INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team NeCS

Networked Control Systems

Grenoble - Rhône-Alpes

THEME NUM

Activity Report

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Table of contents

NeCS is a joint project-team with GIPSA-lab (CNRS, INPG and UJF).

1. Team

Research Scientist
Carlos Canudas-de-Wit [Team Leader DR CNRS, HdR]
Mazen Alamir [DR CNRS, HdR]
Nicolas Marchand [CR CNRS]
Daniel Simon [CR INRIA, HdR]
Alexandre Seuret [CR CNRS from October 2008]

Faculty Member
Olivier Sename [PR Inpg, HdR]
Cyrille Siclet [MdC Ujf]

Technical Staff
Florine Boudin [Young Engineer - from November 2008]

PhD Student
Carolina Albea-Sanchez [MENRT - 2007/2010, in coll with Univ. Sevilla]
Sylvain Durand [ARAVIS project - 2007/2010]
Luc Malrait [MENRT - 2007/2010]
Riccardo Ceccarelli [CIFRE-IFP-GIPSA-lab]
Jonathan Jaglin [MENRT - 2006/2009]
Émilie Roche [FeedNetBack project - 2008/2011]
Lara Briñon Arranz [FeedNetBack project - 2008/2011]

Post-Doctoral Fellow
Denis Jacquet [Industrial post-doc - from November 2008]
Yun-Bo Zhao [ARAVIS project - from September until December 2008]
Brandon Moore [CONNECT project - from September 2008]
Jiri Zikmund [CONNECT project - from November 2008]

Administrative Assistant
Myriam Etienne [Assistant]

2. Overall Objectives

2.1. Introduction

The NeCS project-team goal is to develop a new control framework for assessing problems raised by the consideration of new technological low-cost and wireless components, the increase of systems complexity and the distributed and dynamic location of sensors (sensor networks) and actuators. In this framework, control design is performed under general resources constraints including communication, computation, and energy. In that, the team targets an innovative step forward in the feedback design for networked controlled distributed systems by the development of combined control, computing & communication co-design. The project-team is a bi-located at INRIA (Montbonnot) and at the GIPSA-LAB (at the Grenoble campus).

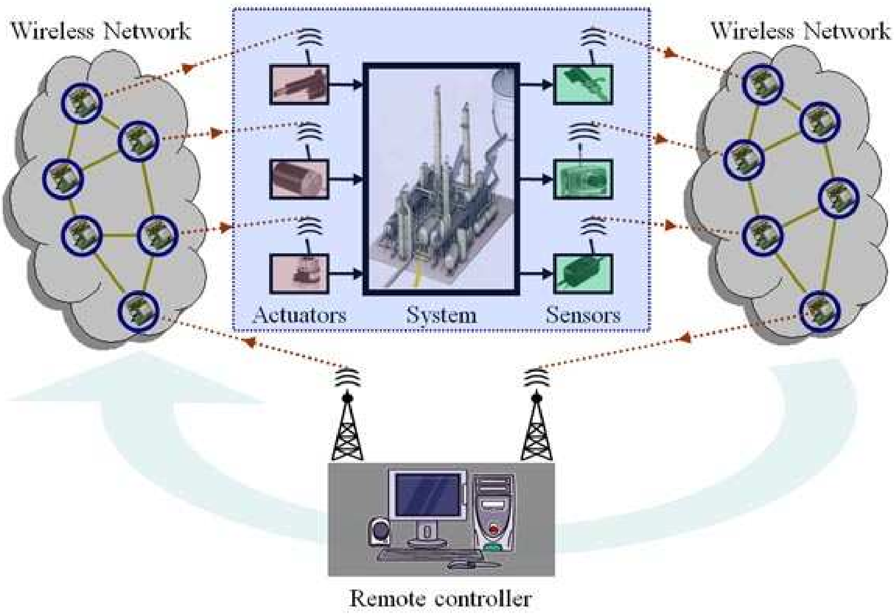


Figure 1. Overview of NeCS systems

The field of Networked Controlled Systems (NCS) refers to feedback systems controlled *over* networks, as shown in Fig 1. These systems result from the arrival of new control problems posed by the consideration of several factors, such as: new technological components (i.e. wireless sensors, RF communications, adhoc networks, etc.), increase of systems complexity (i.e. increase in vehicle components), the distributed location of sensor and actuator, and computations constraints imposed by their embedded nature (i.e. embedded systems, and systems on-chip). In this system class, the way that the information is transferred and processed (information constraints), and the manner in which the computation/energy resources are used (resources management), have a substantial impact in the resulting stability and performances properties of the feedback controlled systems. Inversely, the already designed feedback system, can be affected by the properties of the channel transmission (latency, delay jitter, lost of data, etc.), and the way that the computational and energy resources are used.

