IST-004527 ARTIST2

Network of Excellence

on Embedded Systems Design

Activity Progress Report for Year 3

JPRA-Network Integration

Adaptive Real-Time, HRT and Control

Clusters:

Control for Embedded Systems

Adaptive Real-Time

Real-Time Components

Activity Leader:

Professor Karl-Erik Årzén, Lund University

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

Policy Objective (abstract)

*The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity an flexibility in embedded systems.*

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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 embedded control systems and 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.

Professor Pedro Albertos – UPVLC (Spain)
Role: Provides expertise on embedded control.

Professor: Giorgio Buttazzo – (SSSA, Pisa)
Role: Provides expertise on adaptive RT techniques

Professor Albert Benveniste – (INRIA)
Role : Provides expertise on embedded real-time systems and components.

Professor Gerhard Fohler – (Univ Kaisersluatern)
Role: Provides expertise on flexible scheduling.

Professor Werner Damm – (OFFIS)
Role: Provides expertise on embedded systems.

Dr Pau Marti – (UPC)
Role: Provides expertise on embedded control.

Prof. Vladimir Kucera – (CTU)
Role: Provides expertise in real-time control

Dr Zdenek Hanzalek – (CTU)
Role: Provides expertise in real-time embedded control and scheduling.

Professor Hermann Kopetz (TU Vienna)
Role: Provides expertise on time-triggered formalisms.

Professor Luis Almeida - (University of Aveiro)
Role: Provides expertise on communication platforms.

Professor Juan Antonio de la Puente - (UP Madrid)
Role: Provides expertise on target application platform and scheduling.

Professor Eduardo Tovar - (Polytechnic Institute of Porto)
Role: Provides expertise on distributed systems and middleware.

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

Starting date = 1 Sept 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. Most of the work performed and the collaborations will also continue after the termination of Artist2 within the new NoE ArtistDesign. The majority of the partners in this activity are also either core partners or affiliated partners in ArtistDesign. The work on the use of control techniques to provide adaptivity and flexibility in embedded systems will be continued within the ArtistDesign network activity “Design for Adaptivity”, led by Karl-Erik Årzén. A difference from now is that partners from all the thematic clusters in ArtistDesign will participate in this new activity. Another difference is that also other, non control-based, approaches to adaptivity will be investigated, including, e.g., hardware-based approaches. The work on computational models and implementation techniques for embedded control systems will not continue as a separate activity. However, control will continue to be an important application class for embedded systems also in ArtistDesign. This will in particular be the case in the new thematic cluster “Operating Systems and Networks” led by Giorgio Buttazzo. Here, all the partners in this activity from the Control cluster and the ART cluster are either core or affiliated partners. However, control will also play an important role in the new ArtistDesign thematic cluster “Modelling & Validation” led by Kim Larsen. For example, there the number one objective is to “establish a coherent family of modelling formalisms spanning the areas of computer science, control, hardware and networks covering all aspects of embedded systems”.

1.4 Baseline

The situation at the beginning of this activity, i.e., at the start of ARTIST2 was the following. A number of projects already allowed some structuring and interaction, e.g., FLEXCON (Swedish national project) *Flexible Embedded Control Systems* involving Lund and Mälardalen), OCERA (European project) *Open Components for Embedded Real-Time Applications*, involving Pavia, UPVLC and CTU, RECSYS (European project) *Real-Time Embedded Control of Mobile Systems with Distributed Sensing* involving KTH, ARTIST (European Accompanying Measure) *Advanced Real-Time Systems* involving a majority of the partners, and FIRST (European project) *Flexible Integrated Real-Time Systems Technology* involving Pavia (Pisa) and Mälardalen.

There also existed strong links between the core partners and the affiliated partners, e.g., between Lund and Ericsson, between Lund, Virginia and Illinois, and between UPC and Mälardalen.

1.5 Problem Tackled in Year 3

The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity and flexibility in embedded systems. Each of the clusters have matching internal cluster activities, e.g., in the Control for Embedded Systems the corresponding cluster activities are Real-time techniques in control system implementations and Control in real-time computing. The activities within the cluster can be characterized as follows. There are strong joint research activities between the ART cluster and the Control cluster. These activities have continued also during Year 3.

