IST-004527 ARTIST2
Network of Excellence
on Embedded Systems Design

Activity Progress Report for Year 3

JPRA-Cluster Integration

Real-Time Techniques in Control System Implementation

Clusters:

Control for Embedded Systems

Activity Leader:

Professor Alfons Crespo, Universidad Politécnica de Valencia

http://www.gii.upv.es/personal/acrespo/

Policy Objective (abstract)

The overall objective for this activity is to advance the state of the art in applying real-time system methodology for embedded control system implementation. This report summarizes the achievements obtained during the third year of the network.

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1. Overview of the Activity

1.1 ARTIST Participants and Roles

Professor Pedro Albertos – UPVLC (Spain)
Role: Provides expertise in control systems.

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

Professor Karl-Erik Årzén – LUND (Sweden)
Role: Provides expertise on real-time control.

Ass. Prof. Anton Cervin – LUND (Sweden)
Role: Provides expertise on real-time techniques.

Ass. Prof. Patricia Balbastre – UPVLC (Spain)
Role: Provides expertise on scheduling and real-time techniques

Prof. Martin Törngren – KTH (Sweden)
Role: Provides expertise in development methodology, co-design of control and computer systems.

Ass. Prof. Zdenek Hanzalek – CTU (Czech Republic)
Role: Provides expertise in co-design theory

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1.2 Affiliated Participants and Roles

Göran Arinder – ABB Automation Technology Products (Sweden)
Role: Provied feedback and input from the industrial automation sector.

Prof. Vladimir Havlena – Honeywell Prague Labs (Czech Republic)
Role: Provied feedback and input from the industrial automation sector.

Dr Jakob Axelsson – Volvo Car Corporation (Sweden)
Role: Provied feedback and input from the automotive sector.

Magnus Hellring – Volvo Technology (Sweden)
Role: Provied feedback and input from the automotive sector.

Joachim Stroop – dSpace (Germany)
Role: Provied feedback and input from the automation sector.

Klas Engwall – Maquet Critical Care (Sweden)
Role: Provied feedback and input from the medical equipment sector

1.3 Starting Date, and Expected Ending Date

The activity started September 1, 2004. This activity should provide techniques to improve the performances of real-time embedded control systems. The activity will run over the entire life-time of Artist2. Part of this work will also continue within the OS and scheduling cluster of ArtistDesign.

1.4 Baseline

Each of the core teams has a long tradition of research within real-time and embedded control. The work that is under development within this cluster is based on the work previously carried out by the partners in integrated control and scheduling methods, temporal robustness in control systems, methods for handling delays and jitter in control loops, component technologies for control systems, domain-specific languages and computational models, implementation-aware control system design, and real-time computing platforms for control applications.

1.5 Problem Tackled in Year 3

During the third year the main activity has been joint and individual research projects along the lines of the the roadmap and research agenda developed during the first year. The specific research problems investigated are discussed in more depth in Section 2.3.

1.6 Comments From Year 2 Review

No particular comments related to this activity have been given.

2. Summary of Activity Progress

2.1 Previous Work in Year 1

Since this a rather new research area it was decided that the main integration activity during the first year 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 roadmap consists of approx 60 pages.

Another important integration activity was the 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 collectively as the output from the workshop.

A third important integration activity was the Valencia Graduate Course on Embedded Control Systems in April where all the cluster members lectured and the course material was developed jointly.

Additionally, a number of civilities have been performed.

- RTC 2005, a workshop on real-time control and control of real-time computing systems was organized in association with ECRTS 05 at Mallorca.
- An invited session on control over sensor networks and control of sensor network resources (co organized with RUNES) was accepted for the IEEE Conf on Decision and Control and the European Control Conference, Sevilla, Dec 2005.
- An invited session about the research in the cluster was organized at the IFAC World Congress, Prague, July 8.
- The IFAC Summer School on Control, Computing and Communication, Prague, June 27 – July 1 was co-organized by the cluster. A special session on Model Driven Engineering at Euromicro, Porto, August 30 – September 3 was organized by the cluster.
- A number of quality publications have been produced by the members of the cluster during the year. For example, Årzen and Cervin are co-authors of the RTSS 25 year anniversary article "Real-Time Scheduling: A Historical Perspective" (has appeared in the Real-Time Systems journal). Several of the cluster members are also authors of chapters in the recently published "Handbook of Networked and Embedded Control Systems" (Birkhäuser), with Årzén in the editorial board

2.2 Previous Work in Year 2

Achievement: Dissemination of Roadmap Material

The dissemination of the Roadmap on "Real-Time Control Techniques Implementation" has been performed in several conference papers and courses. However, the complete roadmap has yet not been disseminated. The second edition of the Embedded Control Systems Graduate Course held in Prague April 3-7 2006, provided the opportunity to deliver the Roadmap to the community and to extract the main issues in form of lectures. Additionally, several papers have been presented in different workshops and conferences.

