systems, the controller optimization requires accurate temporal specification of sensitive controller tasks. Logical computation languages such as TDL have successfully eliminated the temporal unpredictability of designing control software. Finally, this thesis constructs an analytical and programmatic rationale on the impact and compensation of unpredictable network delays through discrete-time control algorithms, that are designed in TDL. An adaptive self-tuned regulator is designed for compensating variably bounded delays. The results validate that discrete implementations of the Self-Tuned Controller are able to compensate for delay, thus guaranteeing the stability of the control-loop in the presence of random delays.

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Publications

Journal Publications

1. R. Dhand, G. Lee, G. Cole, 'Industrial Automation Networks for Distributed Real-Time Control', *CSI Communications*, Vol. 31, Issue 12, pp- 22-28, March 2008

2. R. Dhand, G. Lee, G. Cole, 'Applying Service-Oriented Architecture to Industrial Control Systems', Accepted in *CSI Adhyayan* (Quarterly ePublication) Computer Society of India, Mumbai September 2010.

Under Review

1. R. Dhand, G. Lee, G. Cole, 'Communication Delay Optimization using Adaptive Self-Tuning Control for Real-Time Industrial Control Systems', *Computers in Industry*, Elsevier, Under Review

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1. R. Dhand, G. Lee, G. Cole, *'Analytical Temporal Specification Issues for Distributed Real-Time Control Systems',* Conference Proceedings 24th IEEE International Conference on Advance Information Networking and Applications Workshops, ISBN 978-0-7695-4019-1, pp - 68-74, IEEE Computer Society, April 2010.

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