



IST-004527 ARTIST2
Network of Excellence
on Embedded Systems Design

Activity Progress Report for Year 4

JPRA-Cluster Integration
Control in Real-Time Computing

Clusters:

Control for Embedded Systems

Activity Leader:

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<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 fourth year of ARTIST2.

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1. Overview of the Activity

1.1 *ARTIST Participants and Roles*

Professor Karl-Henrik Johansson – KTH (Sweden)

Role: Provides expertise in applying control techniques to communication networks, including sensor networks.

Associate Professor Anders Robertsson – LUND (Sweden)

Role: Provides expertise in performance control of server systems.

Professor Karl-Erik Årzén – LUND (Sweden)

Role: Provides expertise on feedback-based scheduling of control systems.

Professor Alfons Crespo – UPVLC (Spain)

Role: Provides expertise on embedded computing.

Professor Martin Törngren – KTH (Sweden)

Role: Provides expertise in architectural design and automotive embedded system applications involving dynamic configuration.

1.2 *Affiliated Participants and Roles*

Dr Johan Eker – Ericsson (Sweden)

Role: Provides expertise on reservation-based scheduling in mobile terminals.

Professor Lui Sha - University of Illinois (US)

Role: Provides expertise on error control of software systems.

Professor Tarek Abdelzaher - University of Illinois (US)

Role: 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 will continue after the termination of Artist2 within the ArtistDesign NoE.

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 Year 4

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. The application areas include performance control of web server systems, feedback-based reservation management in embedded real-time systems, feedback scheduling of control systems, dynamically configurable automotive 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.

1.6 Comments From Year 3 Review

1.6.1 Reviewers' Comments

"The document is well written. It clearly describes the achievements in year 3, the dissemination activities and the integration activities. The list of publications indicates significant technical progress and interaction among the cluster members. The future work plans are appropriate and consistent with the roadmap. Note that references 53 and 54 are identical to 14 and 15 in D20-Control-Y3. This repetition does not seem to be necessary."

1.6.2 How These Have Been Addressed

Since the reviewer's were very positive both after all the previous reviews we have tried to continue along the same lines as previous year. Care will be taken to ensure that publications are only listed in one deliverable.

2. Summary of Activity Progress

2.1 *Previous Work in Year 1*

Since this is 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 valuable 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 *Previous Work in Year 2*

Achievement: Dissemination of Roadmap Material

The conclusions from the roadmap developed during year1 were summarized into a conference paper 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 has also been 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 follow-up 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!).

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 queuing 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. The new model types derived for queuing 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.

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. The initial states of the controlled plants are taken into account by the feedback scheduler by including the initial 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.

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 include a theoretical framework for self-regulating protocol design, as well as detailed resource control strategies for specific network technologies. The KTH group has also worked on on-line error control adaptation in networked applications, feedback-based error-correction in feedback-based networks, stability of window-based queue control with applications to mobile terminal download, models for network congestion control, and distributed consensus algorithms.

2.3 Previous Work in Year 3

Achievement: Control of Server systems (LUND, UIUC)

Control of server systems is the subject of research in Lund and University of Illinois. Lund has continued its work on improved models for feed-forward based queuing 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. A feedback-based prediction scheme for controlling the response times in a single server queue has been investigated. This control structure has the benefit over other previously suggested control structures that no measurement of the required work of each job is needed. However, the new solution maintains the same attractive properties, regarding average response time and variance as previously suggested solutions.

The work at University of Illinois is focused on content distribution, adaptive rate allocation, and delay control. Dan Henriksson from Lund has spent the year 2006-2007 as a postdoc at University of Illinois working with Tarek Abdelzaher.

In parallel with this KTH has continued their work on control of server farms.