Achievement: Scheduling and control co-design techniques

Two main activities have been developed under this main goal:

- Jitter reduction models
- Evaluationb of different controller task models.

Jitter reduction models. In order to reduce the jitter in control systems several activities have been carried out:

- Probabilistic analysys of the response time of a control task. The response time probabilistic analysis is focused on calculate the response time distribution of a periodic task without simulating all over the hyperperiod (H). Some preliminary results have shown that the response time distribution in the interval [0,t] with t<H is very close (with a low error) to the response time of the task in [0,H]. This behaviour can be observed for any periodic system. However, the window [0,t] is different for every task set. The future work is focused on two ideas of how to find the parameter t:
  - Using relationships between temporal parameters of tasks (C,D,P). We have developed a method to calculate t that achieves a response time distribution very close to the total distribution with an error less than 0.25% and a reduction factor (t/H) of 74%.
  - Using statistical theory to calculate the size of the sample t that represents the population (H).
- Deadline minimisation. The deadline minimisation is used to strongly reduce jitter of control tasks, in a real-time control application. Task periods are usually set by the system requirements, but deadlines and computation times can be modified in order to improve system performance. Sensitivity analysis in real-time systems is focused on changes in task computation times, using fixed priority analysis. The aim of this work is to provide a sensitivity analysis for task deadlines in the context of dynamic-priority, pre-emptive, uniprocessor scheduling. This work permits to obtain a deadline minimisation method that achieves the maximum reduction. As undertaken in other studies concerning computation times, we also define and calculate the critical scaling factor for task deadlines.

Evaluation of different controller task models. A simulated system consisting of three independent plants with different initial parameters has been used to compare the performance when different methods to reduce the jitter are applied. The system is controlled by a computer with limited computational resources. So, a linear digital controller is designed for each plant. The three plants are implemented as real-time tasks such that the overall control performance is optimised. The methods compared are results of the partners previous proposals as:

- STM: Typical task's model. Each task controls one pendulum.
- CO_US: Lund model.
- IMF: UPVLC model.
- ICOFU: Hybrid system between CO_US and IMF. Integrated model proposed by Lund and UPV.

Achievement: Control kernel

The control kernel deals with the essential control activities to guarantee the safe behaviour of the complete system. For this purpose, the control software can be arranged in different layers. At the level of the OS, activities to closing the loop and driving the system to a safe position should be included. At the top level, the control system may include several on-line controller options as well as supervising and optimising activities.

The functionalities of the Control kernel can be summarized as follows:

1) Ensuring control action (CA) delivering: the control action has to be delivered in time even if the calculated action for this period has not been updated. In this case, a backup control action or a safe control action based on previous data has to be delivered.

2) Data acquisition of major signals: Data is acquired based on the appropriate rate, delays on data acquisition can not produce delays in the system. From this point of view, it is considered better a past data than a delayed data and no new control action computation is required (the previous control action computation is still valid.

3) Transfer to new control structure: Control system provides several regulators that can be used in different situations.

4) Communication facilities: Communications with external devices should be fully supported by the control kernel.

The work carried out has been focused in the definition of the parameters to define the platform support and the implementation of the control kernel.

Achievement: Operating system support for embedded systems

The development of specific services in the operating system for embedded control systems is one of the issues to be considered in this activity. These services include:

- Specific scheduling policies related to the proposed task model to minimise the output jitter.
- Control middleware which includes services to support the control kernel concept and functionalities.
- Supervisor to support several execution environments or domains
- Memory management in embedded systems with memory constraints.

Two main results have been obtained:

- XtratuM: It is a supervisor which permits to create different domains spatial and temporal isolated. Currently, a domain is based on control applications based on Partikle and the other one is Linux.
- Partikle: It is a new real-time kernel which includes specific services for control systems. The kernel concept has been implemented as a Control middleware.

Achievement: Developments in Sporadic Event-based control

Normally, controllers are designed assuming equidistant (periodic) sampling. This simplifies the design process greatly, since the sampled plant description becomes a linear time-invariant (LTI) discrete-time system (assuming that the continuous plant was also LTI). However, other sampling schemes could be beneficial. From a computing or network point of view, it makes sense to only sample or control when something significant has occured in the system. In this work, we have investigated sporadic control of a first-order system, and compared the resulting performance and resource usage with ordinary periodic control and with aperiodic control which has been studied before by Lund. It is found that some performance can be gained even in the case where the sporadic controller is only allowed to sample more seldom than the periodic controller.