2.2. Highlights of the year

During the second year of existence of the NECS project-team (officially created on January 1, 2007) its members successfully kept up the efforts towards external collaborations and funding. The main new facts are:

- the recruitment of a new researcher in the Team. Alexandre Seuret has joined NECS as CR CNRS, since October 2008.
- the kickoff of the FeedNetBack project, a STREP project from the European Commission. (8.2). The project starting on September 2008.
- the recruitment of 2 new PhD students, of 3 PostDocs and of a young engineer.

3. Scientific Foundations

3.1. Multi-disciplinary nature of the project

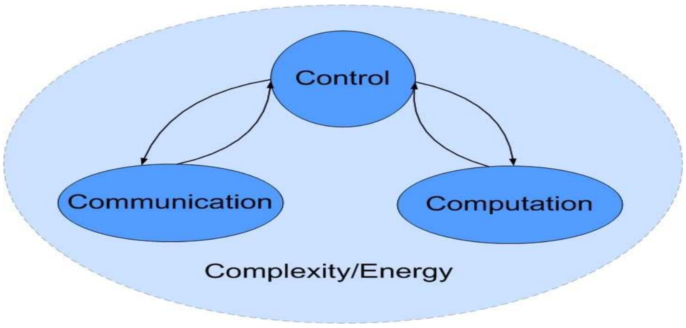


Figure 2. Relation of the NCS area with the fields of: Control, Communication, Computation.

The project propose to investigate problems in the area of NCS with the originality of integrated aspects on computation, communication and control. The combination of these three disciplines requires the interplay of the multi-disciplinary fields of: communication, real-time computation, and system theory (control). Figure 2, shows the natural interaction between disciplines that concern the NeCS project. The arrows describe the direction in which these areas interact, i.e.

(a) *Control in Communication*

(b) *Communication in Control*

(c) *Computation in Control*

(d) *Control in Computation*

Complexity and energy-management are additional features to be considered as well. Complexity here refers to the problems coming from: wireless networks with varying interconnection topologies, multi-agent systems coordination, scale of the number of sensors, etc. Energy management concerns aspect related to the efficient handling of energy in wireless sensors. That is the efficient way to send information, and perform computations.

3.1.1. (a) Control in Communication

This area concerns more control applications where control methods are used to solve problems found in the communication field. Examples are: the Power control in cell telephones, and the optimal routing of messages in an Internet networks.

3.1.2. (b) Communication in Control

This area concerns problems where communication and information theory interacts with system theory (control). A typical scheme of a networked controlled system (NECS) is shown in Fig. 3. As an example, of a classical paradigm we can mention the stabilization problem under channel (communications) constraints. A Key result here [66] was to show that it was generically impossible to stabilize a linear system in any reasonable sense, if the feedback channel's *Shannon classical capacity* C was smaller than the sum of the logarithms, base 2, of the unstable eigenvalues. In other words, in order to be able to cope with the stabilization problem under communication constraints, we need that

