ARTIST 2

Network of Excellence

IST-004527 ARTIST2:
Embedded Systems Design

Activity Progress Report for Year 2

JPRA-Cluster Integration

Control in Real-time Computing

Clusters:

Control for Embedded Systems

Activity Leader:

Professor Karl-Erik Årzén (Lund University)

http://www.control.lth.se/user/karlerik/

Policy Objective (abstract)

The overall objective of this activity is to advance the state of the art in applying control methods for uncertainty handling and as a way to provide flexibility and improved performance in embedded computing and communication systems. This report summarizes the achievements obtained during the second year of ARTIST2.

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1. Overview of the Activity

1.1 ARTIST2 Participants: Expertise and Roles

Professor Karl-Henrik Johansson – KTH (Sweden)
Provides expertise in applying control techniques to communication networks, including sensor networks.

Associate Professor Anders Robertsson – LUND (Sweden)
Provides expertise in performance control of server systems.

Professor Karl-Erik Årzén – LUND (Sweden)
Provides expertise on feedback-based scheduling of control systems.

Professor Alfons Crespo – UPVLC (Spain)
Provides expertise on embedded computing.

Professor Martin Törngren – KTH (Sweden)
Provides expertise in architectural design and automotive embedded system applications involving dynamic configuration.

1.2 Affiliated Participants: Expertise and Roles

Dr Johan Eker – Ericsson (Sweden)
Provides expertise on reservation-based scheduling in mobile terminals.

Professor Lui Sha - University of Illinois (US)
Provides expertise on error control of software systems.

Professor Tarek Abdelzaher - University of Illinois (US)
Provides expertise on feedback scheduling.

1.3 Starting Date, and Expected Ending Date

The activity started September 1, 2004. Since the overall status of the activity is to enhance the state of the art in applying control techniques to real-time control and computing systems the activity will run over the entire life-time of the network, and most likely also continue after the termination of Artist2.

1.4 Baseline

Before this activity started the different groups performed individual research on applying control-based approaches to embedded and real-time systems, e.g., feedback scheduling of servers, feedback scheduling of control systems, and control-based approaches in networking. The research area was strongly dominated by US research groups.

1.5 Problem Tackled in Year2

The overall objective of this activity was to advance the state of the art in applying control methods for uncertainty handling and as a way to provide flexibility and improved performance in embedded computing and communication systems. The application areas include performance control of web server systems, feedback-based reservation management in

embedded real-time systems, feedback scheduling of control systems, and control of communication and sensor networks.

This objective has been achieved in a nice way through the large amount of research that has been performed within and between the partners. The planned meetings have all been held, except for the follow-up workshop to the successful Lund Workshop on Control for Embedded Systems which have been postponed until early Spring 2007 (this time in Urbana-Champaign).

A major objective during the second year was to disseminate the roadmap material developed during the first year. This has been done successfully in the form of one invited conference contribution and one journal article.

1.6 Comments From Previous Review

1.6.1 Reviewers' Comments

The reviewers' comments regarding last years deliverables from the cluster were as follows: *Four deliverables were due from this cluster at the end of Y1:*

- *Deliv-JPIA-a-Control-Y1*
- *Deliv-JPRA-NoE Integration-c-Y1 (this cluster's contribution as planned in the DoW.)*
- *Deliv-JPRA - Cluster Integration – Control for Embedded - a -Y1*
- *Deliv-JPRA - Cluster Integration – Control for Embedded - b -Y1*

The deliverables were of uniformly excellent quality. The deliverable documents themselvesdescribed the problem to be addressed, the current state of the art, what was achieved using ARTIST2 funds in the past year, and natural integrative next steps for the coming 12/18 months. Where Roadmaps (or other collateral documents) were developed as part of a particular task, such documents were succinctly summarized in the deliverable, with pointers to the more complete document for the interested reader.

The specific comments related to this activity were as follows: *"This task is focused on advancing the state of the art in applying control methods for uncertainty handling and as a way to provide flexibility and improved performance control in embedded computing and communication systems. The primary work items for Y1 were the creation of a research roadmap for this research area and hosting an international workshop in Control for Embedded Systems. The key outcomes of the roadmap exercise and the international workshop are succinctly summarized in the deliverable document; the roadmap and a summary of the workshop are provided as separate documents associated with this deliverable."*

1.6.2 How These Have Been Addressed

Since the reviewer's were very positive we have tried to continue along the same lines as previous year. A major goal has been to disseminate the material collected in the roadmap in a wider circle. This we have succeeded well with. For example, we presented an invited talk summarizing the conclusions from the roadmap at FeBID'06, the First International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks that was organized in Vancouver in April 2006. An extended version of this paper has also been published in the ACM SIGBED Review. In parallel with this the research within the groups and in collaboration between the groups has continued.