Achievement: Optimal on-line scheduling of multiple state feedback controllers

Digital controllers are usually designed as periodic tasks that regularly perform their sampling, computation, and actuation activities. In severely constrained systems, a better approach might be to only control one plant at a time. In this work, we have proposed a nonpreemptive on-line scheduling policy that uses the measured state of each plant when deciding which plant to control. Deriving the scheduling policy is very time-consuming but can be done off-line, using a technique called relaxed dynamic programming. We have also compared the nonpreemive on-line policy against common periodic schemes on a set of real laboratory processes. The results show that the new scheme can give large performance improvements while at the same time allowing the background tasks run when the need for control is small.

Achievement: Scheduling of control calculations on FPGAs

To facilitate the FPGA design process CTU works on scheduling algorithms using very universal model, where tasks are constrained by precedence delays and relative deadlines. The precedence relations are given by an oriented graph, where tasks are represented by nodes. Edges in the graph are related either to the minimum time or to the maximum time elapsed between start times of the tasks. The NP-hard problem of finding an optimal schedule satisfying the timing and resource constraints while minimizing makespan C_{max}, is being solved using several approaches. The first one is based on Integer Linear Programming, the second one is implemented as a Branch and Bound algorithm, the third one on budget-like heuristic algorithm and the fourth one on EDF-like heuristic algorithm.

Achievement: Time-Delay compensation

In practical digital implementation of any controller, delays appear due to transport phenomena, computation of the control input, time-consuming information processing in measurement devices, etc. The area of control of delayed systems has attracted the attention of many researchers in the past few years because delays may be responsible for instabilities in closed-loop control systems. In order to cope with these delays, a number of algorithms have been reported.

The algorithm proposed by UPVLC is a discrete-time controller based on state feedback using the prediction of the state. A convergence analysis shows that the state converges to the origin in spite of uncertainties in the knowledge of the plant parameters, the system delay and even variations of the sampling period. The proposed control scheme also has been satisfactory implemented to control the yaw displacement of a real four-rotor mini-helicopter. The experimental validation has been developed on an embedded system, MaRTE OS, which allows the implementation of minimum real-time systems according to standard POSIX.13 of the IEEE.

After these first results, we considered it would be also interesting to study the possibility to obtain some scheme in the framework Smith Predictor able to cope with unstable system and easy to implement in an embedded system. As a result it has been proposed a new scheme of prediction for discrete time systems, easy to implement, such as it is required by embedded system that allows any control both for stable or unstable systems. In the scheme proposed, the undelayed output of the plant is estimated by combining the outputs of both a finite impulse response (FIR) filter for the process input and a stable filter for the process output. Thus, the estimation is stable even for unstable plants. The proposed structure is analyzed in order to show the stability and robustness to control unstable plants with long delays. Robust performances to reject step load disturbances are also analyzed, and a refinement is introduced to improve the controlled plant robustness against disturbances. The proposed scheme, based on a New Smith Predictor (NSP), has been compared with other recently published works. It can be seen that it has better robustness and control performances to reject load disturbances.

The initially proposed output estimator does not work for non-minimum-phase plants, as the output filter becomes unstable. Thus, for unstable non-minimum-phase plants, the control problem is solved in two steps. First, the system is stabilized and then, a conventional SP is used to design the global control. One very important improvement over the previous methods is that, in any case, the tuning of the controllers is made by considering a free-delay model of the plant. This work has been performed in collaboration between UPVLC and LUND. Pedro Garcia has spent the two summers 2005 and 2006 in the control group at LUND.

2.3 Current Results

2.3.1 Technical Achievements

The results generated in this activity consist of technical achievements and jointly organized events. Technical achievements have been done within the areas Java-based embedded control, control kernel implementation, scheduling and control co-design, timed automata modelling of embedded control systems, event-based control, FPGA scheduling of control loops, compensaton for time delays, wireless networked control, and embedded control case studies.

In addition, Bridgit, a repository of embedded control benchmarks has been set up by CTU. Our ambition is to include case studies where both the control design aspects and the implementation aspects are illustrated. The case studies typically contain simulation models of the physical processes in Simulink together with control designs. The intention is that the case studies should be used in education. During this year two cases have been added, a helicopter benchmark from CTU and a truck benchmark from KTH, see

http://dce.felk.cvut.cz/hanzalek/bridgit/

Achievement: Operating system and language support for embedded control systems

Embedded Control and Real-Time Java (LUND, ABB)

Lund has in collaboration with ABB and Sun investigated embedded controller implementation for industrial robots using Sun Java Real-Time System (RTS) 2.0 [36,37]. A motion control system and a robotics application have been implemented entirely in real-time Java for an ABB IRB 340 industrial robot, using standard computer hardware, off-the-shelf etherCAT servo drives, and the Sun JAVA RTS 2.0, running on Solaris 10. This new implementation of RTSJ introduces a new real-time garbage collector (RTGC) making it possible to access the heap for critical control applications. That allows a much cleaner system design, as the real-time and non-real-time parts of the application can share the same reference space. The RTGC implementation is based previous work done at LUND.