The research problems involves both the use of control-techniques in resource scheduling for embedded systems and scheduling techniques and computational models for embedded control applications. These two lines are also combined in the form of feedback-based scheduling of embedded control systems.

During Year 3 the interaction between the Control and the RTC cluster and between the ART and the RTC cluster has been less than during Year 2. Our intention was to organize an industrial workshop, similar to the “Beyond Autosar” workshop together. However, for various reasons this did not happen. One reason is the workshop “Integrated Modular Avionics” already organized by RTC. Adding control as a topic to this workshop was not possible. Organizing another workshop at around the same period was not realistic considering the resources available. Also Karl-Erik Årzén was at the same time organizing both the 3rd Artist2 Graduate School on Embedded Control and the 2nd Interational ARTIST Workshop on Control for Embedded Systems.

Another reason for the lack of interaction has been the proposal preparations for the first Embedded Systems call in FP7 in May. Having STREP and IP projects involving the network of excellence partners is an absolute prerequisite in order to have any real funding for the research to be integrated by the network of excellences. As is turned out also in this work the main connections were between the control and ART clusters.

This does, however, not mean that there is no collaboration with the RTC cluster. Some examples of collaborations and exchanges are:

- Karl-Erik Årzén (Lund) was an invited presenter at the Beyond Software and Control organized by the RTC cluster (co-organized by INRIA) in honor of Paul Caspi, in Grenoble.
- KTH has interacted with several RTC partners (e.g., CEA (within the ATESST project), UU, MdH, Verimag, and PARADES) regarding organizing joint Artist2 workshops; see the tools/platform deliverable for more details. All these cooperations deal with different aspects of model and component development of embedded systems and embedded control systems. KTH, CEA and other ATESST partners have also submitted a proposal for a follow-up project at the last EU call.
- Martin Törngren (KTH) gave an invited talk at the Second International Workshop on Foundations of Component-based Design, Sept. 30, in conjunction with the Emsoft conference, Salzburg. This workshop was arranged by persons from RTC.

Internally within the RTC cluster there is also research being done that very well follows the objectives of this activity. INRIA, PARADES, and VERIMAG have continued their work on architectures for safety-critical distributed control based on the Loosely Time-Triggered Architecture (LTTA). This work has true thematic connections to Control and ART, although it has not been highlighted as such.

During the final year of the aim is to strengthen the connections. Currently under discussion is a jointly organized session for the CDC (Conference on Decision and Control) 2008 on networked control systems that combines the LTTA work from RTC with the approaches and tools from the Control cluster.

1.6 Comments From Year 2 Review

1.6.1 Reviewers' Comments

The reviewers did not have any specific comments concerning 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.

2. Summary of Activity Progress

2.1 Previous Work in Year 1

2.1.1 Work achieved in the first 6 months of Y1

- Kick-off meeting held
- UPVLC (Crespo) has evaluated the performance of the scheduling policies related to offer a constant bandwith behaviour. In conjuntion with SSSA (Lipari), a new version of the CBS called IRIS was developed. This new algorithm was implemented and evaluated in a real-time environment providing both hard and soft real-time constraints. The IRIS algorithm was implemented in RTLinux and included in the distribution of the OCERA project.
- Collaboration between Mälardalen (Fohler) and LUND (Cervin) about the combination of the jitter margin index and flexible scheduling methods.
- CTU studied holistic scheduling methods and analyzed a case study using the MAST tool (Cantabria).
- Karl-Erik Årzén contributed to the Artist2 workshop on diagnosis in Vienna, Dec 20-21, organized by the HRT cluster

2.1.2 Work achieved in months 6-12 of Y1

- The Lund Workshop was held. The interaction between the control cluster, the participants from the ART cluster and the US affiliated partners was very valuable
- In order to add flexibility to the real-time applications UPVLC has developed a nanokernel called Xtratum. XtratuM is a thin layer of software that provides a simple and convenient API to access interrupt mechanims and timer devices. Xtratum permits the execution of environments/applications spatial and temporal isolated. Xtratum has been developed under the OCERA project.
- Collaboration between LUND (Cervin) and Pavia (Buttazzo) about the use of the Shark real-time kernel as a shared platform for implementing control applications.
- Collaboration between LUND (Cervin) and Ericsson (Eker) on distributed versions of the control server model
- A collaboration between UPC (Marti), Mälardalen (Fohler) and LUND on feedback scheduling of control system has been initiated
- CTU has built up several demonstrators for communication components based on the OCERA architecture (UPVLC, SSSA, CTU) including fish breeding control and supervision system (process control application), remote programming of mobile robot (robotics and supervision), human machine interface for autogiro (data acquisition and visualization), robotic arm demonstrator (servocontrol).
- Interaction between CTU and Aveiro (Almeida) on deadline constrained scheduling on FPGAs and multicast traffic optimization.