2. Summary of Activity Progress

2.1 Previous Work

Since this a rather new research area it was decided at the beginning of year1 that the main activity should be the creation of a research roadmap.The aim of the roadmap was to chart the area, provide a common platform for the coming work, and to identify the most important research directions.

- The first version of the roadmap was completed.
- A new feedback scheduling method was developed for control loops by Dan Henriksson and Anton Cervin (LUND). A paper was presented at the CDC-ECC'05 in Sevilla - LUND
- An international workshop in Control for Embedded Systems was held in Lund with 20 participants. The international affiliates Lui Sha and Tarek Abdelzaher participated and gave value input. A separate research agenda for the work within Artist2 was written as the output from the workshop.
- Karl-Erik Årzén and Anders Robertsson were invited to participate as the only non-US participants at a workshop on the future of control of computing systems organized by NFS and held at IBM, May 3-4, 2005
- KTH has been working on control-based error-correction in packet-switched networks, on the use of radio network feedback to improve TCP performance over cellular networks, and on network state estimation.

2.2 Current Results

2.2.1 Technical Achievements / Outcomes / Difficulties encountered

Achievement: Dissemination of Roadmap Material
The concludions from the roadmap developed during year1 were summarized into the conference paper [1] that was presented as an invited talk at FeBID'06, the First International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks that was organized in Vancouver in April 2006. An extended version of this paper [2] has also published in the ACM SIGBED Review. The creation of the FeBID workshop series can potentially be very important for the future development of the area. The followup workshop FeBID'07 will be organized in Munich in May 2007, with a member of the Lund group as a technical co-chair and with another member of the Lund group in the IPC. (constituting two of the only three European members of the organizing committee – compared to 26 members from the US!).

Output from Achievement: Dissemination of Roadmap Material
See Section 2.2.2.

Difficulties with Achievement: Dissemination of Roadmap Material
No difficulties encountered. We were successful in becoming invited to present the material at the FeBID workshop and later having the material accepted for the ACM SIGBED Review.

Achievement: Control of Server systems
Control of server systems is the subject of research in Lund and University of Illinois. Lund is

working on improved models for feed-forward based queing control systems and on providing reservation-based scheduling in Linux systems using the nice value as the control signal. A natural application for the latter is web servers. The work at University of Illinois is focused on content distribution, adaptive rate allocation, and delay control. Dan Henriksson from Lund is spending the year 2006-2007 as a postdoc at University of Illinois working with Tarek Abdelzaher. In [4] the new model types derived for queing control are also applied to traffic flow control in collaboration between CTU and LUND.

In a complementary activity at KTH, the automatic control group has been investigating distributed resource allocation mechanisms for large-scale server clusters. Optimal off-line solutions and high-performing distributed heuristics have been developed and evaluated in detailed system-level simulators of the Chameleon architecture. The initial work has been reported in [7].

Output from Achievement: Control of Server Systems
The licentiate thesis [3]. Numerous publications from University of Illinois that are not part of this review.

Difficulties with Achievement: Control of Server Systems
No difficulties encountered.

Achievement: Feedback Scheduling of Control Systems
In our previous work on feedback scheduling of linear controller tasks it has been assumed that the amount of disturbances entering the control loops is constant over time. In [5], the inital states of the controlled plants are taken into account by the feedback scheduler by including the inital state in the cost function. The motivation for this is that a plant with a large error should receive more resources in order to better cope with the disturbance. However, in all but extreme cases it is the expected future disturbances that completely dominate the cost function. In [6], we have explored how one can obtain a more reactive feedback scheduler by estimating the amount of noise in the various control loops. We have also extended the cost functions to take a constant delay (obtained using Control Servers) into account. This work has been performed in collaboration with UPC.

Output from Achievement: Feedback Scheduling of Control Systems
See Section 2.2.2

Difficulties with Achievement: Feedback Scheduling of Control Systems
No difficulties encountered. A general difficulty is the small means that are available for controlling the research within a network of excellence. Although a center of excellence can derive roadmaps it is extremely difficult to ensure that the actual research work that is performed follows the lines of this roadmap. In this particular case, however, it happens to be the case.

