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Hard Real-time CORBA

Title

# HRTC Final Report

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www.hardrealtimecorba.org

# Summary Sheet

IST Project 2001-37652
HRTC
Hard Real-time CORBA

# D6.8 HRTC Final Report

**Abstract:**

This document is the *HRT Final* Report. It contains a summary of the objectives, achievements and future activities derived from the HRTC project.



**Partners:**

Universidad Politécnica de Madrid, Madrid, Spain
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# Release Sheet (1)

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# Table of Contents

**1 Introduction 6**

1.1 Description of the document 6

1.2 Project scope 6

1.3 Authors 6

**2 Executive Summary 7**

2.1 Rationale 7

2.2 Project Objectives 7

2.3 Expected project results 7

2.4 Project Organisation 8

2.5 HRTC Consortium 8

2.6 Project Assessment 8

**3 Motivation 10**

3.1 Project rationale 10

3.2 CORBA in Control Systems 10

**4 Project objectives 12**

4.1 General Objectives 12

4.2 Concrete results 13

**5 Project Organisation 14**

5.1 Project Team 14

5.2 Work Structure 15

**6 Project Achievements 17**

**7 Execution Summary 19**

7.1 Global execution 19

7.2 Gantt Chart 19

7.3 Efforts 20

7.4 Deliverables 21

**8 Project Testbeds 23**

8.1 Process Control Testbed 23

*8.1.1 Process description 23*

*8.1.2 Testbed Components 23*

*8.1.3 Functionality 26*

8.2 Robot Control Testbed 28
*8.2.1 Purpose of the testbed 28*
*8.2.2 Testbed robot controller 29*
*8.2.3 RCT hard real-time requirements 31*

***9 Future Activities 32***

9.1 OMG Control Systems WG 32

9.2 CORBA Control Systems 33

***10 Annexes 34***

10.1 Project Documents 34

10.2 Published papers 36

10.3 Contact Points 37

# 1 Introduction

## 1.1 Description of the document

This is HRTC project deliverable D6.8 Final Report. This is a public document that summarizes the activities inside the IST HRTC project (IST 37652)

## 1.2 Project scope

The long-term objectives of the work performed in the project were focused in the advancement of the CORBA technology for the implementation of distributed complex control systems.

The concrete main objective of HRTC was to increase the suitability and acceptance of OMG CORBA specifications for the implementation of distributed control systems in industry.

To do this the project focused on the generation of CORBA knowledge to be used by control engineers and the increase of activities related with control systems in the CORBA community. The project has performed activities in domain analysis, testbed implementation as well as specification fostering inside the OMG.

## 1.3 Authors

This report has been written by the HRTC General Project Manager (Ricardo Sanz) on behalf of the rest of the partners.

# 2 Executive Summary

## 2.1 Rationale

The focus of the HRTC project was *distributed control applications*, *i.e.* applications where a distributed information system closes a control loop to keep a target system in a controlled state. Timing is critical in this type of application due to dynamic effects that can be derived from delays or jitter due to the software/hardware path. Complexity is also a challenge in these systems and distributed object technology has proved useful in dealing with this problem.

One of the leading technologies in this field is the object request brokering model proposed by the CORBA specification from the Object Management Group. But, while present CORBA specifications do address real-time issues they deal only with soft real-time systems, and this is not enough for certain types of distributed systems (namely controllers) where timing properties are critical.

## 2.2 Project Objectives

The central objectives of this project were (i) to analyse and identify hard-real time requirements posed by CORBA-based distributed control systems, and to develop theory/methodology for hard-real time CORBA applications, (ii) to enhance CORBA specifications with corresponding interfaces in order to build distributed control systems that have real-time requirements with hard timing constraints, and (iii) to implement a CORBA-pluggable real-time protocol for an ORB for running experiments. They were used to launch a specification process inside the OMG.

## 2.3 Expected project results

The planned final products of this project were described in the project technical annex:

- Know-how in distributed real-time object-oriented control systems.
- A pluggable real-time ORB protocol prototype.
- A robot control testbed.
- A process control testbed.

- A specification process for CORBA-based control systems.

## 2.4 Project Organisation

To achieve the planned results, project work was arranged into six workpackages that directly reflect the lists of pursued results for the project:

1. **CORBA Control Systems**: A sound, theoretical approach to methodologies and models to build hard real-time, software intensive, distributed, object-based control systems.
2. **Hard Real-time Protocols**: Development of a conceptual model for the precise specification of the temporal properties of interfaces. Analysis of protocols for real-time control. Development of a prototype real-time pluggable protocol for an ORB.
3. **Robot Control Testbed**: Construction of a distributed robot control experimental application using CORBA technology with focus on timing aspects.
4. **Process Control Testbed**: Construction of a distributed process control experimental application using CORBA technology with focus on heterogeneity.
5. **Dissemination:** Normal dissemination channels, standardization activities (RFIs, RFPs and proposals for OMG) and policy makers.
6. **Management**.

## 2.5 HRTC Consortium

Universidad Politécnica de Madrid, Madrid, Spain
Lunds Tekniska Högskola, Lund Sweden
Technische Universität Wien, Wien, Austria
SCILabs Ingenieros, Madrid, Spain

## 2.6 Project Assessment

The project work was delayed for several reasons and that caused a final result that does not fully fulfil the original expectations. This issue clarified, the project activities have reached quite good results in all the five main objectives:

- **Know-how in distributed real-time object-oriented control systems**: Domain analysis, architecting and engineering information collection have been performed. The resulting documents are not definitive but should be considered as a first step in the production of engineering material to be used by control engineering practitioners. These documents will be made public through the CORBA Control Systems Website.

- **A pluggable real-time ORB protocol prototype**: Not one but two pluggable protocols have been developed; one over TTP and another one over switched Ethernet. The TTP protocol demonstrates the possibility of jitter reduction sacrificing flexibility of the application object interfaces. The Ethernet protocol demonstrates that existing off-the-shelf hardware technologies can meet the needs of CORBA control systems when properly managed by software.
- **A robot control testbed**: The RCT implements a CORBA control system of a robot. This is a two level controller with visual servoing based on the Ethernet transport.
- **A process control testbed**: The PCT demonstrates the possibility of using CORBA across the whole plant for process control systems. This system demonstrates true networked control, sensor and actuator wrapping, legacy DCS integration, simulation integration and.
- **A specification process for CORBA-based control systems**: The OMG has chartered a working group in control systems and the specification process for CORBA technologies in control applications has started with the preparation of a white paper and an RFI.

In summary, while not all the expectations have been fulfilled, the final result of the project mostly meets the initial objectives. The results are considered very valuable and they will serve the original purpose of enhancing applicability and perceived value of CORBA technology for industrial control systems.

# 3 Motivation

## 3.1 Project rationale

Most present-day control systems are very complex applications running in several interacting computers with varying degrees of integration:

- Chemical plant control systems are running in a collection of heterogeneous computers from process controllers running control algorithms to desktop machines running production planning tools. With the incorporation of intelligent sensors, the computers reach even the blower level of the control hierarchy.
- Satellite control systems are operating in on-board equipment but also in computer networks that span the whole planet.
- Modern cars incorporate tens of computers in their electronic equipment dealing with aspects that go from braking or controlling the inner operation of the engine to navigation or support of leisure activities.

While all of them have differing characteristics and pose different requirements for control engineers, in all these cases the construction, deployment and maintenance of the software system is an extremely difficult problem. Even though there are no silver bullets, *object oriented technology* offers a good way to build complex systems; and when they are running in several, networked computers, *distributed object technology* has been demonstrated as a feasible way to cope with this complexity while keeping costs under control.

## 3.2 CORBA in Control Systems

CORBA is an open standard which provides developers of distributed systems a flexible middleware capable of integrating complex applications in heterogeneous environments. It should not matter the programming language or operating system chosen to be part of the system, CORBA makes it possible through a feature called interoperability.