Achievement: Feedback-Based Resource Management in Cellular Devices (Ericsson, LUND)

Lund and Ericsson have received funding from the Swedish funding agency VINNOVA for the joint project "Feedback Based Resource Management and Code Generation for Soft Real-Time Systems". The project will provide funding for one researcher from Lund University and one researcher from Ericsson over three years. A related EU FP7 STREP project coordinated by Ericsson has also been approved. This will, however, be reported in the activity report for the NoE integration activity Adaptive Real-Time, HRT and Control.

Achievement: Control of Communication Networks (KTH, Ericsson, ABB)

The networked control group at KTH has continued their research on analysis and synthesis of networked control systems, including resource allocation, traffic control and routing for wireless networks and distributed control and estimation. The work includes laboratory implementations and testing as well as industrial dissemination through collaborative projects with ABB, Ericsson, Scania etc. KTH participated in the 2nd International ARTIST Workshop on Control for Embedded Systems in Urbana-Champaign, where samples of these results were presented.

Achievement: Adaptive Resource Management in Wireless Networked Embedded Systems (KTH, LUND, Ericsson)

Resource control in wireless networked embedded systems has been the subject for the collaboration between KTH, Lund and Ericsson funded by the RUNES IP during Year 3. A challenging demonstrator scenario has been developed and implemented involving mobile robots and sensor network nodes, in which control and localization techniques closed over a wireless network were combined with feedback-based radio transmit power control

Achievement: Dynamically Configurable Automotive Embedded Systems (KTH, Volvo)

Within the project Dyscas (www.dyscas.org), KTH in cooperation with European automotive industries (including ARTIST2 affiliated partners Volvo, and DaimlerChrysler), Enea (providing the OSE real-time operating systems), Univ. of Paderborn and Univ. of Greenwich, have spent considerable efforts on dynamically configurable automotive embedded systems. The goals are to provide new platforms and methods that support scenarios such as software download (also during run-time), flexible internal resource configuration schemes (for availability or performance purposes), and flexible connectivity with external devices such as PDA's (for functionality and performance purposes). The main emphasis is on non-safety critical functions related to the telematics/infotainment domains, but in a connected Swedish national project the same scenarios are also considered for more safety critical functions. The challenge is to be able to fully exploit the flexibility of software while guaranteeing performance and dependability (including not distracting the driver).

2.4 Final Results

In many cases the technical achievements for Year 4 are continuations of work presented and described among the results of Year 3, i.e., in the previous section. Rather than repeating the same information we in those cases refer to the corresponding parts of the Year 3 section.

2.4.1 Technical Achievements

Achievement: Control of Server systems (LUND, UIUC, KTH)

The work on control of server systems in LUND has continued. Feedback in server systems has during last year's gained much interest in order to fulfil still increasing demands on performance and optimization regarding, for example, quality of service (QoS) requirements. In [1] Lund expand the feedback-based prediction scheme [2] for controlling a single server queue together with a new control strategy. These control structures have the benefit over other previously suggested control structures that no off-line estimation of the required work is needed. In addition, our solutions maintain or improve the performance, regarding average response time and loss of computational resources. At KTH work has been done on congestion control for small queues [14].

At UIUC Tarek Abdelzaher's group is working on feedback-based QoS control with applications to server systems. They are also developing new theory for real-time schedulability in open distributed systems based on aperiodic utilization bounds and synthetic utilization. The results are applicable to server systems under feedback control. The publications from UIUC are not reported here.

Achievement: Feedback-Based Resource Management in Cellular Devices (Ericsson, LUND)

Lund and Ericsson are continuing their collaboration in the national project "Feedback Based Resource Management and Code Generation for Soft Real-Time Systems". In the project a demonstrator based on dynamic resource control on a web-camera hosting multiple media streams is currently being developed. The support for reservation-based scheduling in the form of control groups within the new Linux kernel is also being investigated.

Achievement: Control and Optimization of Networked Systems (KTH, Ericsson, ABB, LUND)

KTH continues its activities on applying control and optimization to networked systems, and in particular wireless sensor and actuator networks. In this context they also study distributed optimization mechanisms for resource sharing. Part of this is performed in collaboration with ABB in the SOCRADES project and part of it with Ericsson and Swedish Institute for Computer Science (SICS). The work has led to the following publications [3-13, 15-20].

