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Proposal for Extension of Project “Flexible Reliable Timing Constraints”

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Summary

The project “Flexible Reliable Timing Constrains” has been approved by ARTES and started in February 2000. Academic partner is Prof. Krithi Ramamritham of University of Massachusetts/IIT Bomaby, industrial partner is MECEL AB, Gothenburg. Damir Isovic was hired as Ph.D. student. The initial phase has worked out well: two papers have been accepted at conferences, simulators for analysis work have been acquired, and a master thesis addressing a problem in the project context has resulted in a publication to be submitted as well.

Furthermore, the project has attracted additional industrial interest: Rolls Royce, UK, aircraft engines, is interested in the capability of the proposed reliable timing constraints to maintain design information over product cycles and versions for continuity and safety. In addition, the company has pointed out that part of the project is relevant for the design of aeronautic applications. The transformation techniques of reliable timing constraints into a variety of scheduling constraints, seem well suited to address a number of issues. Rolls Royce has expressed interest in a joint EU project based on results from initial analysis and case study.
TTTech, Austria, is interested in the aspects of maintaining flexibility in the specification, even if the resulting system has to be constructed inflexible and strict, as aimed for with flexible timing constraints.

The project is composed of two separate, but closely coupled major areas: first, *design and specification* of flexible reliable timing constraints, maintaining flexibility information and design options; second, *system construction* based on these constraints, utilizing flexibility expressed during design, and providing feedback. Experiences from initial project phase and industrial perspective emphasize this division into areas strongly and call for an “interface mechanism” between both parts. The transformation algorithm developed within the Master’s thesis related to this project will serve as a starting point.

The project “flexible reliable timing constraints” in its original form provided an ambitious and work intensive plan for a single student (the proposal asked for two). The additional industrial interest, and application possibilities in the project, together with the potential of sub problems, i.e., transformation of complex constraints, to become research focus themselves, will make it hard for a single student to do high quality work and explore the full potential, e.g., to prepare for a future EU project. Therefore, an additional Ph.D. student for the project is proposed. Radu Dobrin, who showed his potential in his Master’s thesis project, which evoked further industrial interest, has expressed interest in the position.

1 Status of Project - Initial Three Months

The project started in 2000-2 with Damir Isovic, Adjunkt at Mälardalen Högskola, as Ph.D. student.
Goal of the initial phase is to set up an environment for analysis of applications and algorithms for use with flexible reliable timing constraints. We have started to prepare for sensitivity analysis of timing parameters, developed a scheduling algorithm which is powerfull enough to handle a number of non classical timing constraints, e.g., diverse instance separations, bandwidth requirements, and looked into ”interface” issue between specification and system construction. In particular, the following activities and results can be reported:

- Two papers have been accepted for conferences:
  - D. Isovic and G. Fohler, “Online handling of firm aperiodic tasks in time triggered systems”, In Proceedings of Work-in-Progress Session, 12th Euromicro Conference on Real-Time Systems, *June 2000*.
  - D. Isovic, M. Lindgren, I. Crnkovic, “System Development with Real-Time Components”, In Proc. of ECOOP2000 Workshop 22 - Pervasive Compont , June 2000
- Another paper has been submitted:

  - D.Isovic and G. Fohler, “Efficient Scheduling of Sporadic, Aperiodic, and Periodic Tasks with Complex Constraints”
- A master’s thesis carried out by Radu Dobrin and Yussef Özedmir addresses the issue of an “interface” between complex constraints and simple, general scheduling algorithm. The thesis develops an algorithm to transform tasks with complex constraints and execution windows into tasks suited for fixed priority runtime scheduling. A paper on the algorithm is in preparation. The project has received industrial interest, in particular for aeronautics applications.
- Simulators for sensitivity analysis have been acquired: The matlab toolbox for real-time control, developed by Lund university and the real-time control simulator program developed by Paolo Gai at University of Illinois.
- Further contacts with industry have been established, two have expressed concrete interest in the project:
  - Rolls Royce, UK, aircraft engines
  - TTTech, Austria

2 New Perspectives

The initial work identifies additional potential of the project. Two companies have expressed concrete interest:

- Rolls Royce, UK, aircraft engines, is interested in the capability of the proposed flexible reliable timing constraints to maintain design information over product cycles and versions for continuity and safety.
  In addition, the company has pointed out that part of the project solves an existing problem for the design of aeronautic applications: the transformation techniques of flexible timing constraints, to a variety of simple scheduling algorithm, such as fixed priority, as addressed in the master’s thesis mentioned above, seem well suited. Rolls Royce has expressed interest in a joint EU project based on results from initial analysis and case study.
- TTTech, Austria, is interested in the aspects of maintaining flexibility in the specification, even if the resulting system has to be constructed inflexible and strict, as aimed for with flexible timing constraints.