In the global distributed object computing landscape, CORBA is a well known framework for the construction of modularised, object oriented,

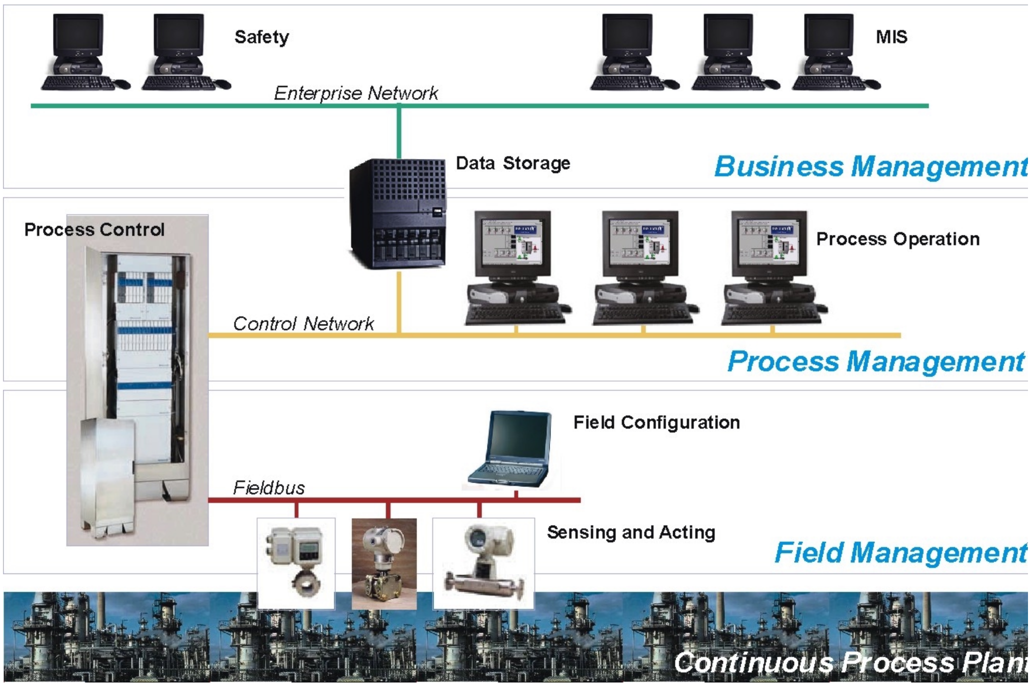



**Figure 1**: Typical layering in a plant-wide control system in the chemical industry. CORBA-based complete vertical integration is only possible if hard real-time predictability is achieved for CORBA to be used at the lower level.

distributed applications. It was designed from the perspective of surpassing heterogeneity barriers and provide support for modularity and reuse. CORBA, however, was originally designed with large business applications in mind and is not perfectly suited for the construction of embedded control applications. This has changed in the last months because the RTESS PTF inside the OMG is very active in the development of specifications for this field. Real-time CORBA has found its place into the main CORBA specification. This makes CORBA a specification that deals with real-time issues from the very core (a real difference from other distributed objects technologies).

The CORBA object model (and the development processes and tools associated with it) *is extremely adequate for the construction of complex distributed applications* and hence our interest in extending it to be useful in the real, embedded control domain. But there is a problem. Present day CORBA specifications are suitable only for soft real-time applications and do not deal with the tight requirements of closed control loops.

# 4 Project objectives

## 4.1 General Objectives

The central objective of HRTC was to extend CORBA specifications in order to broaden them to cover the construction of real time distributed systems with hard timing constraints. This means putting CORBA down to the basic control, sensor and actuator levels (See Figure 1).

Present-day RT CORBA is not fully suitable to implement control systems because:

- It has been designed to build systems with soft real-time requirements.
- CORBA lacks a real-time interoperable protocol, necessary to integrate control and real time systems. IIOP is not reliable or predictable enough.
- The Scheduling Service is incomplete, can not be dynamically reconfigured and does not provide a wide range of scheduling algorithms.
- Most real-time systems are also embedded ones. There is an effort called Minimum CORBA to build a small ORB, tailoring it to fit in embedded systems, but this seems to exclude RT CORBA which increases ORB size.
- Interface specification needs to be extended to express temporal issues.

It was the purpose of this project to analyse hard-real time requirements posed by CORBA-based distributed control systems and to develop theory/methodology and technology for hard-real time applications. This will lead us to extend the set of CORBA specifications with interfaces dealing with hard real-time issues. It is the purpose of this consortium to take these developments into the OMG specification process.

The concrete project goals are the following:

- Identify hard real-time requirements for distributed control systems by means of theoretical analysis and experiments.

- Build two different experimental CORBA-based control systems.
- Implement a CORBA pluggable protocol over a hard real-time transport[1].
- Map identified requirements to a specification in the framework of the OMA and collaborate with OMG in extending the approved specifications.
- Create awareness of HRTC technology among systems developers.

There are also some after-project goals like extending hard-real time predictability to a complete ORB implementation or exploration of complex object-based control designs for advanced applications.

## 4.2 Concrete results

The planned final products of this project were:

- An advance in know-how in distributed real-time object-oriented control systems.
- A prototype implementation of a pluggable real-time protocol for an ORB.
- A robot control testbed.
- A process control testbed.
- Enhancements of OMG CORBA specifications to deal with control systems.

This collection of final products is what defined the workpackage structure of the project.

[1] At the end, several alternatives were evaluated but two were implemented (not one as originally planned); one over TTP ant the other over ThrottleNet (a bandwidth aware variation of Ethernet).

# 5 Project Organisation

## 5.1 Project Team

The structure of the consortium was simple, and focused on the work to be done in the project. The partners were selected based on their previous experience and extensive knowledge of the field to perform a very specific role in the project:

- Universidad Politécnica de Madrid, Madrid, Spain
- Lunds Tekniska Högskola, Lund Sweden
- Technische Universität Wien, Wien, Austria
- SCILabs Ingenieros, Madrid, Spain

The background of the project partners in the field was as follows:

**UPM** has ample experience in the construction of CORBA applications in industrial settings; from object request brokers to embedded CORBA-based controllers. As a milestone of this work, the first release of the ICa Broker was developed as part of a previous project (ESPRIT 22139 DIXIT). The role UPM plays in the consortium is as coordinator and as expert on complex distributed process control architectures.

**Ulund's** Automatic Control department is a world-wide reference center for advances in control theory and the exploration of the frontier between control theory and real-time software (kernels, programming, communications, etc). Networked control loops are well known by them (see for example references related with DICOSMOS projects). The reason why they are needed (the role they play) in the consortium is based on this solid capability of theoretical analysis of implications that networking has for control performance, reliability and fault tolerance. They have also ample experience in robot control.

**TUWien** has a deep experience on real-time computer systems. The ITI of the TU Vienna is internationally renowned for its leadership role in the development of the time-triggered architecture. This architecture offers a mechanism for constructing distributed systems that are predictable: are able to meet hard real-time constraints. This experience on hard-real time distributed systems is what was sought with their participation in the consortium. Their main role is providing knowledge on hard real-time issues and implementing a hard real-time transports.

**SCILabs** is a small software house specialized in industrial computing systems integration. They have a real-time CORBA product – i.e. ICa ORB - specifically built for industrial applications. Their role in the project is to drive the industrialization approach. Their intentions are to adapt their product to the specifications developed in this project to have a differentiated ORB product specifically tailored for control purposes**.**
They are the only company in Europe with a real-time object request broker and the only company worldwide that is trying to address hard-real time issues in their CORBA brokering products (as known by the consortium).

## 5.2 Work Structure

To achieve the objectives the project work is organised into five technical workpackages (WPs):

**WP1**: Domain engineering of CORBA-based control systems. The project will develop a sound, theoretical approach to methodologies and models to build hard real-time, software intensive, distributed, object-based control systems. It will produce a domain analysis of distributed object-based control systems, will define a set of reusable domain architectures and will define an engineering process specifically tailored to these applications.

**WP2**: Real-time interoperation protocols. The IIOP protocol used by ORBs to interoperate is not adequate for hard real-time applications. This WP will abnalyse protocols for distributed control and will develop a conceptual model for the precise specification of temporal properties of interfaces. It will further design and implement a new protocol for ORB interoperation to be used by ORBs by means of the extensible transports framework of the OMG.