OS and Control Kernel Implementation (UPVLC)

This activity line is in charge of the implementation of the theoretical developments. The implementation concerns the operating system level (basic functionalities for embedded systems) and a control middleware (Control Kernel). At the operating system level, some services to improve the memory management including an integrated quality of service of CPU and memory have been proposed.

On the other hand, a middleware specially designed for control purposes and interacting with the peripherals (sensors, actuators and communication channels), with the OS, and exchanging information with the control algorithms implemented for different control loops in the application area in the same CPU has been designed and implemented.

This control kernel based on a middleware architecture provides to the control application basic features involving input/output, fault tolerance, relialability, etc. This work is reported in [10-16]

Achievement: Scheduling and control co-design techniques (UPVLC, LUND)

Adjustment and analysis of periodic task parameters is one of the issues related to Real-Time Control in order to increase the control performance and reduce the system degradation. The parameters considered are

- Deadlines: The deadline minimization permits the reduction of the control task jitter. The aim of this work is to provide a sensitivity analysis for task deadlines in the context of dynamic-priority, pre-emptive, uniprocessor scheduling. The work permits a reduction of the deadline of a set of tasks mantaining system schedulability. Publications [1,2,57] analyse and propose new schemes to improve the system performance. Research considering period and deadline reduction in a coordinated way is on going.

- Computation: Feasibility tests for hard real-time systems provide information about the schedulability of the task set. However, this information is a yes or a no answer, that is, whether the task set achieves the test or not. From the real-time system design point of view, having more information available would be useful. This work provides methods to determine on-line how much a task can increase its computation time, by maintaining the system feasibility under a dynamic priority scheduling. The extra time can be determined not only in all the task activations, but in n of a window of m invocations [3].

- Variable execution time of task: The execution times of flexible control systems are affected by variables that originate in external environments, and this leads to a new class of task allocation problems. The use of histograms to analyse the execution distribution and propose methods for these systems based on stochastic processes has been considered. A deep analysis of the real-time tasks with high variability of its execution time is shown in [4] and [5].

Achievement: Automotive Embedded Control (CTU)

CTU has been working on how a multitasking automotive application running under a real-time operating system compliant with an OSEK/VDX standard can be modeled by timed automata. The applications under consideration consist of several non-preemptive tasks and interrupt service routines that can be synchronized by events. A model checking tool is used to verify time and logical properties of the proposed model. Use of this methodology is demonstrated on an automated gearbox case study and the result of the worst-case response time verification is compared with the classical method based on the time-demand analysis. It is shown that the model-checking approach provides less pessimistic results due to a more detailed model and exhaustive state-space exploration [48]

Further CTU has presented a hybrid Hardware-in-the-Loop (HIL) testing methodology based on both the discrete event system, given by timed automata, and the continuous systems, given by difference equations [42]. The methodology is implemented using an FPGA platform. It guaranties not only the speed enhancement but also the time accuracy and extensibility with no performance loss. Compared to the operating system based platforms, the FPGA platform is able to achieve much faster sampling frequency. The FPGA implementation is generated while using Xilinx System Generator, bit exact toolbox for Matlab/Simulink and UPPAAL.

Achievement: Sporadic Event-based control (LUND)

The work on sporadic event-based control started during Year 2 has been continued by LUND [32]. During this year the focus has been on how delays, jitter and measurement noise effect the event-based approach [34] and how load disturbances and limit cycles can be handled [31]. LUND has also collaborated with Chenyang Liu at Washington Univ, St Louis on how these results can be used in the context of control of client-server systems. The idea is to apply event-based control theory to load control and end-to-end delay control in client-server systems. Viewing the collective workload from the clients as a Wiener process, the server should regulate the workload only when specified limits are exceeded. At the same time, each client should control its own end-to-end delay by a combination of local adaptation and requests to the server.