2.2 Previous Work in Year 2

Achievement: Organization of Workshop

The workshop **Interaction between control and embedded electronics in automotive industry** was jointly organized by the RT Components and the Control clusters in Innsbrück, March 23. It was co-locacted with the Beyond AUTOSAR meeting organized by the network activity "Forums with Specific Industrial Sectors". Three invited presentations were given by Stefan Kowalevski (RWTH Aachen), Karl-Erik Årzén (Lund University), and Carlos Canudas de Wit (LAG Grenoble) followed by a panel discussion. A more detailed description of the content and focus of the presentations is given in the activity report of the "Forums with Specific Industrial Sectors" activity. Several conclusions can be drawn:

- There is a permanent misunderstanding between control & software engineers in the automotive industry
- Regarding the relative merits of ET/TT, control design aspects provide complementary views, not considered in the embedded design community. For example, in general a long but constant controller input-ouput latency is worse from a control performance point of view than a shorter but time-varying latency, also if the former constant latency is taken into account in the control design.
- The control systems in automotive systems are often structured in a multi-layer or multi-cascade fashion. This further increases the need to minimize the input output latency and puts special requirements on component-based architectures. For example, it is important to organize the computations in such a way that first only the parts of the controller components that are needed for the generation of the component outputs are calculated and then, afterwards, the parts of the components that are responsible for updating the state of the controller components are calculated. This is someting that is well-known within the field of process automation, but for some reason has not yet spread to, e.g., the automotive systems area
- In an automotive system there is only a limited amount of sensors and actuators. Both the sensors and actuators are typically used by several control systems or control functions. In an integrated system it is important to make it possible for several functions to use the same physical sensors and actuators, rather than, e.g., use several sesnors to measure the same physical entity, something which is not uncommon in federated architectures. Hence sensor and actuator component should have a special role in a component-based automotive system.
- Today, the structure of the control systems in an automotive system is to a large degree derived from the constraints of the federated system architecture. In an integrated system new possibilities for structuring the control systems open up. Hence, it would be worthwhile to take a completely new look upon how the overall control system for a car ought to be structured, including powertrain control, chassis control, safety systems, etc.

Achievement: Joint Research Activities Involving the ART and the Control Cluster

The joint research initiatives that were started during Y1 have continued. These include

- Anton Cervin (Lund) and Giorgio Buttazzo (Pisa) have worked on a comparison of jitter reduction techniques for control tasks. When implementing a controller in a multitasking operating system, there is a risk that the control loop will experience delay and jitter due to preemption from other tasks. Several jitter control methods have been proposed in the literature, and they all have different strengths and weaknesses with respect to timing and control performance. In this work, we have compared and evaluated four

different task models: the Standard Task Model (STM), Reducing Jitter by Task Splitting (RJTS), Reducing Jitter by Advancing Deadlines (RJAD), and Reducing Jitter by Non Preemptive Execution (RJNP). It is found that RJTS is good for jitter reduction, but introduces a long delay which gives sluggish control performance. RJAD works well for reducing both jitter and delay, and gives good control performance in most cases. RJNP reduces input-output jitter to a minimum but may cause some tasks to miss their deadlines. A conference publication describing this joint work is under preparation and a technical report is available [3].