Achievement: Control of Communication Networks
The automatic control group at KTH has been working on theory and engineering principles for cross-layer optimization of wireless networks. Specific achievements includes a theoretical framework for self-regulating protocol design [14], as well as detailed resource control strategies for specific network technologies [15]. The KTH group has also worked on on-line error control adaptation in networked applications [8], feedback-based error-correction in feedback-based networks [9], stability of window-based queue control with applications to mobile terminal download, [10], models for network congestion control [11], and distributed consensus algorithms [12]

Output from Achievement: Control of Communication Networks
See Section 2.2.2

Difficulties with Achievement: Control of Communication Networks
No difficulties encountered.

2.2.2 Publications Resulting from these Achievements

A complete list of publications produced by the Control cluster, with downloads available for most of the papers, is available here: http://www.md.kth.se/RTC/ARTIST2/publications.html

[1] Karl-Erik Årzén, Anders Robertsson, Dan Henriksson, Mikael Johansson, H. Hjalmarsson, Karl Henrik Johansson. Conclusions from the European Roadmap on Control of Computing Systems. In *First International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks,* Vancouver, Canada, April 2006. Invited presentation.

[2] Karl-Erik Årzén, Anders Robertsson, Dan Henriksson, Mikael Johansson, H. Hjalmarsson, Karl Henrik Johansson. Conclusions of the ARTIST2 Roadmap on Control of Computing Systems. ACM SIGBED (Special Interest Group on Embedded Systems) Review, Vol 3, No 3, July 2006. http://www.cs.virginia.edu/sigbed/vol3_num3.html

[3] Martin Ohlin. Feedback Linux Scheduling and a Simulation Tool for Wireless Control. Licentiate thesis ISRN LUTFD2/TFRT--3240--SE, Department of Automatic Control, Lund University, Sweden, June 2006.

[4] Michal Kutil, Zdenek Hanzalek, Anton Cervin. Balancing the Waiting Times in a Simple Traffic Intersection Model. In *Proc. 11th IFAC Symposium on Control in Transportation Systems,* Delft, The Netherlands, August 2006.

[5] D. Henriksson and A. Cervin. “Optimal on-line sampling period assignment for real-time control tasks based on plant state information.” The 44th IEEE Conference on Decision and Control and European Control Conference ECC 2005, Seville, Spain, December 2005.

[6] Rosa Castañé, Pau Martí, Manel Velasco, Anton Cervin, Dan Henriksson. Resource Management for Control Tasks Based on the Transient Dynamics of Closed-Loop Systems. In *Proceedings of the 18th Euromicro Conference on Real-Time Systems,* Dresden, Germany, July 2006.

[7] B. Johansson, C. Adam, M. Johansson and R. Stadler. Distributed Resource Allocation Strategies for Achieving Quality of Service in Server Clusters, IEEE Conference on Decision and Control, San Diego, USA, December 2006.

[8] A control framework for online error control adaptation in networked applications, O. Flärdh, C. Fischione, K. H. Johansson, and M. Johansson. International Symposium on Communications, Control and Signal Processing, Marrakech, Morocco, 2006. Invited paper.

[9] A new feedback control mechanism for error correction in packet-switched networks, O. Flärdh, K. H. Johansson, and M. Johansson. IEEE CDC-ECC, Seville, Spain, 2005. Invited paper.

[10] Stability of window-based queue control with application to mobile terminal download, N. Möller, K. H. Johansson, and K. Jacobsson. MTNS, Kyoto, Japan, 2006.

[11] Towards accurate congestion control models: validation and stability analysis, K. Jacobsson, H. Hjalmarsson, and K. H. Johansson, MTNS, Kyoto, Japan, 2006.

[12] Distributed model predictive consensus, B. Johansson, A. Speranzon, M. Johansson, and K. H. Johansson. MTNS, Kyoto, Japan, 2006.

[13] Richard Anthony, Alexander Leonhardi, Cecilia Ekelin, Dejiu Chen, Martin Törngren, Gerrit de Boer, Isabell Jahnich, Simon Burton, Ola Redell, Alexander Weber, Vasco Vollmer: A

Future Dynamically Reconfigurable Automotive Software System. Elektronik im Kraftfahrzeug, Dresden, Germany, June 27-28 2006

[14] B. Johansson, P. Soldati and M. Johansson, Mathematical Decomposition Techniques for Distributed Cross-Layer Optimization of Data Networks, IEEE Journal on Selected Areas in Communications, Volume 24, No. 8, pp 1535-1547, 2006.