Achievement: Scheduling of control and signal processing calculations on FPGAs (CTU)

The work on off-line scheduling of control applications on architectures with pipelined processors by CTU presented above has continued also during this year [38,39]. This work deals with a scheduling technique used to optimize computation speed of iterative algorithms running on architectures that may include pipelined dedicated processors. The problem under consideration is to find an optimal periodic schedule satisfying the timing constraints. Motivated by FPGA (Field-Programmable Gate Array) architecture we formulate a problem of cyclic scheduling on one dedicated processor where tasks are constrained by the precedence delays. Further we generalize this result to the set of dedicated processors. We also show how the set of constraints in both problems can be extended by start time related deadlines, multiprocessor tasks, changeover times and minimization of data transfers. We prove that this problem is NP–hard by reduction of Bratley's scheduling problem 1|rj,dj|Cmax and we suggest a solution based on ILP (Integer Linear Programming) that allows one to minimize the completion time. Besides this, we suggest elimination of redundant constraints and binary variables in integer linear programming model which leads to a speedup of the scheduling algorithm. The experimental results are shown on an application of recursive least square filter and other control engineering benchmarks.

Further we extend this approach to iterative algorithms with matrix operations or nested loops [40,41]. The method is demonstrated on an implementation of the Finite Interval Constant Modulus Algorithm. It is an equalization algorithm with QR-decomposition which is suitable for modern communication systems (4G and behind). Traditional approaches to the scheduling of nested loops lead to a relatively large code, which is unsuitable for FPGA implementation. Our methodology models both, iterative loops and imperfectly nested loops, by means of the system of linear inequalities. Moreover, memory access is considered as an additional resource constraint. Since the solutions of ILP formulated problems are known to be computationally intensive, an important part of this work is devoted to the reduction of the problem size. This method is also demonstrated on a synthesis of LQ controller.

Achievement: Time-Delay compensation (UPVLC, KTH, LUND)

The work on control of systems with delays started in Year 2 has been continued by UPVLC. Control of systems with delays, by considering the option of stable/unstable and minimum/non-minimum-phase processes, is a challenging one and very relevant for networked embedded systems. Most of the existing solutions do not cover all the situations and, in any case, they lead to complex controllers. Simple controllers, easy to design and tune, are very important in the process industry. In this activity line, some control schemes have been proposed. Internal stability and robust stability analysis for these control structures have been studied. On the other hand, the study has been completed when scarce irregular measurements with time varying delays are present in the system. A model based predictor that takes into account the past measured outputs is used. These results are presented in [6-9, 58]. KTH has utilized the jitter margin result developed by Lund in order to derive new simple tuning rules for PID controller subject to input-output latency [28,30].

Achievement: New results in Wireless Embedded Control and Automation (KTH, LUND, ABB, CTU)

Wireless networked control and estimation poses a multitude of new theoretical challenges caused by the unreliable and time-verying communication properties. KTH and Lund have been investigating the implications of this within the EU FP6 IP RUNES led by Ericsson [53,54] and KTH and ABB are investigating these issues within the EU FP6 SOCRADES project.

During the year KTH have done work on estimation over wireless sensor networks [20,21,23,24,25], predictive control over sensor networks [22], and distributed consensus [26,27]. Lund has worked on localization and navigation techniques for mobile robots over sensor networks [33].

CTU and KTH have proposed an algorithm for optimal real-time routing in multi-hop communication networks for multi-source/multi-sink connection [56]. The algorithm deals with various capacity constraints in terms of communication limits and real-time constraints expressed as deadline for each particular flow of data. The objective is to find the optimal routing in terms of energy consumption. The algorithm is based on a data flow model leading to Linear Programming formulation and therefore it ensures polynomial-time complexity. An extension handling simultaneous real-time and non real-time routing is added. We have shown an example of data collection from 100 nodes and performance experiments illustrating time complexity in dependence on the number of nodes.

Achievement: Embedded Control System Implementation Case Studies (CTU)

As case studies a number of challenging embedded control systems have been implemented. First, an open project, dealing with autopilot design for autonomous Unmanned Aerial Vehicles has been realized. Networked hierarchical distributed control system is used. Control algorithms, based on PI, LQG and SDRE approaches, focused on rotorcraft UAVs have been proposed, including a complex hierarchical autopilot design. Real data, measured during test-flights of an experimental UAV, have been presented and evaluated. [43,44]

The second case study is an embedded control system for a biped walking robot, including hardware, basic software and control design.. Primary goal achieved is a static walking with non-instantaneous double support phase and fixed trajectory in joint coordinates. The robot with two legs and no superior body is capable to walk with fixed, manually created, static trajectory using simple SISO proportional controller, yet it is extendable to use MIMO controllers, flexible trajectory, and dynamic gait. Distributed servo motor control over a CAN fieldbus is used. We solved interesting problems in the area of construction and kinematics, motor current cascaded control and fieldbus timing. The project is open with full documentation available [45].