- Lund (Cervin) and Pisa (Bini) are working on optimal period selection for multiple controllers under fixed-priority scheduling. Traditionally, when scheduling controllers, it has been assumed that the deadline of each control task is less than or equal to its period. Under fixed-priority (FP) scheduling, this typically implies that the processor cannot be fully utilized. In this work, we have explored what control performance is possible to gain by moving outside the FP schedulability bound. Utilizing a simple upper bound on the response time of a task, the input-output delay can be bounded. Combining this bound with an approximate expression for the control performance (as a function of the rate and the delay of the controller), the optimal task periods can be found by solving a constrained optimization problem. For certain simple cases, exact analytical solutions can be found. A publication describing this joint work is under preparation.
- UPC (Marti, Selga) and Lund (Henriksson, Cervin) have worked on feedback-based scheduling of linear controllers with varying disturbance intensities. In previous work from Lund 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 [1] 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 this work, 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. The project has included a PhD student visit from UPC to Lund: Rosa Castañe spent 5 months (from August 2005 to December 2005) in Lund. In addition, several working meetings have taken place during 2006, in Pisa, March 2006 and Dresden, June 2006.
- Lund (Cervin) and Mälardalen/Univ Kasierslautern (Moris, Isovic, Fohler) have continued the work on flexible scheduling of controllers based on the jitter margin. The work combines two previously developed tools and techniques for flexible real-time systems: the jitter margin and the slot-shifting algorithm. Using the jitter margin, it is possible to guarantee a level of a performance of a controller, given bound on the worst-case input-output jitter. On the other hand, the slot-shifting technique can be used to allow sporadic tasks to execute at the cost of more jitter for the periodic tasks. In this work, an off-line design method based on simulated annealing has been devloped that tries to find an optimal schedule such that all control tasks meet their performance specifications, while at the same time allowing as many sporadic tasks as possible to execute. The work has resulted in the Master Thesis [2] which recently received the price for the best Swedish Master Thesis in the field of Real-tIme and Embedded systems during 2005-2006.
- Several of the groups have focused their activities on the SHARK kernel and the TrueTime tools as common platforms for feedback-based scheduling work. In Lund a project has started in which the suitability of using SHARK in control laboratories will be

investigated. UPC has modified the Truetime simulator to better study new feedback scheduling theoretical results [4]. UPC has also added new features to Shark to allow easy implementation of feedback scheduling [5].

- A strong research connection is currently being established between CTU and UPCLC in the Control cluster and UCantabria, Pisa, and UYork in the ART cluster. This is funded through the FRESCOR project. Here several activities are currently being initiated, e.g., the implementation of contract-based kernels for embedded systems. Both CTU and UPVLC also participated in the ARTIST2 requirements workshop (Paris June 16 2006).

Achievement: Joint Summer School

The summer school Firrst European Laboratory on Real-Time and Control for Embedded Systems was organized in Pisa, Italy, July 10-14, 2006. The number of participants were 40. http://www.artist-embedded.org/FP6/ARTIST2Events/Events/RT-Control/

2.3 Current Results

Achievement: Organization of 2nd International Artist2 Workshop on Control for Embedded Systems

The 2nd International Artist2 Workshop on Control for Embedded Systems was successfully organized in Urbana-Champaigne at Univ of Illinois with Tarek Abdelzaher as the local host. The topics of the workshop were Real-Time and Control in Sensor/Actuator Networks, Control in Cyber-Physical Systems, Event-Based Control and Computing, and Control of Software Errors. The workshop activity was intended and planned as a network activity. However, due to two unfortunate late cancellations from participants from the ART cluster, we ended up with Artist2 participants representing only the control cluster (Lund, KTH, UPVLC, and the international associated partner UIUC). However in spite of this the workshop was very valuable.

The number of participants was 20, excluding PhD students. Out of these six were fom Europe. The US control community was represented by Bruce Krogh, Geir Dullerud and Michael Lemmon. The US real-time systems community was represented by Lui Sha, Tarek Abdelzaher, Marco Caccamo, P.R. Kumar, and Chenyang Lu. Industry was represented through Microsoft and PARC. The conclusions from the workshop are available as a separate document available through

http://www.artist-embedded.org/artist/-Control-for-Embedded-Systems,810-.html

Achievement: Joint Research Activities Involving the ART and the Control Cluster

The joint research initiatives that were started during Y1 have continued also into Y3. These include:

- The joint work between Lund and SSSA/Pisa on jitter reduction methods for control system applications has continued [11] and has been extended to also include Halmstad University [2,3].
- TUKL and Lund have recently started working on a control-based evaluation infrastructure for combined offline and online scheduling. The Truetime tool of Lund is used as an initial basis for this work.