Achievement: Dynamically Configurable Automotive Embedded Systems (KTH, Volvo)

The work on dynamic reconfiguration of automotive embedded systems reported last year has continued and led to several joint publications. This has, however, been reported in the JPIA-Platform deliverable "Design Tools for Embedded Control" since it also relates to that activity.

Achievement: Resource Management

In this work UPVLC focus on dynamic memory management. Dynamic memory management can be considered in the proper way in real time applications due to the availability of dynamic memory allocators with constant allocation and deallocation. This work proposes a framework for handling dynamic memory in real-time systems. The framework provides both a flexible contract negotiation model to adapt the memory allocated to a set of task as closed as the required during the execution. Since UPVLC is doing this work partly in collaboration with the University of York the publications resulting from this are reported in the network activity report Hard RT, ART and Control.

2.4.2 Individual Publications Resulting from these Achievements

Lund

[1] Martin Ansbjerg Kjær, Maria Kihl, Anders Robertsson, "Response-Time Control of a Processor-Sharing System using Virtualized Server Environments", In *Proc. 17th IFAC World Congress*, pp. 3612-3618, Seoul, Korea, July 2008.

[2] Martin Ansbjerg Kjær, Maria Kihl, Anders Robertsson, "Response-Time Control of Single Server Queue", In *Proc. 46th IEEE Conference on Decision and Control*, New Orleans, LA, December 2007. (reported as "to appear" in Year 3 report)

KTH

[3] Björn Johansson, Maben Rabi and Mikael Johansson, A randomized incremental subgradient method for distributed optimization in networked systems, Submitted for journal publication, July 2008.

- [4] Maben Rabi, Luca Stabellini, Alexandre Proutiere and Mikael Johansson, Networked estimation under contention-based medium access, Submitted for journal publication, May 2008.
- [5] Björn Johansson, Alberto Speranzon, Mikael Johansson and Karl Henrik Johansson, On Decentralized Negotiation of Optimal Consensus, *Automatica*, Vol. 44, pp. 1175-1179, April 2008.
- [6] Björn Johansson and Mikael Johansson, Faster Linear Iterations for Distributed Averaging, IFAC World Congress, Seoul, South Korea, July 2008.
- [7] Mikael Johansson, On the source-channel coding trade-off in networked control, IFAC World Congress, Seoul, South Korea, July 2008.
- [8] Björn Johansson, Cesare Maria Carretti and Mikael Johansson, On Distributed Optimization using Peer-to-Peer Communications in Wireless Sensor Networks, Proceedings of IEEE SECON, June 2008.
- [9] Pablo Soldati and Mikael Johansson, A mathematical programming approach to deadline-constrained transmission scheduling in wireless HART networks, Swedish National Control Conference (Reglermöte, Luleå, May 2008.
- [10] Pablo Soldati and Mikael Johansson, A low-signalling scheme for distributed resource allocation in multi-cellular OFDMA systems, Proceedings IEEE Global Telecommunications Conference, March 2008.
- [11] Björn Johansson, Maben Rabi and Mikael Johansson, A Simple Peer-to-Peer Algorithm for Distributed Optimization in Sensor Networks, Proceedings IEEE Conference on Decision and Control, December 2007.
- [12] Anders Gunnar and Mikael Johansson, Robust Routing Under BGP Reroutes, IEEE Global Telecommunications Conference, GLOBECOM, pp. 2719-2723, November 2007.
- [13] Maben Rabi, Luca Stabellini, Peter Almström and Mikael Johansson, Analysis of networked estimation under contention-based medium access, IFAC World Congress, Seoul, South Korea, July 2008.
- [14] N. Möller and K. H. Johansson, Congestion control for small queues: analysis and evaluation of a new protocol. In journal submission.
- [15] L. Bao, M. Skoglund, and K. H. Johansson, Joint encoder–controller design for feedback control over noisy channels. In journal submission.
- [16] C. Fischione, M. Butussi, K. H. Johansson, and M. D’Angelo, Power and rate control with outage constraints in CDMA wireless networks. In journal submission.
- [17] A. Speranzon, C. Fischione, and K. H. Johansson, A distributed minimum variance estimator for sensor networks, *IEEE Journal on Selected Areas in Communications*, 26:4, 609-621, 2008. Special Issue on Control and Communication
- [18] N. Möller and K. H. Johansson, Congestion control for small queues: analysis and evaluation of a new protocol, IEEE CDC, Cancun, Mexico, 2008. To appear.
- [19] A. Seuret, D. Dimarogonas, and K. H. Johansson, Consensus under communication delays, IEEE CDC, Cancun, Mexico, 2008. To appear.
- [20] P. G. Park, C. Fischione, and K. H. Johansson, A simple power control algorithm for wireless ad-hoc networks, IFAC World Congress, Seoul, Korea, 2008.