2.3.2 Individual Publications Resulting from these Achievements

UPVLC

[1] Patricia Balbastre, Ismael Ripoll and Alfons Crespo. Minimum deadline calculation for periodic real-time tasks in dynamic priority systems, IEEE Trans on Computers. To appear.

[2] A. Crespo, P. Albertos, P. Balbastre, M. Vallés, M. Lluesma and J. Simó. Schedulability issues in complex embedded control systems IEEE International Conference on Control Applications October 4-6, 2006

[3] P. Balbastre Betoret, I. Ripoll, A. Crespo. Analysis of Window-Constrained Execution Time Systems. Journal of Real-Time Systems. Vol 35, Issue 2, pp: 109-134 (2007)

[4] Joan Vila i Carbó and Enrique Hernández Orallo. An Analysis Method for Variable Execution Time Tasks Based on Histograms, To appear in Real-Time Systems Journal. Ed. Springer. ISSN: 0922-6443

[5] Enrique Hernández Orallo and Joan Vila i Carbó. "A Histogram-Based Stochastic Process for Finite Buffer Occupancy Analysis". 2nd International Conference on Performance

Evaluation Methodologies and Tools. ICST in technical cooperation with ACM Sigmetrics and ACM Sigsim. Nantes, France. October 23-25, 2007

[6] Pedro García and Pedro Albertos. A new dead-time compensator to control stable and integrating processes with long dead-time. Automatica. Accepted for publication

[7] JL Guzman, P. Garcia, S. Dormido, P. Albertos. Interactive tool for analysis of time-delay systems with dead-time compensators. Control Engineering Practice. Accepted for publication

[8] R. Sanchis, I. Peñarrocha, P. Albertos. Design of robust output predictors under scarce measurements with time-varying delays. Automatica . Vol 43 (2007) 281 – 289

[9] P. Albertos and P. García. Dead-Time Compensation on Discrete Time Control Internacional Conference on Systems Science. Wroclaw. 2007. pp 20-30.

[10] A. Cuenca, J. Salt y P. Albertos. Implementation of algebraic controllers for non-conventional sampled-data systems, Journal of Real time Systems . Vol. 35. N. 1 January, 2007 pp 59 - 89

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[13] A. Marchand, P. Balbastre, I. Ripoll, M. Masmano and A. Crespo. Memory Resource Management for Real-Time Systems,19th Euromicro Conference on Real-Time Systems (ECRTS 07). Pisa, Italy. July 4-6, 2007

[14] A. Crespo, I. Ripoll, M. Masmano. Dynamic Memory Management for Embedded Real-Time Systems. IFIP Working Conference on Distributed and Parallel Embedded Systems. Braga, Portugal. October 11-13, 2006

[15] M. Masmano, I Ripoll, A. Crespo. A Comparison of Memory Allocators for Real-Time Applications. The 4th International Workshop on Java Technologies for Real-time and Embedded Systems - JTRES 2006 11-13 October 2006. Paris, France

[16] M. Masmano, A. Gonzalez,I. Ripoll, A. Crespo Embedded RTLinux: A New Stand-Alone RTLinux Approach. Eight Real-Time Linux Workshop. October 2006. Lanzhou, P.R.China

[17] A. Crespo, P. Albertos and J. Simo. Embedded systems: From Design to Implementation. IFAC Symposium on Cost Oriented Automation. Havana . 2007. Plenary paper.

[18] P. Albertos M. Vallés, A. Cuenca, A. Valera. Essential Control In Embedded Control Systems. IFAC Symposium on Cost Oriented Automation. Havana . 2007.

[19] P. Albertos and A. Crespo. New Control Challenges in the Design of Embedded Control Systems. Keynote speaker at 2007 IEEE Multiconference on Systems and Control. Singapore. 2007.

KTH

[20] A. Speranzon, C. Fischione, B. Johansson, and K. H. Johansson, Adaptive distributed estimation over wireless sensor networks with packet losses, IEEE CDC, New Orleans, LA, USA, 2007. To appear.

[21] L. Shi, K. H. Johansson, and R. M. Murray, Kalman filtering with uncertain process and measurement noise covariances with application to state estimation in sensor networks, IEEE Conference on Control Applications, Singapore, 2007. To appear.

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[23] A. Speranzon, C. Fischione, and K. H. Johansson, On distributed estimation for sensor networks, Workshop on Networked Distributed Systems for Intelligent Sensing and Control, Kalamata, Greece, 2007.

[24] A. Speranzon, C. Fischione, and K. H. Johansson, A distributed estimation algorithm for tracking over wireless sensor networks, IEEE International Conference on Communications, Glasgow, Scotland, 2007.