[15] P. Soldati, B. Johansson and M. Johansson, "Proportionally Fair Allocation of End-to-End Bandwidth in STDMA Wireless Networks", ACM Mobihoc, Florence, Italy, May 22-25, 2006.

2.2.3 Keynotes, Workshops, Tutorials

Invited Presentation : Karl-Erik Årzén, Anders Robertsson, Dan Henriksson, Mikael Johansson, Håkan. Hjalmarsson, Karl Henrik Johansson. Conclusions from the European Roadmap on Control of Computing Systems. In *First International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks,* Vancouver, Canada, April 2006 http://www.controlofsystems.org/febid2006/

Keynote : Karl-Erik Årzén. Implementering av reglersystem: utmaningar och forskningsinriktningar (Control System Implementation: Challenges and Research Directions). In Reglermötet 2006 (Swedish Control Conference), Stockhlm, June 2006. http://www.s3.kth.se/control/reglermote/

Keynote: Karl Henrik Johansson: Modeling and analysis of hybrid control systems, Modelling and Verifying Parallel Processes (MOVEP), http://movep.labri.fr/, Bordeaux, France, June 19-23, 2006

Keynote: Karl Henrik Johansson. Control over wireless networks, 25th Benelux Meeting on Systems and Control, Heeze, The Netherlands, March 13-15, 2006

3. Future Work and Evolution

3.1 Problem to be Tackled over the next 18 months (Sept 2006 – Feb 2008)

The exact topics that will be investigated are to a large extent decided by the forces outside the control of the network. However, our aim is to work on control-based models and methods for queuing systems with applications in server systems, control of multi-tier server systems, feedback scheduling of control systems, feedback-based and hierarchical resource reservation schemes for embedded systems, control of communication networs in different settings, e.g., congestion control, control of tramit power in wireless networks, control-based error coding, and optimization-based network protocol design.

The applicability of control based approaches to automotive embedded systems will be investigated in the context of the DYSCAS project (www.dyscas.org). Scenarios associated with dynamic configurations will be investigated. Services and an architecture handling the required dynamic configurations will be developed in the course of which control based approaches will be considered for this type of applications.

On a more general scale it is important to increase the visibility for this type of research. Currently there is a large industrial interest in the US, but so far it has been more modest in Europe. A good vehicle for achieving this goal is the next FeBID workshop in Munich in May 2007. Here it could be possible to make a dedicated ARTIST2 activity aimed at European industry.

3.2 Current and Future Milestones

Year1 Milestone: Roadmap describing the current state-of-the-art and the important research issues *(Achieved to 95%)*

The roadmap has been completed and partially disseminated. What remains is to make the entire roadmap more easily available to the general public. We plan to print the two roadmaps together as a single document or report during the fall of 2006.

Year2-4 Milestones:

- Progress made on the fundamental underlying issues: decreased requirements on prior knowledge about resource utilization, increased possibilities to use COTS implementation platforms, and enhanced robustness towards load variations (*Achieved to 30 % currently)*

The research performed during this year contributes to the solution of several of the above items. For example, the work on feedback control of Linux scheduling is a step towards being able to utilize COTS implementation platforms, and the work on queueing system models is motivated by the aim to be robust against load variations.

New Year 3-4 Milestone:

- Increase our international and industrial visibility. A good means for this is through the organization of and the participation in the FeBID workshops.

3.3 Indicators for Integration

Joint research work indicated by joint high-quality publications, mobility of team members among the teams, and jointly organized workshops and sessions.

3.4 Main Funding

The main sources of funding for this work are:

- Nationally funded projects. For the Swedish partners these include FLEXCON, SAVE, SAVE++ and numerous projects and grants funded by the Swedish Research Council, the Swedish Foundation for Strategic Research, and the Swedish Programme Council for Vehicle Research. For the partners from other countries the situation is similar.
- EU projects. The following are examples of currently running EU projects that to some extent cover these acivities: RUNES, SOCRADES, DYSCAS, CEMACS, and FRESCOR.

3.5 Internal Reviewers for this Deliverable

Martin Törngren, KTH

Alfons Crespo, UPVLC