**WP3**: A distributed robot control testbed will be built, which will be used to elicit requirements and perform experiments in conditions of tight timing constraints. Experiments will be done using conventional IIOP and the new real-time protocol from WP2.

**WP4**: A distributed process control testbed will be built, which will be used to elicit requirements and perform experiments in conditions of systems heterogeneity and legacy integration. Experiments will be done using conventional IIOP and the new real-time protocol from WP 2

**WP5**: Elaboration of CORBA specifications. The project will collaborate with OMG real-time task force to enhance CORBA specifications to deal with hard real-time requirements. In addition to the above technical work, the project will undertake targeted dissemination actions in order to achieve maximum impact of the project findings. These will in particular include contributions to the CORBA standardisation activities and the launch of a specification process inside the OMG.

# 6 Project Achievements

The project work changed a little in relation with was planned for varying reasons (delays, refocus of work, additional issues not considered initially, etc) and that had the consequence of produced a final result that does not fully fulfil the original expectations. This fact clarified, the project has reached quite good results in all the five main objectives:

- **Know-how in distributed real-time object-oriented control systems**: Domain analysis, architecting and engineering information collection have been performed. The resulting documents cannot be considered final but as a first step in the production of usable material by control engineering practitioners. These documents are public through the CORBA Control Systems Website. As an additional work not originally planned, the tools Jitterbug an TrueTime were extended to be able to analyze CORBA-based control loops.

- **A pluggable real-time ORB protocol prototype**: Not one but two pluggable protocols have been developed; one over TTP and another one over switched Ethernet. The TTP protocols demonstrate the possibility of jitter reduction sacrificing flexibility of the application object interfaces. The Ethernet protocol demonstrates that existing of-the-self hardware technologies can meet the needs of CORBA control systems when properly managed by software.

- **A robot control testbed**: The RCT implements a CORBA control system of a robot. This is a two level controller with visual servoing based on the Ethernet transport.

- **A process control testbed**: The PCT demonstrates the possibility of using CORBA across the whole plant for process control systems. This system demonstrates sensor and actuator wrapping, legacy DCS integration, simulation integration and effective networked control.

- **A specification process for CORBA-based control systems**: The OMG has chartered a working group in control systems and the specification process for CORBA technologies in control applications has started with the preparation of a white paper and an RFI.

In summary, while not all the expectations have been fulfilled, the final result of the project mostly meets the initial objectives. The results are considered very valuable and they will serve the original purpose of enhancing applicability and perceived value of CORBA technology for industrial control systems.

# 7 Execution Summary

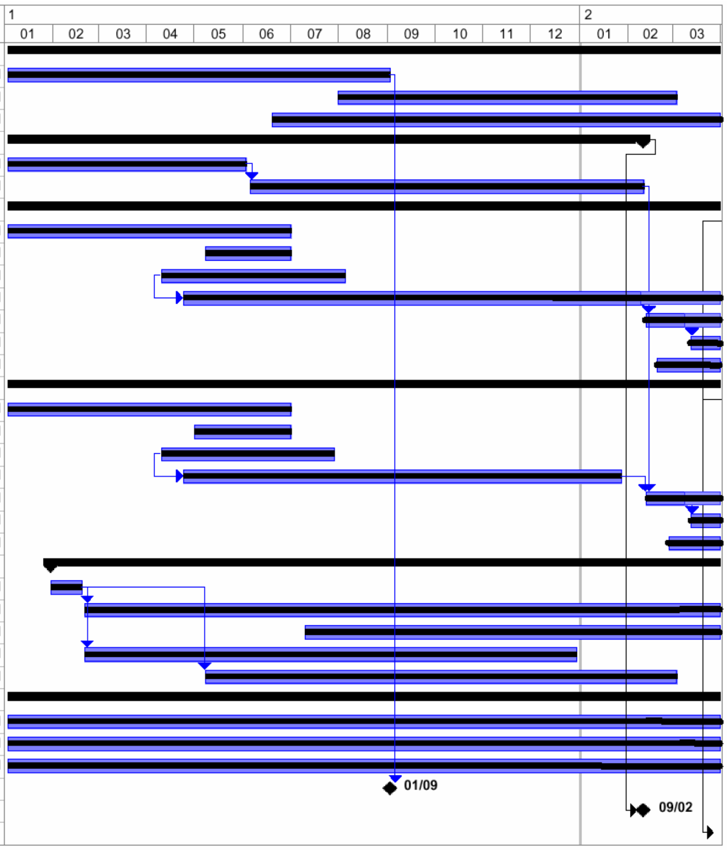
## 7.1 Global execution

The project was scheduled for 12 months but was extended for three months more up to 15. The work in some workpackages was delayed for different reasons (perhaps it was too optimistically scheduled initially) and that caused accumulated delays in other tasks of the project.

Globally the execution was good enough to reach acceptable results for all the partners and objectives.

## 7.2 Gantt Chart

| Id | Nombre de tarea | Duración |
|---|---|---|
| 1 | **1 CORBA Control Systems** | **325 d** |
| 2 | 1.1 CCS Domain Analysis | 175 d |
| 3 | 1.2 CCS Domain Architectures | 155 d |
| 4 | 1.3 CCS Engineering Process | 205 d |
| 5 | **2 HRT Protocols** | **290 d** |
| 6 | 2.1 Protocols for Real-time Control | 110 d |
| 7 | 2.2 HRT Pluggable CORBA Protocols | 180 d |
| 8 | **3 Test 1: Robot Control** | **325 d** |
| 9 | 3.1 RCT Requirements specification | 130 d |
| 10 | 3.2 RCT Design | 40 d |
| 11 | 3.3 RCT Procurement | 85 d |
| 12 | 3.4 Non HRTP RCT Implementation | 210 d |
| 13 | 3.5 HRTP RCT implementation | 20 d |
| 14 | 3.6 RCT Testing | 15 d |
| 15 | 3.7 RCT Documentation | 30 d |
| 16 | **4 Test 2: Process Control** | **325 d** |
| 17 | 4.1 PCT Requirements specification | 130 d |
| 18 | 4.2 PCT Design | 45 d |
| 19 | 4.3 PCT Procurement | 80 d |
| 20 | 4.4 Non HRTP PCT Implementation | 200 d |
| 21 | 4.5 HRTP PCT implementation | 20 d |
| 22 | 4.6 PCT Testing | 15 d |
| 23 | 4.7 PCT Documentation | 25 d |
| 24 | **5 Dissemination** | **305 d** |
| 25 | 5.1 Dissemination Planning | 15 d |
| 26 | 5.2 OMG Standardization | 290 d |
| 27 | 5.3 Publications | 190 d |
| 28 | 5.4 HRTC Web site | 225 d |
| 29 | 5.5 Exploitation and Use Planning | 215 d |
| 30 | **6 Management** | **325 d** |
| 31 | 6.1 Project Coordination and Reporting | 325 d |
| 32 | 6.2 Project Management | 325 d |
| 33 | 6.3 Project Assessment | 325 d |
| 34 | 6.4 Milestone 1: Domain Analysis | 0 d |
| 35 | 6.5 Milestone 2: HRT Protocols | 0 d |
| 36 | 6.6 Milestone 3: Final Results | 0 d |