[25] A. Speranzon, C. Fischione, and K. H. Johansson, Distributed and collaborative estimation over wireless sensor networks, IEEE CDC, San Diego, CA, USA, 2006. Earlier version at Reglermöte, Stockholm, Sweden, 2006.

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

[27] B. Johansson, A. Speranzon, M. Johansson, and K. H. Johansson, On decentralized negotiation of optimal consensus, Automatica, To appear.

[28] L. M. Eriksson and M. Johansson, "Simple PID tuning rules for varying time-delay systems", IEEE CDC, 2007, To appear.

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[30] L. M. Eriksson and M. Johansson, "PID Controller Tuning Rules for Varying Time-Delay Systems", American Control Conferene, New York, July 2007.

LUND

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2.3.3 Interaction and Building Excellence between Partners

Integration and excellence building among the partners have been implemented in several different ways. The following is a list of the major collaborations between partners in the Control in Real-Time Computing activity which has contributed to creation of excellence between partners.

- All partners have jointly organized and executed our Embedded Control Graduate School. This year we had 34 participants, mainly European PhD students but also industrial participants from Ericsson, Tetra Pak, and Elasis. The feedback from the students was very positive.
- Lund, KTH, UPVLC all participated in the 2nd International Artist2 Workshop on Control for Embedded Systems organized by the cluster.
- The partners interact through the Bridgit embedded control benchmark repository. This year the interaction has primarily involved KTH and CTU.
- KTH, Lund, and Ericsson collaborate on wireless networked embedded control, in particular sensor/actuator networks within RUNES. CTU and KTH also collaborate on wireless networking. ABB and KTH collaborate on wireless automation within SOCRADES. This has resulted in three joint publications.
- UPVLC and Lund collaborate on compensation for time delays. This has resulted in one joint publication.
- The development of a common framework for control and scheduling co-design is something that unites, in particular, Lund and UPVLC. However, UPVLC and CTU also work on these issues within the FRESCOR context. This has resulted in one joint publication.
- ABB and Lund have a long history of collaboration on embedded control in industrial robotics. During this year the work has also involved Sun

2.3.4 Joint Publications Resulting from these Achievements

[53] Karl-Erik Årzén, Antonio Bicchi, Gianluca Dini, Stephen Hailes, Karl Henrik Johansson, John Lygeros, Anthony Tzes. A component-based approach to the design of networked control systems, In Proceedings of the European Control Conference, July 2007.

[54] Karl-Erik Årzén, Antonio Bicchi, Gianluca Dini, Stephen Hailes, Karl Henrik Johansson, John Lygeros, Anthony Tzes. A component-based approach to the design of networked control systems, European Journal of Control, 13:2-3, June 2007. (extended version of [53])

NOTE: The references [53] and [54] above also appear as joint publications in D20-Control-Y3 the reason being that the references both apply to real-time control over networked embedded systems, i.e., the area of this activity, and control of the resources in the networked embedded system itself, i.e., the area of the activity Control in Real-Time Computing. To be more precise the papers present an ultrasound-based localization scheme for mobile agents in a sensory network. The scheme is based on feedback over a wireless embedded network and therefore fits into this activity. The papers also present a feedback-based scheme for controlling the radio transmit power levels of the mobile agents, i.e., an example of using control techniques for control of embedded system resources, in this case power, hence the inclusion also in delivarable D20.

[55] Karl-Erik Årzén, Antonio Bicchi, Stephen Hailes, Karl Henrik Johansson, John Lygeros. On the Design and Control of Wireless Networked Embedded Systems, In Proceedings of the 2006 IEEE Computer Aided Control Systems Design Symposium, October 2006.

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[57] A. Cervin, K.E. Årzén, D. Henriksson, M. Lluesma , P. Balbastre, I. Ripoll, A. Crespo. Control Loop Timing Analysis Using TrueTime and Jitterbug In Proceedings of the 2006 IEEE Computer Aided Control Systems Design Symposium, October 2006.

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2.3.5 Keynotes, Workshops, Tutorials

The members of this activity given four keynotes or plenary addresses, organized one tutorial session, organized one international workshop, one national workshop, and four summer shool or graduate courses.

Keynote: Real-Time Aspects in Control,. By Karl-Erik Årzén
Location: ANIPLA, November 15 2006, Rome, Italy

Plenary Paper: Embedded systems: From Design to Implementation. [A. Crespo, P. Albertos and J. Simo.
Location: IFAC Symposium on Cost Oriented Automation. Havana . 2007.