2.4.3 *Interaction and Building Excellence between Partners*

There are interactions between all core partners in the activity and with several of the associated partners. These are of several types, including participation in the same European projects, joint participation in national projects, participation in meetings organized by this cluster, and joint execution of the Graduate Course on Embedded Control (which includes control of computer systems as one of the topics). Most of the interactions are bilateral or trilateral, with only the joint organization of the Graduate Course involving all the core partners.

The following is a list of the major collaborations, except the Graduate Course on Embedded Systems between partners in the Control in Real-Time Computing activity as well as with partners outside the activity which has contributed to creation of excellence between partners.

Activities within the activity:

- KTH and Volvo are working together within the Dyscas project on Dynamically Configurable Automotive Embedded Systems, together with DaimlerChrysler, Enea, Univ. of Paderborn and Univ. of Greenwich.
- KTH, Lund, and Ericsson are all working on distributed estimation and resource-control in sensor networks and.
- KTH and Ericsson are collaborating on control of communication networks.
- UPVLC and CTU are collaborating on contract-based adaptive reservation techniques within the FRESCOR project together with SSSA/Pisa, UYork, UCantabria, TUKL, Enea, Thales, Visual Tools, Rapita Systems, and Evidence.
- Ericsson and Lund have jointly applied for a Swedish VINNOVA project on Feedback Based Resource Management and Code Generation for Soft Real-Time Systems

2.4.4 *Joint Publications Resulting from these Achievements*

No joint publications to report except the joint publications related to dynamically reconfigurable automotive systems reported in the JPIA-Platform deliverable Design Tools for Embedded Systems.

2.4.5 *Keynotes, Workshops, Tutorials*

Keynote: “Adaptivity in Embedded Systems - Why, What and How”: By Karl-Erik Årzén

Conference name: Workshop on Adaptive and Reconfigurable Embedded Systems (APRES), St Louis, US, April 21, 2008

Workshop: “Embedded Control Systems: From Design to Implementation”, in association with the IFAC World Congress, Seoul, Korea, 6 July, 2008

Summer School: Fourth Artist2 Graduate School on Embedded Control Systems. All cluster members

Location: KTH, May, 2008

Summer School Participation: Four lectures at the ARTIST2 Summer School in Autrans 8-12 September, 2008 were initiated and/or given by the cluster. The presentations were a keynote by Karl Johan Åström, Lund and three presentations by Karl-Erik Årzén and Pedro Albertos, Tarek Abdelzaher (UIUC), and Steve Vestal (Honeywell).

3. Milestones, and Future Evolution Beyond the NoE

3.1 Milestones

The milestones for year 4 as defined in the previous activity report were as follows.