## 7.3 Efforts

| Partner | WorkPackage | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | Total | Accumulated |
|---|---|---|---|---|---|---|---|---|---|
| UPM | Q1 | 1 | 0 | 0,2 | 2 | 1 | 1,5 | 5,7 | 5,7 |
| | Q2 | 2 | 0,5 | 0 | 8 | 1 | 1,5 | 13 | 18,7 |
| | Q3 | 3 | 0,5 | 0 | 7,5 | 1 | 1,5 | 13,5 | 32,2 |
| | Q4 | 2 | 0 | 0 | 8 | 0,25 | 1 | 11,25 | 43,45 |
| | Q5 | 4,5 | 0 | 0 | 2 | 1 | 2 | 9,5 | 52,95 |
| | Used | 12,5 | 1 | 0,2 | 27,5 | 4,25 | 7,5 | 52,95 | |
| | Planned | 12,5 | 2 | 5 | 12 | 7,5 | 7 | 46 | |
| ULUND | Q1 | 1,5 | 0,5 | 2 | 0 | 0 | 0,5 | 4,5 | 4,5 |
| | Q2 | 5 | 0,5 | 3 | 0 | 0 | 0,5 | 9 | 13,5 |
| | Q3 | 2,5 | 0,5 | 3 | 0 | 0 | 0,25 | 6,25 | 19,75 |
| | Q4 | 2,5 | 2 | 3 | 0 | 0 | 0,25 | 7,75 | 27,5 |
| | Q5 | 1 | 5 | 10 | 0 | 0 | 0,25 | 16,25 | 43,75 |
| | Used | 12,5 | 8,5 | 21 | 0 | 0 | 1,75 | 43,75 | |
| | Planned | 14 | 2 | 10 | 5 | 4 | 2 | 37 | |
| TUV | Q1 | 0 | 1,34 | 0,13 | 0 | 0,465 | 0,645 | 2,58 | 2,58 |
| | Q2 | 0,5 | 2,1 | 0 | 0,2 | 0,2 | 0,5 | 3,5 | 6,08 |
| | Q3 | 0 | 0,92 | 0,18 | 0 | 0,89 | 0,67 | 2,66 | 8,74 |
| | Q4 | 0,49 | 0 | 1,86 | 0 | 0,73 | 0,17 | 3,25 | 11,99 |
| | Q5 | 1,47 | 1,43 | 0 | 0,57 | 0,5 | 0,48 | 4,45 | 16,44 |
| | Used | 2,46 | 5,79 | 2,17 | 0,77 | 2,785 | 2,465 | 16,44 | |
| | Planned | 3 | 4 | 1 | 1 | 2,5 | 2 | 13,5 | |
| SCILabs | Q1 | 0 | 1 | 0,5 | 0,5 | 0,75 | 0,25 | 3 | 3 |
| | Q2 | 0 | 1,5 | 1 | 1 | 1,25 | 0,25 | 5 | 8 |
| | Q3 | 1 | 1,5 | 0,5 | 0,5 | 0,5 | 0,3 | 4,3 | 12,3 |
| | Q4 | 0 | 1 | 1 | 1,5 | 0,5 | 0,2 | 4,2 | 16,5 |
| | Q5 | 0,7 | 0,7 | 0,5 | 0,5 | 0,5 | 0,3 | 3,2 | 19,7 |
| | Used | 1,7 | 5,7 | 3,5 | 4 | 3,5 | 1,3 | 19,7 | |
| | Planned | 1,5 | 5 | 4 | 4 | 3,5 | 1 | 19 | |

| Global | | WP1 | WP2 | WP3 | WP4 | WP5 | WP6 | Total | Accumulated |
|---|---|---|---|---|---|---|---|---|---|
| | Q1 | 2,5 | 2,84 | 2,83 | 2,5 | 2,215 | 2,895 | 15,78 | 15,78 |
| | Q2 | 7,5 | 4,6 | 4 | 9,2 | 2,45 | 2,75 | 30,5 | 46,28 |
| | Q3 | 6,5 | 3,42 | 3,68 | 8 | 2,39 | 2,72 | 26,71 | 72,99 |
| | Q4 | 4,99 | 3 | 5,86 | 9,5 | 1,48 | 1,62 | 26,45 | 99,44 |
| | Q5 | 7,67 | 7,13 | 10,5 | 3,07 | 2 | 3,03 | 33,4 | 132,84 |
| Total | Used | 29,16 | 20,99 | 26,87 | 32,27 | 10,535 | 13,02 | 132,84 | |
| Total | Planned | 31 | 13 | 20 | 22 | 17,5 | 12 | 115,5 | |

## 7.4 Deliverables

The following table contains the list of deliverables produced during the project.

| Doc Id | Document Name | Lead | Date |
|---|---|---|---|
| Deliverables | | | |
| D1.1 | CCS Domain Analysis | ULUND | M8 |
| D1.2 | CCS Domain Architectures | UPM | M12 |
| D1.3 | CCS Engineering Handbook | UPM | M15 |
| D2.1 | Protocols for Real-time Control | TUWien | M6 |
| D2.2 | HRT Protocol Specification | SCILabs | M8 |
| D2.3 | HRT Protocol | SCILabs | M12 |
| D3.1 | RCT Requirements specification | ULUND | M6 |
| D3.2 | RCT Design | ULUND | M6 |
| D3.3 | RCT Procurement | ULUND | M8 |
| D3.4 | Non HRTP RCT Implementation | ULUND | M15 |
| D3.5 | HRTP RCT implementation | ULUND | M15 |
| D3.6 | RCT Testing | ULUND | M15 |
| D3.7 | RCT Documentation | ULUND | M15 |
| D3.7 | PCT Documentation | UPM | M15 |
| D4.1 | PCT Requirements specification | UPM | M6 |
| D4.2 | PCT Design | UPM | M6 |
| D4.3 | PCT Procurement | UPM | M6 |
| D4.4 | Non HRTP PCT Implementation | UPM | M12 |
| D4.5 | HRTP PCT implementation | UPM | M15 |
| D4.6 | PCT Testing | UPM | M15 |
| D5.1 | Dissemination Plan | UPM | M3 |
| D5.4 | HRTC Project Web Page | SCILabs | M14 |
| D5.5 | Draft Exploitation and Use Plan | SCILabs | M6 |
| D5.6 | Exploitation and Use Plan | SCILabs | M14 |
| D6.1 | Project Management Manual | UPM | M3 |
| D6.2 | Evaluation Plan | UPM | M5 |
| D6.3 | Quarterly Report M3 | UPM | M5 |
| D6.4 | Periodic Report M6 | UPM | M6 |
| D6.5 | Quarterly Report M9 | UPM | M10 |
| D6.6 | Periodic Report M12 | UPM | M14 |
| D6.7 | Project Evaluation Report | UPM | M15 |
| D6.8 | Final Report | UPM | M15 |
| D6.9 | Periodic Report M15 | UPM | M15 |
| **Additional Deliverables in WP5** | | | |
| D5.2.1 | HRTC Overview | UPM | M3 |
| D5.2.2 | Hard Real Time CORBA | TUV | M3 |
| D5.2.3 | IST HRTC Toward HRT CORBA | UPM | M5 |

| | | | |
|---|---|---|---|
| D5.2.4 | OMG CSWG Charter | UPM | M5 |
| D5.2.5 | CSWG Meeting SF | UPM | M7 |
| D5.2.6 | CSWG Rationale | UPM | M7 |
| D5.2.7 | CSWG White Paper | UPM | M8 |
| D5.2.8 | HRTC Poster at OMG | UPM | M13 |
| D5.2.9 | CORBA over TTP at OMG | TUV | M13 |
| D5.2.10 | Control Systems RFI | UPM | M15 |
| D5.3.1 | HRTC Flyer | All | M3 |
| D5.3.2 | ADCHEM Paper | UPM | M6 |
| **Additional non-contractual documents** | | | |
| HRTC057 | TrueTime and Jitterbug | LTH | M15 |
| HRTC066 | RTE Protocol Definition | SCI | M14 |
| HRTC067 | TTP Protocol Definition | SCI | M14 |
| HRTC082 | HRTC Market Study | SCILabs | M14 |
| HRTC088 | Technology Implementation Plan | SCILabs | M15 |

# 8 Project Testbeds

## 8.1 Process Control Testbed

### *8.1.1 Process description*

The controlled process is the neutralization of acetic acid (0.1M) with sodium hydroxide (0.1M). It has two control loops: one controls the pH and another one controls the temperature.

The main objective of the distributed process control testbed is to identify (mainly hard real time) requirements for distributed control systems and perform experiments in conditions of systems heterogeneity and legacy integration. Experiments will be done using conventional IIOP and the new real-time protocol.

The process has two feeds, the first one is the acid which is the one to be neutralized. This is set to a fixed flow and concentration and any variation is a disturbance to the process. The second one is the base feed, this feed is set by the pH control loop. This loop has the pHmeter a controller (PI) and the base pump as the actuator.

There is a small reactor for the neutralization process and its output stream goes to a product tank through a weir.