The new industrial interest gives new emphasis to parts of the project and indicates that some of the addressed problems can become research topics themselves, e.g., the transformation techniques issues.
The project is composed of two separate, but closely coupled major areas:

- Design and specification of flexible reliable timing constraints, maintaining flexibility information and design options: how can a system be designed which express feasibility information of activities rather than numbers demanded by common system models?
- System construction based on these constraints, utilizing flexibility expressed during design, and providing feedback: how can a system be constructed which utilizes the flexible and reliable constraints, how can it be scheduled?

Experiences from initial project phase and industrial perspective emphasize this division into areas strongly. In addition, there is a need for a “general interface mechanism” between both parts. The transformation algorithm developed within the master’s thesis related to this project will serve as a starting point. The interest and potential applicability in aeronautics applications suggest this issue to become a research focus as well.

3 Revised Plans

The original project has been approved by ARTES, and started well. Additional industrial interest during the initial phase underlines the relevance of the technical contents.
The division of the project into two parts has become more evident and a new research focus within the project has emerged.

The original project provides an ambitious and work intensive plan for a single student (the proposal asked for two). We propose to add a Ph.D. student to the project to allow for comprehensive research work, explore new industrial potential and research focus, and a realistic workload for the involved students.
The new Ph.D. will concentrate in the beginning on the new industrial case studies and transformation techniques (phases 1-2 of project plan). He will use the insights gained for the design and specification part of the project (phases 4-8).

<table>
<tr><td>Year</td><td>Phase</td><td>Damir Isovic</td><td>New Student</td></tr>
<tr><td>1</td><td>1</td><td>Analysis of industrial applications for constraints and system requirements</td><td rowspan="2">Analysis of industrial applications, in particular aeronautics, development of “interface method” based on transformation technique</td></tr>
<tr><td>1.5</td><td>2</td><td>Definition of requirements on methods</td></tr>
<tr><td>2</td><td>3</td><td colspan="2">Analysis of system construction, scheduling and specification methods</td></tr>
<tr><td>3</td><td>4</td><td>Development of system construction and scheduling methods</td><td>Development of specification methods and design process</td></tr>
<tr><td>3</td><td>5</td><td colspan="2">Development of integrated design/system construction method based on “interface method”</td></tr>
<tr><td>4</td><td>6</td><td colspan="2">Implementation of tool support</td></tr>
<tr><td>4.5</td><td>7</td><td colspan="2">Analysis and tuning of methods</td></tr>
<tr><td>5</td><td>8</td><td colspan="2">Deployment</td></tr>
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Radu Dobrin, who is currently working on the mentioned master’s thesis, which invoked additional interest, has shown interest becoming this new Ph.D. student.

4 Appendices

Appendix A: Support letter Prof. Ramamritham
Appendix B: Support letter Rolls Royce
Appendix C: Support letter TTTech
Appendix D: Approved Proposal “Flexible Reliable Timing Constraints”

Appendix A: Support Letter Prof. Ramamritham

to be provided

Appendix B: Support Letter Rolls Royce

to be provided

Appendix C : Support Letter TTTech

to be provided

Appendix D: Approved Proposal “Flexible Reliable Timing Constraints”

Proposal to ARTES
Flexible Reliable Timing Constraints

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Summary

The goal of the proposed research is to develop methods for the derivation, specification, and run-time execution of activities with timing constraints, which exploit inherent flexibility in temporal demands, e.g., on application level, instead of *overconstraining* specifications. We propose to use *flexible timing constraints,* which express feasibility information of activities rather than numbers demanded by common system models and scheduling algorithms. These will be scheduled by *novel offline algorithms*, which are capable of exploiting the expressed flexibility, while maintaining *reliability* requirements.