- Aveiro and UPC are working together on dynamic rate and control adaptation in networked control systems [13,14,15]. The TrueTime tool from Lund is used as the simulation platform for this work. In particular they study dynamic rate adaptation in simple microcontroller-based computer control systems, maximizing the admitted load in such systems while minimizing the control performance degradation. They also work on minimizing the resources (computing and communicating) consumed by a feedback control loop using a dual-rate (dual-controller) approach, i.e., one nominal controller and a low bandwidth one, for periods of near stationarity.
- CTU and Porto have worked together on simulation of wireless radio protocols [12]. The IEEE 802.15.4 protocol has the ability to support time-sensitive Wireless Sensor Network (WSN) applications due to the Guaranteed Time Slot (GTS) Medium Access Control mechanism. Recently, several analytical and simulation models of the IEEE 802.15.4 protocol have been proposed. Nevertheless, currently available simulation models for this protocol are both inaccurate and incomplete, and in particular they do not support the GTS mechanism. In this paper, we propose an accurate OPNET simulation model, with focus on the implementation of the GTS mechanism. The motivation that has driven this work is the validation of the Network Calculus based analytical model of the GTS mechanism that has been previously proposed and to compare the performance evaluation of the protocol as given by the two alternative approaches. Therefore, in we provide an accurate OPNET model for the IEEE 802.15.4 protocol. Additionally, and probably more importantly, based on the simulation model we propose a novel methodology to tune the protocol parameters such that a better performance of the protocol can be guaranteed, both concerning maximizing the throughput of the allocated GTS as well as concerning minimizing frame delay.
- UPC and Lund are working jointly on feedback scheduling of real-time control tasks. A theoretical framework for feedback scheduling of real-time control tasks was reported in last year's deliverable. This year the work has focused on implementing a case study at UPC to show the validity of the theoretical approach. The experimental implementation corroborates the simulated results reported last year.
- A strong research connection is currently being established between Ericsson, Lund, SSSA/Pisa, TU Kaiserslautern, and Evidence though the new FP7 STREP project ACTORS (Adaptivity and Control of Resources in Embedded Systems) that recently has been approved. The project also contains two non-ARTIST2 partners and has Xilinx US as an associated partner. The goal of the project is to combine reservation-based scheduling, data-flow actors-based programming models, and feedback control for control and media processing applications on Linux-based multicore platforms and FPGA platforms. The project will formally start 1 Dec 2007, but the preparations for the project started already in February 2007.
- The integration between the control cluster and the ART cluster will continue within the new FP7 NoE ArtistDesign. Most of the current partners of the control cluster and the ART cluster will be either core partners of associated partners in the ArtistDesign OS and Networks cluster.
- During the HSCC conference in Pisa in April 2007 a special meeting was held involving several partners in this activity, on the topic Future trends on Networked and Embedded Control Systems. The participants were Michael Lemmon (University of Notre Dame, Indiana, USA), Paulo Tabuada (University of California at Los Angeles, California, USA), Giorgio Buttazzo (University of Pisa, Italy), Enrico Bini (University of Pisa), Anton Cervin (University of Lund), Manel Velasco (Technical University of Catalonia) and Pau Martí (Technical University of Catalonia). After reviewing the state-of-the-art on Networked and Embedded Control Systems, several topics were discussed. One of the clear conclusions was that event-based scheduling, or

alternatively event-based control, is a major trend that should be further studied because it has the ability of dramatically saving computing resources while guaranteeing acceptable control performance.

2.3.1 *Individual Publications Resulting from these Achievements*

The individual publications from the core partners of the control cluster and the publications by UPC are reported in the cluster activity reports from the respective cluster.

SSSA/Pisa

[1] Gianluca Franchino, Giorgio Buttazzo, and Tullio Facchinetti, "BuST: Budget Sharing Token Protocol for Hard Real-Time Communication", Proceedings of the 12th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2007), Patras, Greece, September 2007.

[2] Hoai Hoang and Giorgio Buttazzo, "Reducing Delay and Jitter in Software Control Systems", Proc. of the 15th International Conference on Real-Time and Network Systems, Nancy, France, March 29-30, 2007.