This is the process with its main control loop, there is an additional loop for temperature control. This loop has no special relevance for the process but it is needed for the experiments to be taken. This loop has a temperature transmitter (pt100) a controller (PI) and pump as actuator. This pump is fed by hot water coming from a heater.

### *8.1.2 Testbed Components*

**Networks**

A 100BASE-TX Ethernet with with redundant connection to 2 switches.
A TTP cluster with five nodes and redundant hubs.

**Sensors**

Sensors measure physical values of the process variables. There are different types in a process plant: temperature sensors, pressure sensors, flowmeters, etc.

Sensors are usually connected to conventional (4-20 mA) or ‘smart’ (digital bus) transmitters, that transport the measurement to the control system. In the commercial DCS they enter through the I/O cards.

For connecting the sensors to the Ethernet network in the PCT it is necessary to have a wrapper node that, ideally, could be integrated in the instrument.

Two kind of sensors shall be used:

- Actual (physical) instruments with a transmitter and an input card in the DCS (analog signal or serial interface) or the wrapper node (serial interface).
- Simulated sensors instantiated on the wrapper node. They will allow to test the effect of a large number (a more realistic scenario at a reasonable cost) of sensor on the system performance.

**Actuators**

Actuators are the final elements of a control loop, modifying the process conditions as the result of the controller command. They include control valves, frequency variators, etc.

As it happened in the case of the sensors, a wrapper node (or the DCS) with I/O cards is necessary to connect them to the network (or the HPM controller, see TPS subsection below). Also two kinds of actuators shall be used: actual and simulated

**Controllers**

The controllers receive the signal of the sensors and as a function of their setpoints and control algorithms calculate the output signal to be sent to the actuator. There will be two controller types:

- Controllers integrated in the DCS (HPM) that receives and sends signals (initially) internally without entering the Ethernet network.
- Autonomous controller nodes built for this project that implement the CORBA Control algorithms, and that communicate with the sensors and actuators through the Ethernet or TT networks.

**Human-Machine Interface**

The Human-Machine Interface in modern Plant Control Systems is usually a graphical interface, with or without windows. The HMI allows the monitoring function carried by human operators, as well as their interaction with the process by means or control actions, such as starting up/stopping units, changing setpoints, etc.

In the PCT, preferentially graphical HMI nodes shall be built in order to access and interact with the data and agents on the network.

**Database**

Historical databases record selected data from the control system configuration and/or operation. Also, they usually contain the sistem software files. Operators can access to them through HMIs.

**Commercial DCS**

An already available commercial DCS, the Honeywell TPS (TDC 3000), will be used. The system is composed by:

- A High-Performance Process Manager (HPM) controller
- A Global User Station (GUS)
- A History Module (HM)
- A Network Interface Module (NIM)
- A redundant Local Control Network (LCN)
- A redundant Universal Control Network (UCN)
- Several I/O cards:
- Analog Input (AI)
- Analog Output (AO)
- Digital Input (DI)
- Digital Output (DO)
- Serial (Modbus) Interface (SI)

With the available hardware, to integrate the TPS in the Ethernet network the system could be wrapped (with a PC) via the serial bus or via the GUS. The serial bus has the advantage of directly accessing the controller (HPM) like sensors or actuators do.

A temperature sensor and transmitter enter the system through the AI card. The heating module is controlled by an AO output signal.

**Simulator**

An increasing number of control and monitoring functions utilize models in on-line and off-line applications as:

- Hardware in the loop
- Operator training

In such context, the availability of pluggable simulation nodes accessible by the other components in a transparent way will constitute and advance from the current state. In the PCT the ABACUSS II simulator is used by means of an object wrapper.

### *8.1.3 Functionality*

The PCT was designed to be able to comprehend the functionality of both present and future process plant control systems. The idea is to try to build such a control system using CORBA components and check whether it is possible to:

- Perform the tasks that current systems usually do.
- Accomplish the tasks that future systems are expected to achieve.

The results of the experiments (mainly the negative ones) will identify the features needed in HRTC to be used in control systems.

During the HRTC project some experiments were performed.

- Single control loop
- Legacy system integration
- Simulation components integration
- Traffic capacity test
- Concurrent access

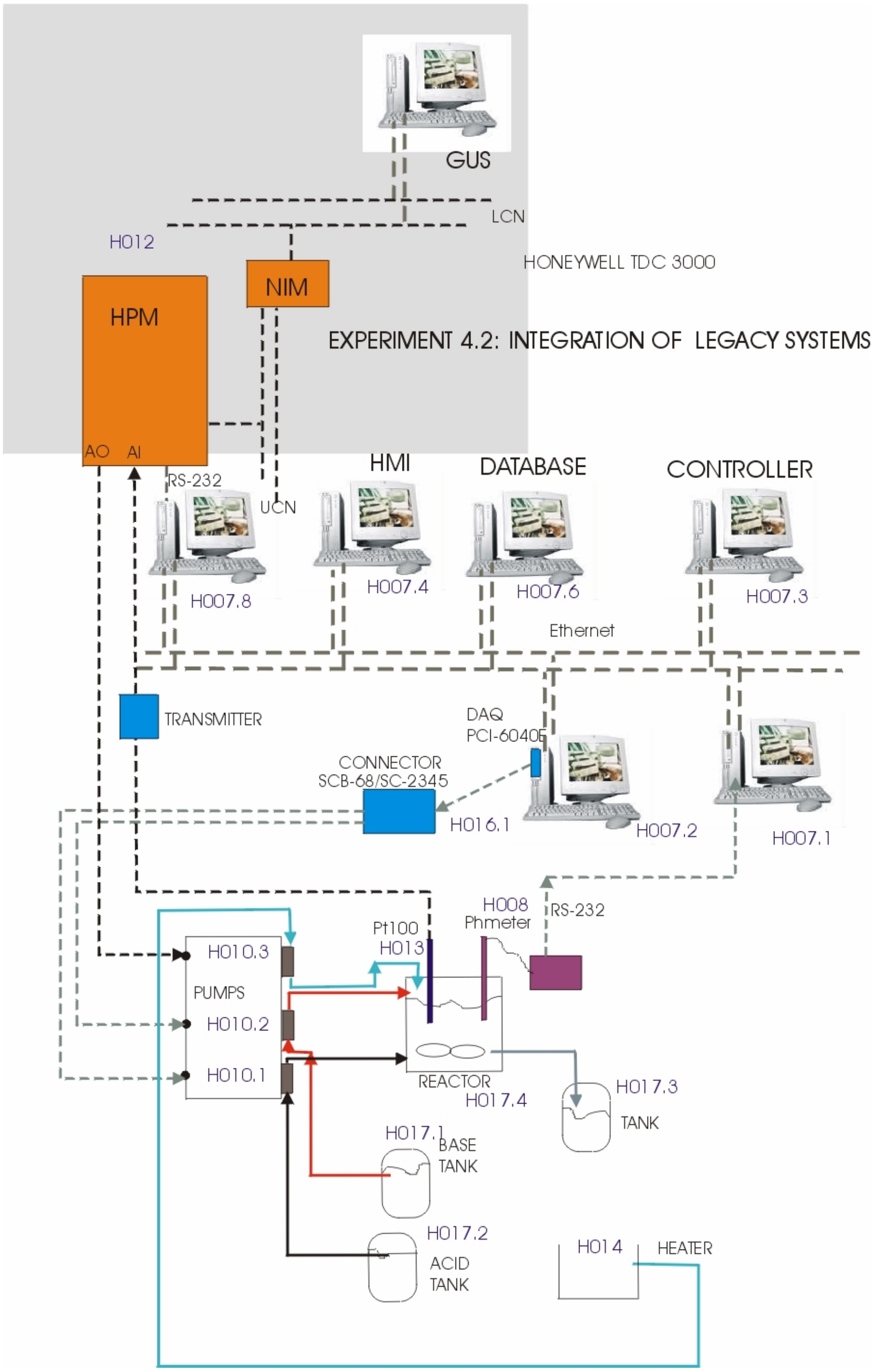



**Figure 2:** Process Control Testbed setup.

## 8.2 Robot Control Testbed

### 8.2.1 Purpose of the testbed

The purpose of the Robot Control Testbed experiment was to catch a thrown object using a 6-DOF industrial robot. A stereo vision system estimates the ball trajectory and a predicted catch point.