1 Problem Statement

The main concern with respect to temporal behavior of a real-time system is meeting the timing relations between input and output from and to the environment, resp.. Timing constraints such as period and deadline meet demands of system models and in particular scheduling algorithms rather than application level requirements. Instead of focussing on application demands, timing constraints are determined to suit task models mandated by system operation.

Many real-world industrial applications, e.g., control applications, have timing requirements which cannot be expressed deadlines and periods or which restrict the system if expressed by standard timing constraints. Only few tasks have “natural” periods and deadlines. Most are only derived during system design in a iterative process: they are artefacts. Often, several settings for deadline and period may be feasible, but only one can be selected: the specification becomes *overconstrained.* In addition, the knowledge about original requirements and their inherent flexibility is abandoned and no longer available to subsequent design and runtime phases. The decomposition of end-to-end deadlines in distributed systems, for example, results in constraints for tasks on individual nodes with no information about other tasks and overall deadlines. Only when the entire design is completed, a wrong selection can be detected, e.g., by a failed scheduling attempt.

Most current scheduling techniques are designed to handle constraints expressed on the level of periods and deadline. Consequently, they cannot exploit extra flexibility in temporal demands efficiently. One particular restriction is the assumption of timing constraints being *static*, i.e., they are the same and stay fixed for all instances of an activity. This prevents solving timing problems by changing the set of timing constraints for single instances, e.g., to avoid collisions with other periodic or aperiodic activities, or rearrange subtask deadlines.

No temporal guarantees can be given if the system does not provide certain reliability: deadlines are at risk if simple faults cannot be tolerated and lead to failure. Special attention has to be given to the impact of increased temporal flexibility on reliability, e.g., with respect to fault tolerance methods such as replica determinism.

2 Main Ideas

We propose to investigate into *flexible timing constraints*, which help to overcome the above stated problems. Instead of using numbers to constrain tasks, such as for period and deadline, these represent information about the *feasibility* of system activities: Timing entities, i.e., functional units whose execution is temporally constrained, are given feasibility functions describing the temporal relations on the unit’s input and output. Instances of timing entities and constraints can be tested by the feasibility function. In the case of repeating or periodic entities, the derived constraints can either constant for all instances or varying.

We envision *decomposition* of the proposed flexible timing constraints: Given a timing entity composed of subentities and a feasibility function, a set of feasible timing constraints for the subentities can be instantiated, keeping information about flexibility.

Starting from application level demands on input and output of system services, an iterative design process refines until a scheduling algorithm can process the timing constraints.

While knowledge of flexibility in temporal constraints facilitates the design process, it can be fully exploited when taken into account during scheduling: Artifacts created during design can be changed, e.g., to change subtask deadlines, within the flexibility provided during scheduling, instead of requiring redesign and rescheduling. New scheduling methods will have impact on runtime complexity and reliability of the system. We will investigate into several directions for scheduling of timing entities and flexible timing constraints and analyze each for such tradeoffs.
In systems where standard scheduling algorithms with standard timing constraints are mandated, the scheduler can use the knowledge about artifacts, their constraints, and alternatives to pinpoint candidates for change, instead of a “blind” redesign. Another direction will be to develop algorithms which work without the “bottleneck” of standard constraints by directly scheduling timing entities with full exploitation of their flexibility. These will allow for varying constraints for different instances. As mentioned above, we will study the effect of added flexibility on system properties, in particular on reliability for each of the new scheduling methods.

3 Expected Results and Impact

The results of our research will be methods for derivation, specification and scheduling to exploit temporal flexibility in real-time systems while maintaining demands on reliability.
Mecel has expressed demand for the proposed research and will provide applications to be studied for their temporal constraints and flexibility. As a case study, a specification method will be provided and an appropriate scheduler selected and modified to suit the BASEMENT architecture.

4 Project Plan

This project will be conducted by two Ph.D. students with 20% of department duties and supervised by Gerhard Fohler and Prof. Krithi Ramamritham. The project will span over a period of 2.5+2.5 years.