[3] Hoai Hoang, Giorgio Buttazzo, Magnus Jonsson, and Stefan Karlsson. Computing the Minimum EDF Feasible Deadline in Periodic Systems. Proceedings of the 12th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, Sydney, Australia, August 2006.

Aveiro

[4] A. Antunes, P. Pedreiras, L. Almeida, A. Mota. Improving Operational Flexibility in Distributed Control Systems: The Dynamic Rate Adaptation Technique. Automazione e Strumentazione. Anno LV, Nº2, pp:90-97. VNU business publications, Italia, February, 2007.

[5] A. Antunes, P. Pedreiras, L. Almeida, A. Mota. Dynamic Rate and Control Adaptation in Networked Control Systems. INDIN 2007, 5th IEEE Conference on Industrial Informatics, Vienna, Austria, July 2007.

[6] A. Antunes, P. Pedreiras, L. Almeida, A. Mota. Dynamic Rate Adaptation: a method to improve operational flexibility in distributed control systems (poster). FeBID 2007, 2nd IEEE Workshop on Feedback Control Implementation and Design in Computing Systems and Networks. Munich, Germany, May 2007.

[7] A. Antunes, P. Pedreiras, L. Almeida, A. Mota. Dynamic Rate Adaptation in Distributed Computer Control Systems. ANIPLA 2006 - International Congress of the Italian National Association for Automation, Rome, Italy, 13-15 November, 2006. (best paper award; selected for journal publication)

INRIA

[8] A. Benveniste, P. Caspi, P. Le Guernic, H. Marchand, J-P. Talpin, and S. Tripakis. ``A Protocol for Loosely Time-Triggered Architectures". In *Proc. of 2002 Conference on Embedded Software, EMSOFT'02*, J. Sifakis and A. Sangiovanni-Vincentelli, Eds, LNCS vol 2491, 252--265, Springer Verlag.

[9] A. Benveniste, B. Caillaud, L. Carloni, P. Caspi, A. Sangiovanni-Vincentelli. Communication by Sampling in Time-Sensitive Distributed Systems. In *Proceedings of the Sixth Annual ACM Conference on Embedded Software, EMSOFT'06*, 2006.

[10] A. Benveniste, P. Caspi, M. Di Natale, C. Pinello, A. Sangiovanni Vincentelli, and S. Tripakis. Loosely Time-Triggered Architectures based on Communication-by-Sampling. IRISA Research Report Nr 1854, June 2007, and *Proc. of EMSOFT'07*, Oct. 1-3, 2007.

2.3.2 Interaction and Building Excellence between Partners

There are interactions between several of the core partners in the activity and with several of the associated partners. These are of several types, including participation in the same European project, joint participation in national projects, and participation in meetings organized by this cluster.

Most of the interactions are bilateral or trilateral, with only the joint organization of the Graduate Course involving all the core partners. The reason for the difficulties of integration all the partners is explained in the corresponding cluster report.

The following is a list of the major collaborations 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:

- Lund and SSSA are collaborating on jitter reduction techniques for embedded control. This also involves Halmstad University. The result is published in one joint paper.
- TUKL and Lund have recently started working together on control-based evaluation of scheduling schemes, see above.
- Aveiro and UPC are collaborating on dynamic rate adaptation in networked control systems. This has led to three joint publications.
- CTU and Porto have worked together on simulation of wireless radio protocols. This has led to one publication.
- UPC and Lund are working jointly on feedback scheduling of real-time control tasks.
- Ericsson, Lund, SSSA/Pisa, TU Kaiserslautern, and Evidence are collaborating within the context of the new FP7 STREP project ACTORS on control-based reservation-scheduling in soft embedded systems. In this project also EPFL and AKATech participate, plus Xilinx US as an associated partner.
- The collaboration between CTU and UPCLC in the Control cluster and UCantabria, Pisa, TUKL, and UYork in the ART cluster within the FRESCOR project.
- The collaboration that led to the ArtistDesign proposal, which involves a majority of the partners in the acivity.

In addition to this all of the partners have collaboration outside the scope of this activity, both with partners in Artist2 and partners outside Artist2.

2.3.3 Joint Publications Resulting from these Achievements

[11] Giorgio Buttazzo, Anton Cervin. Comparative Assessment and Evaluation of Jitter Control Methods. In Proc. 15th International Conference on Real-Time and Network Systems, Nancy, France, March 2007.