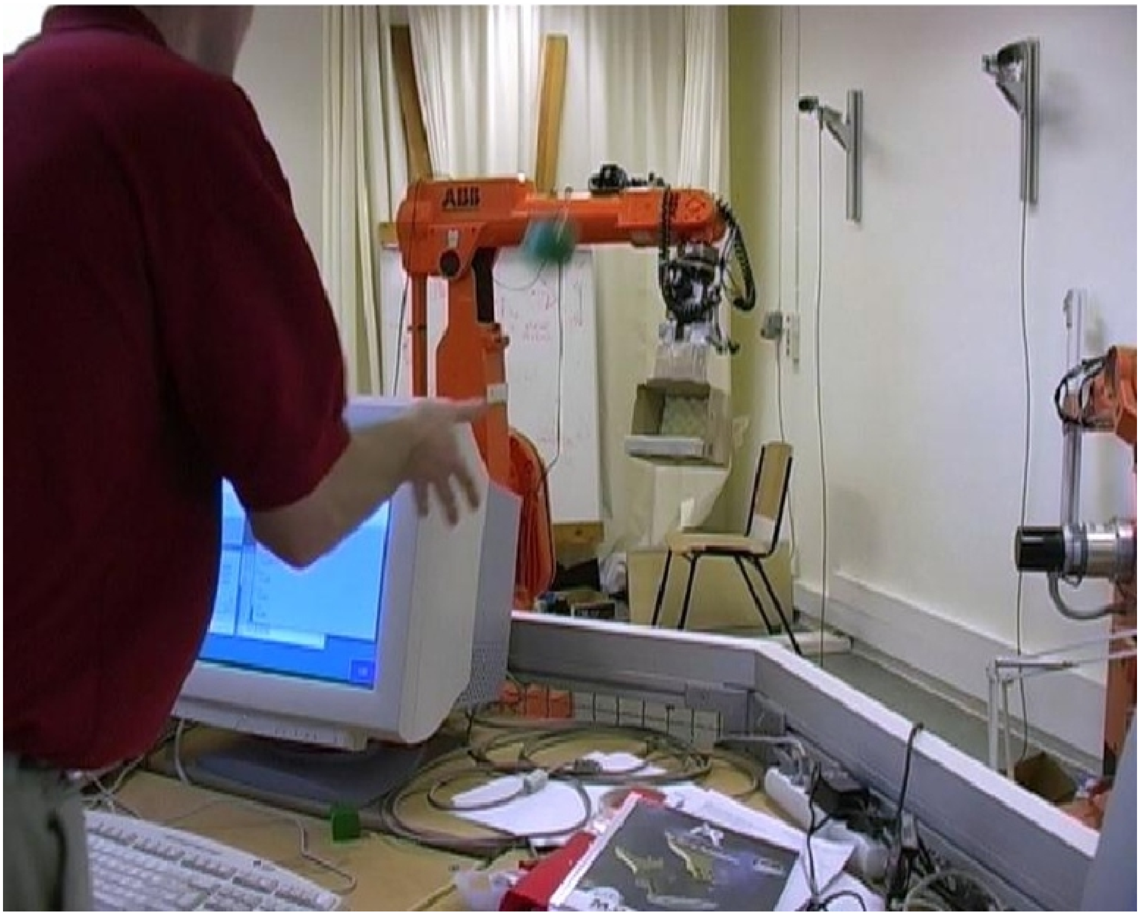


**Figure 3:** Experimental setup showing the two digital cameras mounted on the wall with the Irb-2000 robot ready to catch the thrown ball.

The experiment setup consists of an ABB Irb-2400 industrial robot and two digital video cameras calibrated to Cartesian space. The two cameras are placed on a wall behind the robot in stereo configuration, facing the throwing person.

Included in the vision subsystem are three computers, each with one dedicated task. The images from the cameras are sent through an IEEE 1394 network to the low-level vision computer. From this computer, image feature points are sent to the ball trajectory estimation computer, located on a TCP/IP network. This computer in turn sends a predicted catch point to a third computer which calculates a robot reference trajectory. Finally, the trajectory is sent to the robot control system through a TCP/TN network bridge.

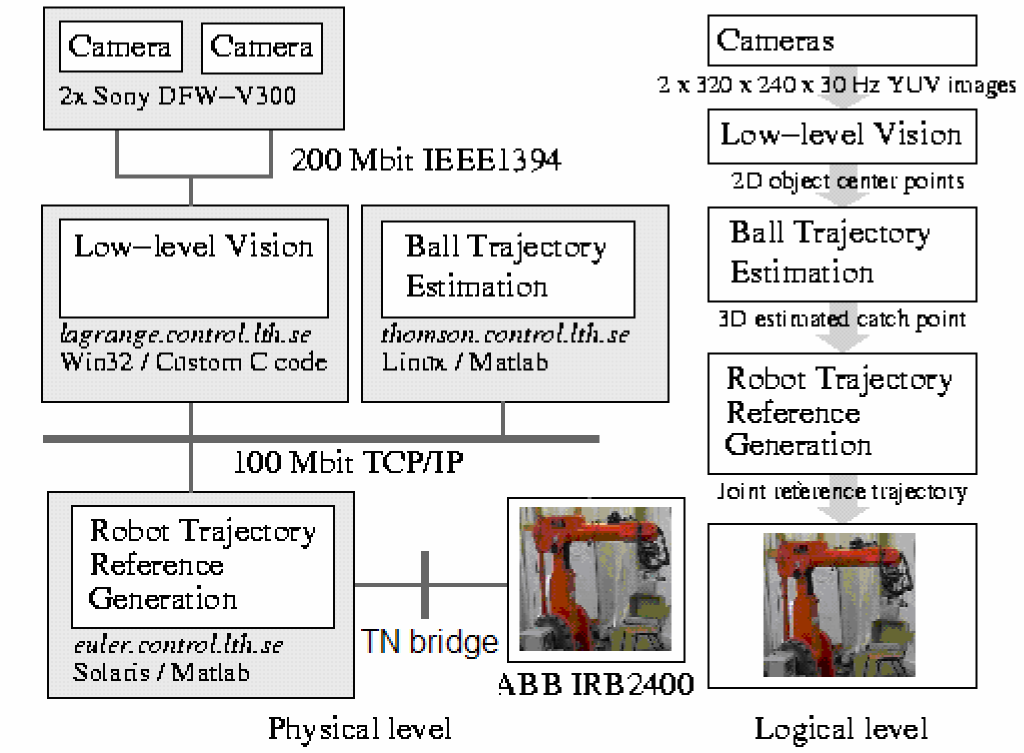



**Figure 4:** The vision subsystem runs on three different computers (excluding the TN bridge which is run on a separate Linux/RTAI machine). To the right, the information flow in the vision subsystem is shown.

### *8.2.2 Testbed robot controller*

The ABB Irb2000 robot is controlled through an open controller (which is not ABB original) developed at Dept. of Automatic control. The control system consists of cascaded PID controllers with velocity feed-forward typically running at 8 (or 4 in some tests) kHz.

The testbed robot controller is built from four computer nodes. A distributed system is formed where three of the nodes communicate through switched Ethernet. From a control perspective a closed loop is formed by measuring current joint angles (resolver), calculating reference joint torques (controller) and driving joint motors (actuator).

The resolver and actuator computer nodes consist of Etrax computers running Linux. The controller node is implemented on two PPC MVME cards running Linux and a proprietary RTOS called Stork (developed at Dept. of Automatic Control). The Stork PPC card acts as slave against the Linux PPC card. Stork PPC and Linux PPC communicates through shared memory over the VME bus.