Year	Phase	Activity
1	1	Analysis of industrial application for constraints and system requirements
1.5	2	Definition of requirements on methods
2	3	Analysis of scheduling methods
3	4	Development of specification method and design process
3	5	Modifications to existing and new scheduling algorithms
4	6	Implementation of tool support
4.5	7	Analysis and tuning of methods
5	8	Deployment

5 Preliminary Budget

We project the total project budget to be comprised of funding for

- Two Ph.D. student salaries for 2.5 + 2.5 years, considering departmental duties
- supervision cost
    - Gerhard Fohler, salary, 20%
    - Prof. Ramamritham, salary, 2 weeks/year
- research stays for Ph.D. students at international institution (2-3 months)
- conference travel for presentation of results
- a 20% department overhead is added to the above listed items

6 Related Research

The issue of timing constraints, their origins and use has been discussed in [Ramamritham:]. The creation of artefacts and constraints in the design process with respect to predictability was addressed in [Stankovic:90].
Early versions of flexible timing constraints have been proposed in [Fohler:97].

Gerber et. al. have studied relative timing constrains [Gerber:95b] and design based on end-t-end deadlines [Gerber:95]. Cheng and Agrawala [Cheng:97] developed a scheduling algorithm for relative timing constraints.
[Seto:97] presented a method to derive periods for rate monotonic scheduling from a control application.
[Fohler:94] presented the modification of a static scheduler to include constraints specified in RTL [Jah86:].
Issues of incremental schedule construction and offline scheduling to meet general requirements are currently studied in ARTES projects “Incremental, iterative schedule construction”, and “Identification of Complexity-Reduction Techniques for Optimal Scheduling in Embedded Distributed Real-Time Systems”.

7 Relation to Profile and Industry

Our proposed research aims at solving real-time problems meeting industrial demands. It will be carried out in co-operation with the industrial partner. The process will provide us with insights in concrete, application specific real-time engineering practice and broaden the scientific foundation for industry.
We expect to learn how to specify and design real-world real-time systems by analysing the actual problems, their requirements and used industrial practice, and by providing solutions and research to meet the encountered demands.
The use of flexible timing constraints acknowledges the need of specifications meeting industrial application demand rather than that of target system and scheduling algorithm. It will enable designers to focus on application constraints and design, reduce design cycles, and provide more general and efficient scheduling methods.

8 Context

8.1 The research group

The proposed research will be carried out at the Computer Engineering Department (IDt) at Mälardalen University, Västeras in co-operation with Mecel AB, Gothenburg as industrial partner and Prof. Ramamritham, University of Massachusetts/IIT Bombay as external supervisor.
Real-time Systems research was established at MdH around 1990 by three persons as a glue between academia and industry. It has since then been the most active and fast growing research area, as well as a strong educational profile, at MdH. The real-time research at MdH is supported by a number of regional and national authorities, foundations and companies. As a result, real-time systems has been identified (by the university board) as the research area of highest priority at MdH. It has grown to approximately 40 persons providing 500 full time student equivalents.

8.2 Complimentary activities

The SALSART tool suite for distributed schedule design and analsys which is currently being developed will be used assist the development of the proposed research and methods. A number of master thesis projects both at IDt and Mecel will help with implementions.
The ARTES funded project, “Incremental, iterative schedule construction”, currently carried out at IDt will provide help for the development of schedules and constraints.
Our project will interact closely with the ARTES funded project, “Identification of Complexity-Reduction Techniques for Optimal Scheduling in Embedded Distributed Real-Time Systems”, currently carried out at Chalmers Universtiy under supervision of Jan Jonsson

8.3 International co-operation

Prof Krithi Ramamritham from University of Massachusetts/ IIT Bombay will be partner in the project and student co-supervisor. His participation will be 2 weeks/year.

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8.4 Industrial co-operation

Mecel AB has a group consisting of around 10 persons working with the design of distributed real-time system in automotive applications. Mikael Strömberg leads this group.

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10 Appendices

Appendix A: C.V. of Gerhard Fohler
Appendix B: Support letter Prof Ramamritham
Appendix B: Support letter Mecel

Appendix A
C.V. of Gerhard Fohler

Appendix B
Support letter Prof Ramamritham

Appendix C
Support letter Mecel