[12] Petr Jurcik, Anis Koubaa, Mário Alves, Eduardo Tovar, Z. Hanzalek: A Simulation Model for the IEEE 802.15.4 protocol: Delay/Throughput Evaluation of the GTS Mechanism, to be published in the 15th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS´07), Istanbul, Turkey, October 2007.

[13] Ricardo Marau, Pedro Leite, Luis Almeida, Manel Velasco, Pau Mart´i, Josep M. Fuertes. Performing Flexible Control on Low Cost Microcontrollers using a Minimal Real-Time Kernel. Submitted to IEEE Transactions on Industrial Informatics.

[14] M. Santos, L. Almeida, J. Fuertes. Design Space of a Dual-Rate Switching Controller. CONTROLO 2006, Lisboa, Portugal, September 2006.

[15] M. Santos, L. Almeida, J. Fuertes. Dual-Rate Switching Control. Submitted to Control Engineering Practice.

2.3.4 Keynotes, Workshops, Tutorials

The keynotes, workshops and tutorials related to this activity have all been reported as parts of the three involved cluster's internal cluster activity reports.

3. Future Work and Evolution

3.1 Problem to be Tackled over the next 12 months (Sept 2007 – Aug 2008)

The activity will continue the joint research projects that already have started. These mainly involve the Control and the ART cluster. We will put stronger emphasis on dissemination of the total amount of work performed than previous years. Our aim is also to organize a new industrial workshop during the late Spring 2008.

3.2 Current and Future Milestones

Year1: Setting the technical background and assess the needs (Achieved 100%)

Year2: Demonstrate that applications of diverse type can be specified in terms of resource aware tasks (Achieved 80 %)

The work within the activity has focused on two application types only: multimediaapplications and real-time control. Within these two broad application areas, several types ofapplication have, however, been studied. These two application types are also the ones thatare most natural for these techniques.

Update Milestone for Year3:

- Demonstrate that scheduling algorithms can be made adaptive by means of control schemes *(Acheived 50%) This is a quite general milestone that is fulfilled through the joint and individual research performed by the partners.*
- The organization of a new industrial workshop along the lines of the workshop organized jointly with the Beyond AUTOSAR activity
  (Not achieved) Due to lack of time from the key personnel this milestone has been pushed into Year 4.
- The organization of a follow-up research workshop to the Lund Workshop on Control for Embedded Systems held in June 2005. The workshop is currently planned for Jan-Feb 2007
  (Achieved 100%)

Updated Milestones for Year 4:

- The organization of a new industrial workshop along the lines of the workshop organized jointly with the Beyond AUTOSAR activity
- Disseminate the total amount of work done within this activity at Artist organized events.
- Continued joint and individual research along the lines of the roadmaps developed during Year 1-2. This includes research on control of server systems, control-based resource management, and interactions between control, scheduling and networking, including feedback scheduling-based approaches.
- Coordinate and help to disseminate the results generated by the EC projects FRESCOR and ACTORS which both can be seen as continuations of the work done within this network activity.

3.3 Indicators for Integration

Joint research work visible through joint publications, mobility of team members among the teams, joint transfer of results to industry, and jointly organized workshops and sessions.

The results obtained by combining the forces of the hard real-time, adaptive real-time and embedded control communities within ARTIST2 will make a strong contribution to the advancement of the state-of-the-art in this field.

3.4 Main Funding

The main sources of funding for this work are:

- Nationally funded projects. For the Swedish partners these include grants funded by the Swedish Research Council, the Swedish Foundation for Strategic Research, VINNOVA and the Swedish Programme Council for Vehicle Research. For example during 2007 LUND has obtained one new project from the Swedidh Resarch Council on control of server systems and one new VINNOVA project om feedback-based resource management. For the partners from other countries the situation is similar.
- EU projects. The following are examples of currently running or recently completetd EU FP6 projects that to some extent cover these acivities: RUNES, SOCRADES, DYSCAS, CEMACS, and FRESCOR.
- New EU FP7 projects. These include the ArtistDesign NoE and ACTORS.

4. Internal Reviewers for this Deliverable

Pau Martí, UPC