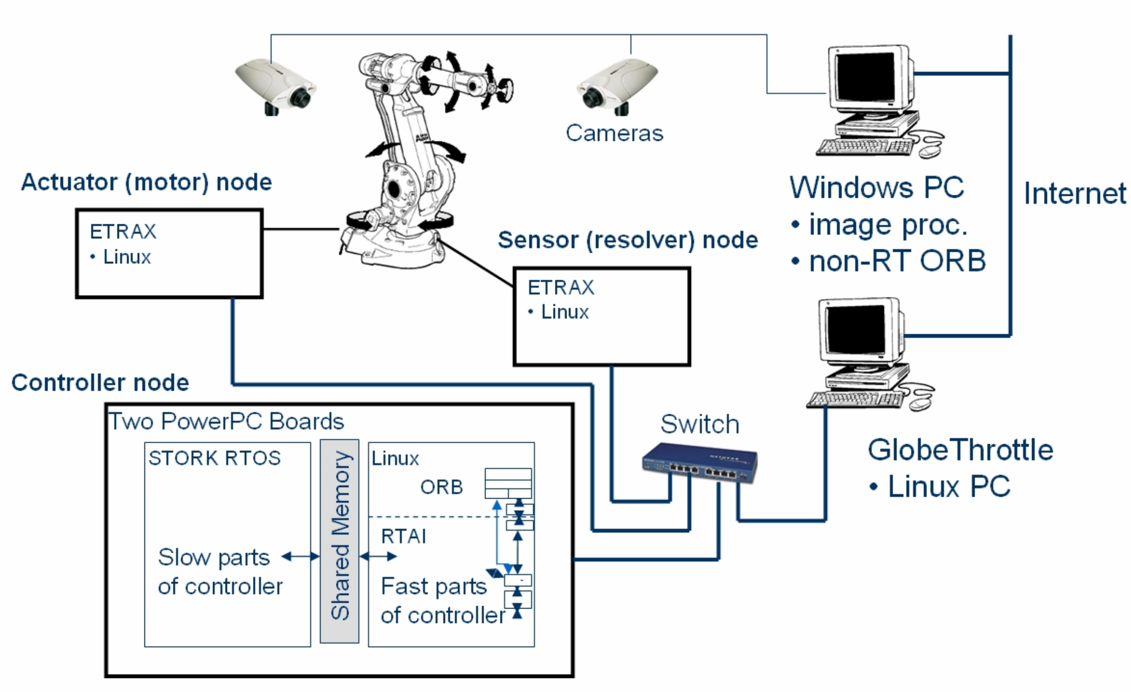



**Figure 5:** The robot controller together with the vision subsystem**.**

From an extrinsic perspective the robot controller expects to receive trajectories consisting of a vector of time-stamps, joint positions and joint velocities for joints 1-6. It is possible to divide a trajectory into several subtrajectories which are sent gradually to the controller. Thus, the end-point of the trajectory does not need to be known at the time the trajectory is started. This fact is utilized in the testbed experiment.

In the current setup the testbed experiment runs OCI-RT-ORBs on all nodes except the Etrax computers. For the moment it is not possible to run the TN driver on the Etrax:es due to Linux/RTAI problems, and therefore not the TN OCI transport. The old RT-system is therefore still used on the Etrax:es. On the other hand, all computer nodes connected through switched Ethernet have been running ORBs communicating through IIOP, so there seem to be no inherent problem with using CORBA technology on Etrax:es.

### *8.2.3 RCT hard real-time requirements*

The base frequency of the controller is adjustable up to 10 kHz, but typical sampling rates are 4 or 8 kHz. The controller implementation assumes the maximum latency from resolver to actuator to be one sample. This implies a maximum latency of 250 and 125 microseconds. The TN transport consumes a total of 100 microseconds in communication latency (resolver to controller and controller to actuator) leaving 150 and 25 microseconds respectively for allowable computational delay. On the faster MVME-2400 boards, 25 microseconds is also the CPU time needed for performing the joint servo control. Hence, the likely overhead of full CORBA would not be acceptable, but the hybrid communication approach used permits a sufficiently fast processing.

# 9 Future Activities

## 9.1 OMG Control Systems WG

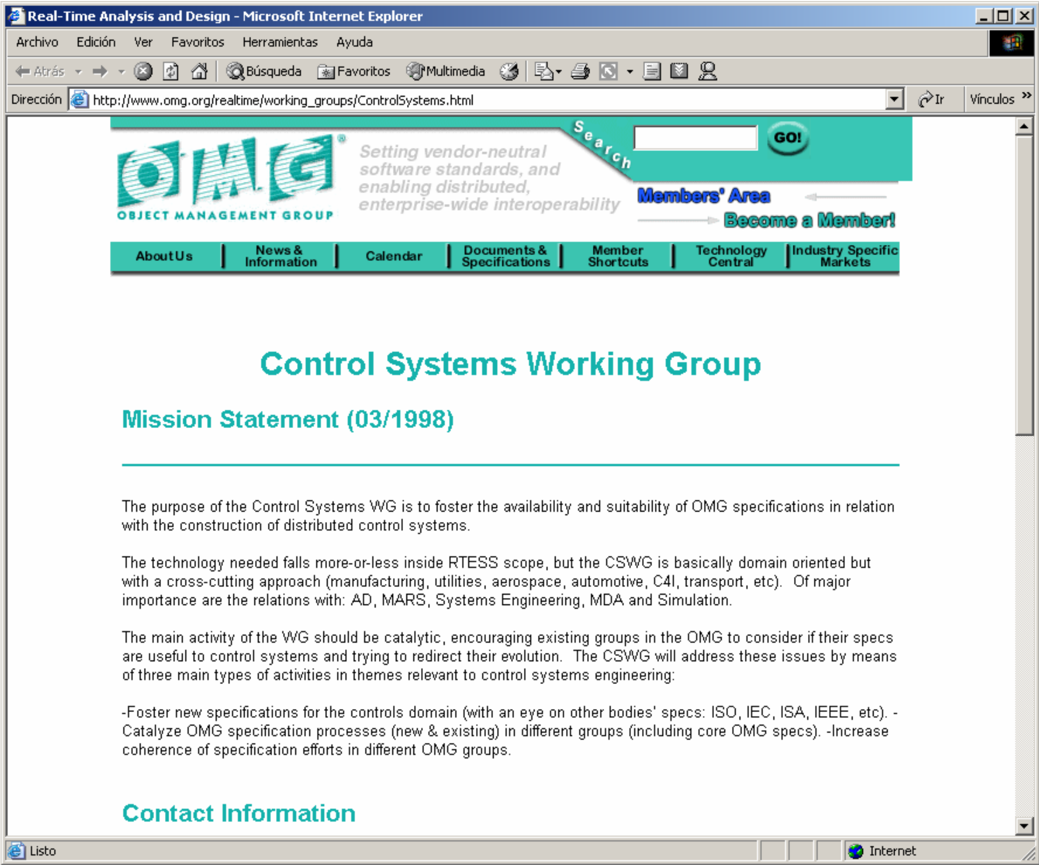
During the project, the Control Systems Working Group was chartered by the OMG to coordinate activities related with OMG specifications of interest to the control community. This is the charter of the CSWG:

- The purpose of the **Control Systems WG** is to foster the availability and suitability of OMG specifications in relation with the construction of **distributed control systems**.
- The technology needed falls more-or-less inside RTESS scope, but the CSWG is basically **domain oriented** but with a **cross-cutting approach** (manufacturing, utilities, aerospace, automotive, C4I, transport, etc). Of major importance are the relations with: AD, MARS, Systems Engineering, MDA and Simulation.
- The main activity of the WG should be **catalytic**, encouraging existing groups in the OMG to consider if their specs are useful to control systems and trying to redirect their evolution.
- The **CSWG** will address these issues by means of **three main types of activities** in themes *relevant to control systems engineering*:
  - **Foster** new specifications for the controls domain (with an eye on other bodies' specs: ISO, IEC, ISA, IEEE, etc).
  - **Catalyze** OMG specification processes (new & existing) in different groups (including core OMG specs).
  - **Increase** coherence of specification efforts in different OMG groups.

The Web page of the CSWG can be found at:

http://www.omg.org/realtime/working_groups/ControlSystems.html

It is the intention of the people in the consortium deeply involved on OMG activities to continue this relation.