- Increase our international and industrial visibility. A good means for this is through the organization of and the participation in the FeBID workshops.
Achieved. We participated in the organization of FeBID 2008. Årzén is currently co-chair of FeBID 2009.
- Disseminate the total amount of work done during the four years in this activity at Artist and ArtistDesign organized events.
Achieved: The cluster has itself organized events and actively contributed to this year's Artist2 summer school in Autrans.
- Continue our presence at workshops and conferences in the area. *Achieved.*
- Continue the research performed within control of server systems, in control-based reservation management and feedback-based scheduling, on applying control to communication networks and sensor networks, and dynamically configurable embedded systems. *Achieved.*

3.2 Indicators for Integration

The indicator for a successful integration in this area is continued joint work (publications, proposal, etc) on control of embedded computing systems within ArtistDesign and within the related STREP projects ACTORS and FRESCOR.

3.3 Main Funding

The partners have a good funding situation for the coming years. The main sources are:

- Nationally funded projects. These include
 - Lund: The large 10 year VR Linneaus center "LCCC – Controlling Complex Engineering Systems". The VINNOVA project "Feedback Based Resource Management and Code Generation for Soft Real-Time Systems". The VR projects "Control of Server Systems" and "Periodic and Event-Based Control over Networks".
 - KTH: The large 10 year VR Linneaus center ACCESS. The VINNOVA projects reSENSE, WISA II, NECS and SERAN. The VR projects Wireless Control and CoopNets, The Rembrant project together with Scania and Chalmers. The SSF projects NEC and IDIOM. KTH has also created ICES – Innovative Centre for Embedded Systems where among others ABB, Ericsson, Scania, and Enea participate.
 - UPVLC: SIDIRELI: Sistemas distribuidos con recursos limitados. Núcleo de control y coordinación funded by the Ministerio de Ciencia y Tecnología. RT-Model: Plataformas de tiempo real para diseño de sistemas empotrados basado en modelos funded by the Ministerio de Ciencia y Tecnología.
- European projects. The European projects where the partners participate are the following: ArtistDesign (Lund, KTH), SOCRADES (KTH, Ericsson), WIDE (KTH), FeedNetBack (KTH), ACTORS (Lund), CHAT (Lund), AEOLUS (Lund), DIAdvisor

(Lund), ATESSST II (KTH, Volvo Cars, Volvo Technology), DySCAS (KTH, Enea, Volvo Technology), ROSETTA (Lund), Euro-NF (KTH), VIKING (KTH), TECOM/ITEA-2 (UPVLC). Part of these projects are projects that have been accepted but not yet started. KTH is also a member of the ARTEMIS proposal CESAR - Cost-Efficient Methods and Processes for Safety Relevant ES coordinated by Airbus.

3.4 Future Evolution Beyond the Artist2 NoE

The use of feedback to provide performance and robustness in networked embedded computer systems becomes more natural, the more complex and hard to statically analyze the systems are. Since increased complexity and an ever increasing amount of software is one of the most prominent trends in embedded systems today we are convinced that dynamic feedback-based resource management will be increasingly important for the future.

The majority of this work will be continued within the transversal activity Design for Adaptivity led by Karl-Erik Årzén in ArtistDesign. The focus here is software and hardware techniques for providing run-time flexibility in networked embedded systems. These techniques include, but are not limited to, feedback control. A kick-off meeting was held in Lund, 13-14 May, 2008 where several of the members from the Artist2 Control and the ART clusters were present together with partners from the MPSoC cluster in ArtistDesign.

The partners also intend to continue supporting the FeBID (International Workshop on Feedback Control Implementation and Design in Computing Systems and Networks) workshop series (<http://controlofsystems.org/>) and the APRES (Adaptive and Reconfigurable Embedded Systems) workshop series. During 2009 FeBID will be held in conjunction with the Cyber-Physical Week in San Francisco in April with Karl-Erik Årzén as one of the three co-chairs and with several Artist partners as members of the IPC. APRES 2009 is planned to be held in association with ECRTS in Dublin in July.

4. Internal Reviewers for this Deliverable

Anton Cervin, LTH

Alfons Crespo, UPVLC