Keynote: New Control Challenges in the Design of Embedded Control Systems. P. Albertos and A. Crespo.
Location: 2007 IEEE Multiconference on Systems and Control. Singapore. 2007.

Keynote: Wireless Control Systems: Scientific Challenges and Emerging Applications, Karl Henrik Johansson
Location: 15th Mediterranean Conference on Control and Automation, Athens, Greece, 27-29 Jun, 2007

Workshop : 2nd Int'l ARTIST Workshop on Control for Embedded Systems
Location: University of Illinois, Urbana-Champaigne, Illinois, US, May 31 – June 1, 2007
The second in the series of International Workshops in Control for Embeded Systems was organized by the cluster at Urbana-Champaigne is Illinois with Tarek Abdelzaher as the local host. The formal topics of the workshop were Real-Time and Control in Sensor/Actuator Network, Control in Cyber-Physical Systems, Event-Based Control and Computing, and Control of Software Errors. However, several of the presentations given were very relevant also for this activity. This cluster was represented by LUND, KTH and UPVLC. More information about the workshop including the conclusions are available at

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

Summer School: 3rd Artist2 Graduate School on Embedded Control Systems. All cluster members
Location: Lund University, May, 2007
The third graduate school organized by the cluster on embedded control was successfully given in Lund in May 2007. In addition to lectures and laboratories given and organized by the core partners the course also contained four industrial presentations related to embedded control from ABB, Ericsson, Volvo, and Dynasim. More information about the course can be found on

http://www.artist-embedded.org/artist/Objectives-and-Scope,880.html

Summer School Participation: Four lectures on “Control for Embedded Systems - Introduction and Motivation” within the Artist2/UNU-IIST School, By Karl-Erik Årzén
Location: Suzhou, August 2007.

Course: Graduate course on Embedded Control Systems. By Karl-Erik Årzén
Location: UNED, Madrid, April 2007.

Course: Graduate course on “Embedded Control - Controller Implementation with Resource Limitations”. By Karl-Erik Årzén.
Location: Aalborg University, January 2007

Tutorial Session: Toward a Component-Based Framework for Networked Control,
Conference name: European Control Conference, Kos, Greece, July 2-5.
An invited tutorial session about control-related issues in wireless networked embedded systems was held as a part of the ECC conference. The session contained three presentations authored by members of this cluster.

Workshop: Embedded systems colloquium
Location: CTU Prague, Czech Republic, February 1st, 2007

Course: Design of Embedded Real-time Systems: a graduate course given within the Artes++ graduate school – with invited speakers from Artist2 affiliated industries
Location: KTH, Autumn 2006

3. Future Work and Evolution

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

The work during the final year of this activity will be focused on completing the work performed during the previous three years and disseminate it through journal articles and presentations at Artist events. In parallel with this the individual and joint research will continue. The focus will continue to be fundamental trade-offs that exist between sampling rates, delays, and jitter in networked control, event-triggered feedback control, future development of the control kernel concept, server-based implementation methods for control systems, optimization-based scheduling, and the definition of a common framework for the interaction between controllers and the underlying OS-middleware-hardware layer.

During Spring 2008 we will organize the Fourth Graduate School on Control for Embedded Systems.

3.2 Current and Future Milestones

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

Year2: A common framework of the control parameters that can be influenced by an embedded control system implementation and the real time operating systems criteria that can be adjusted to increase the robustness of the control system (*Achieved to 50%*)
This milestone has not been fully completed yet. Our aim is to complete this during the reminder of 2006.

Year3-4:

- A common framework model in order to facilitate the control and computing codesign

This has not been finalized yet. An estimate is that it currently is finalized to around 75%. This will be the focus of the work during Year 4.

- Organization of an annual Graduate School on Embedded Control Systems

Achieved.

- Organization of a follow-up of the Lund Workshop on Control for Embedded Systems

Achieved

Updated Milestones for Year 4:

- Finalize and disseminate the common codesign framework model. At least one joint major publication summarizing this work should be generated
- Organization of the Fourth Graduate School on Embedded Control Systems during Spring 2008
- Disseminate the total amount of work done within this activity at Artist organized events.
- Add at least two additional benchmarks to Bridgit.
- Continue the individual and joint research on control and scheduling co-design, OS and kernel support for embedded control, event-based control, wireless networked control, and modeling and analysis of embedded control systems, according to the roadmap developed in Year 1-2.

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. The publications should include at least one joint publication on the common codesign framework.

Increased usage of the Bridgit embedded control benchmark repository. In order for this to be considered successful each benchmark should have been used by at least one other group than the group that developed that particular benchmark.

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 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. This includes the ArtistDesign NoE.

4. Internal Reviewers for this Deliverable

Anton Cervin, Lund