## 9.2 CORBA Control Systems

During the project three documents were generated to be disseminated in the control systems community:

- CORBA Control Systems Domain Analysis
- CORBA Control Systems Domain Architectures
- CORBA Control Systems Engineering Handbook

# 10 Annexes

## 10.1 Project Documents

Contractual deliverables have the deliverable number in the fourth column. Entries marked with * were not contractual deliverables but were released for revision in addition to project deliverables.

| Number | Title | Main Author | Deliverable |
|---|---|---|---|
| 001 | HRTC Contract | HRTC Consortium | |
| 002 | Barcelona Meeting Minutes | Ricardo Sanz | |
| 003 | Dissemination Plan | Ricardo Sanz | D5.1 |
| 004 | Project Management Manual | Ricardo Sanz | D6.1 |
| 005 | Evaluation Plan | Ricardo Sanz | D6.2 |
| 006 | PCT Requierements Specification | Manuel Rodrigez | D4.1 |
| 007 | Reading List | Ricardo Sanz | |
| 008 | Long Report Template | Ricardo Sanz | |
| 009 | Short Report Template | Ricardo Sanz | |
| 010 | Presentation Template | Ricardo Sanz | |
| 011 | Vienna Meeting Minutes | Ricardo Sanz | |
| 012 | Vienna Meeting Agenda | Thomas Losert | |
| 013 | Meeting Objectives and Project Status | Ricardo Sanz | |
| 014 | CORBA Control Systems | Ricardo Sanz | |
| 015 | Real-time CORBA | Miguel Segarra | |
| 016 | CORBA Pluggable Transports | Miguel Segarra | |
| 017 | Networked Control Systems | Karl-Erik Årzën | |
| 018 | Scheduled Switched Ethernet | Anders Blomdell | |
| 019 | Introduction to TTA | Thomas Losert | |
| 020 | OMG Smart Sensors Specification | Thomas Losert | |
| 021 | TTTech Demonstration | Ralf Schlatterberg | |
| 022 | Robot Control Testbed | Klas Nilsson | |
| 023 | Process Control Testbed | Manuel Rodrigez | |
| 024 | Meeting Closing Issues | Ricardo Sanz | |
| 025 | Advance Payment | Ricardo Sanz | |
| 026 | HRTC Flyer | Ricardo Sanz | D5.3.1 |
| 027 | Presentation Template (Light Side) | Ricardo Sanz | |
| 028 | HW/SW Platforms | Thomas Losert | |
| 029 | HRTC Overview - OMG Sep'03 | Ricardo Sanz | D5.2.1 |
| 030 | Quarterly Report M3 | Ricardo Sanz | D6.3 |
| 031 | OMG Helsinki Technical Meeting Report | Ricardo Sanz | |
| 032 | Hard Real Time CORBA - IST 37652 | Thomas Losert | D5.2.2 |
| 033 | Control Systems WG | Ricardo Sanz | D5.2.3 |
| 034 | OMG Nov'03 Technical Meeting Report | Ricardo Sanz | |

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|---|---|---|---|
| 035 | OMG CSWG Charter | Ricardo Sanz | D5.2.4 |
| 036 | Protocols for Real-time Control | Thomas Losert | D2.1 |
| 037 | Review Meeting Agenda | Ricardo Sanz | |
| 038 | PCT Design | Santos Galan | D4.2 |
| 039 | PCT Procurement | Santos Galan | D4.3 |
| 040 | CORBA for Control Systems White Paper | Ricardo Sanz | |
| 041 | HRTC for Chemical Control Systems | Santos Galan | D5.3.3 |
| 042 | Periodic Report M6 | Ricardo Sanz | D6.4 |
| 043 | RCT Requierements Specification | Klas Nilsson | D3.1 |
| 044 | RCT Design | Klas Nilsson | D3.2 |
| 045 | Paper for ADCHEM 2003 | Santos Galan | D5.3.2 |
| 046 | RCT Procurement | Klas Nilsson | |
| 047 | First Review Shipment | Ricardo Sanz | |
| 048 | HRT Protocol Specification | Miguel Segarra | D2.2 |
| 049 | Draft Exploitation and Use Plan | Miguel Segarra | |
| 050 | CCS Domain Analysis | Karl-Erik Arzen | D1.1 |
| 051 | Questionarie | Carlos Baeza | |
| 052 | Minutes of the Brussels PM | Santos Galán | |
| 053 | Minutes of the 6M Review | Santos Galán | |
| 054 | Brief Questionaire | Miguel Segarra | |
| 055 | OMG TC Jan. 2003 Meeting Report | Ricardo Sanz | |
| 056 | Madrid Meeting Minutes | Santos Galán | |
| 057 | TrueTime and Jitterbug | Anton Cervin | * |
| 058 | ICa Install | Rafael Chinchilla | |
| 059 | HRTC Consortium Agreement | Sibylle Kuster | |
| 060 | CCS Domain Architectures | Santos Galán | D1.2 |
| 061 | Minutes of the 4th Technical Meeting | Ricardo Sanz | |
| 062 | Short Term Planning | Ricardo Sanz | |
| 063 | CSWG Meeting | Ricardo Sanz | D5.2.5 |
| 064 | CSWG Rationale | Ricardo Sanz | D5.2.6 |
| 065 | CSWG Control Systems White Paper | Thomas Losert | D5.2.7 |
| 066 | RT Ethernet transport definition | Anders Blomdell | * |
| 067 | TTP transport definition | Thomas Losert | * |
| 068 | PCT Testing | Manuel Rodriguez | D4.6 |
| 069 | PCT Documentation | Manuel Rodriguez | D4.7 |
| 070 | RTE-DOC HRTC Poster | Ricardo Sanz | D5.2.8 |
| 071 | RTE-DOC CORBA in the TTA | Hermann Kopetz | D5.2.9 |
| 072 | CCS Engineering Handbook | Ricardo Sanz | D1.3 |
| 073 | Second Review Meeting Agenda | Ricardo Sanz | |
| 074 | CSWG RFI | Ricardo Sanz | D5.2.10 |
| 075 | Non HRT PCT Implementation | Manuel Rodriguez | D4.4 |
| 076 | HRT PCT Implementation | Manuel Rodriguez | D4.5 |
| 077 | Non HRT RCT Implementation | Klas Nilsson | D3.4 |
| 078 | HRT RCT Implementation | Klas Nilsson | D3.5 |
| 079 | RCT Testing | Klas Nilsson | D3.6 |
| 080 | RCT Documentation | Klas Nilsson | D3.7 |
| 081 | HRT Protocol | Miguel Segarra | D2.3 |
| 082 | HRT CORBA Market Study | Miguel Segarra | * |
| 083 | Web Page | Miguel Segarra | D5.4 |
| 084 | First payment | Ricardo Sanz | |

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|---|---|---|---|
| 085 | Exploitation and Use Plan | Miguel Segarra | D5.6 |
| 086 | Second Review Deliverables | Ricardo Sanz | |
| 087 | Second Review Minutes | Ricardo Sanz | |
| 088 | Technology Implementation Plan | Miguel Segarra | |
| 089 | Project Evaluation Report | Ricardo Sanz | D6.7 |
| 090 | Peridic Report M15 | Ricardo Sanz | |
| 091 | Final Report | Ricardo Sanz | D6.8 |

## 10.2 Published papers

**Hard Real-Time CORBA (HRTC) For Process Control Systems**
International symposium on Advance Control of Chemical Processes
ADCHEM 2003, Hong Kong, June 18-20, 2003[2].

**Scalable Distributed Intelligence**
Plenary Speech at IEEE Intelligent Control Symposium
ISIC 2003, Houston, USA, October 2003.

**CORBA in the Time-Triggered Architecture**
OMG Workshop on Distributed Object Computing for Real-time and Embedded Systems
Washington D.C., USA, July 2003.

**Adding Hard Real-Time Capabilities to CORBA**
Proceedings of the First Workshop on Intelligent Solutions in Embedded Systems
Vienna, Austria, June 2003

**An Experiment in Distributed Objects for Real-Time Control**
9th International Conference on Emerging Technologies and Factory Automation
ETFA 2003, Lisbon, Portugal, Sept. 16-19, 2003.

**A Pattern Schema for Complex Controllers**
9th International Conference on Emerging Technologies and Factory Automation
ETFA 2003, Lisbon, Portugal, Sept. 16-19, 2003.

[2] Moved to January 2004 due to SARS.

## 10.3 Contact Points

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