$$C > \sum_i \log_2 \lambda_i$$

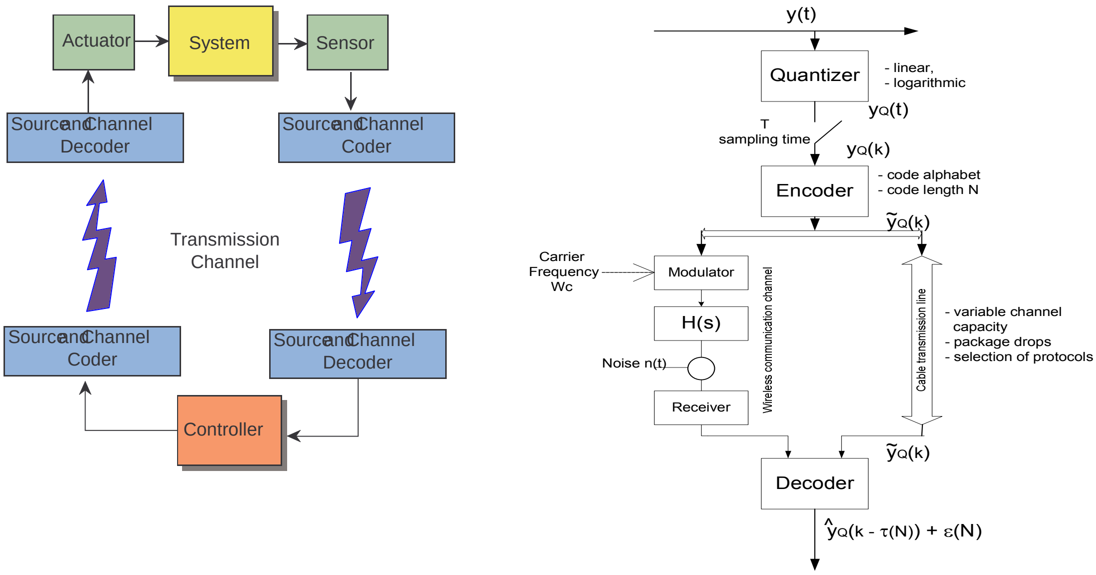


Figure 3. Block diagram of a networked controlled system. General closed-loop configuration (left), details of the transmission path (right)

where the $\lambda_i' s$ are unstable eigenvalue of the open loop system. Intuitively, this means that the rate of information production (for discrete-time linear systems, the intrinsic rate bits/time equals $\sum_i \log_2 \lambda_i$) should be smaller than the rate of information that can be transmitted throughout the channel. In that way, a potentially growing signal can be cached out, if the information of the signal is send via a channel with fast enough transmission rate. In relation to this, a problem of interest is the coding and control co-design. This issue is motivated by applications calling for data-compression algorithms aiming at reducing the amount of information that may be transmitted throughout the communication channel, and therefore allowing for a better resource allocation and/or for an improvement of the permissible closed-loop system bandwidth (data-rate).

3.1.3. (c) Computation in Control

This area concerns the problem of redesigning the control law such as to account for variations due to the resource allocation constraints. Computation tasks having different levels of priority may be handled by asynchronous time executions. Hence controller need to be re-designed as to account for non-uniform sampling times resulting in this framework. Question on how to redesign the control laws while preserving its stability properties are in order. This category of problems can arise in embedded systems with low computation capacity, or lows level resolution.

3.1.4. (d) Control in Computation

The use of control methods to solve or to optimize the use of computational resources is the key problem in this area. This problem is also known as a scheduling control. The resource allocations are decided by the controller that try to regulate the total computation load to a prefixed value. Here, the "system" to be regulate is the process that generated and used the resources, and not any physical system. Hence, internal states are computational tasks, the control signal is the resource allocation, and the output is the period allowed to each task.

3.1.5. (c + d) Integrated control/scheduling co-design

Control and Computation co-design describes the possibility to study the interaction or coupling between the flows (c) and (d). It is possible, as shown in Figure 4, to re-frame both problems as a single one, or to interpret such an interconnection as the cascade connection between a computational system, and a physical system.

In our framework the feedback scheduling is designed w.r.t a QoC (Quality of Control) measure. The QoC criterion captures the control performance requirements, and the problem can be stated as QoC optimization under constraint of available computing resources. However, preliminary studies suggest that a direct synthesis of the scheduling regulator as an optimal control problem leads, when it is tractable, to a solution too costly to be implemented in real-time [35]. Practical solutions will be found in the currently available control theory and tools or in enhancements and adaptation of current control theory. We propose in Figure 4 a hierarchical control structure : besides the usual process control loops we add an outer control loop which goal is to manage the execution of the real-time application through the control of the scheduling parameters of the inner loops. Together with the outer loop (working on a periodic sampled time scale) we also need a scheduling manager working on a discrete events time scale to process exception handling and admission control.

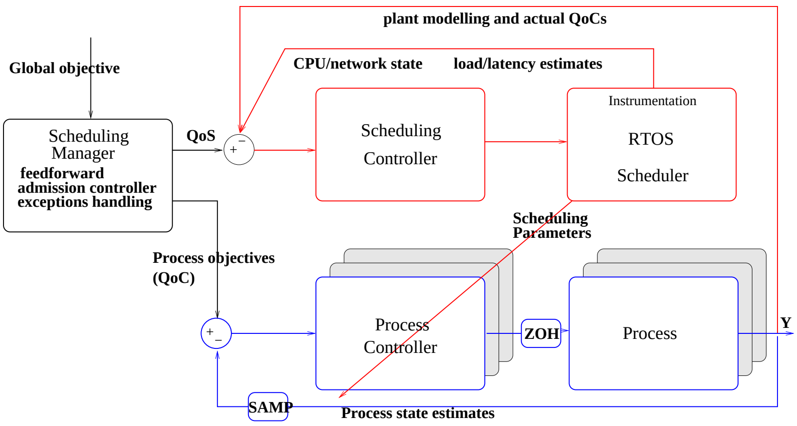


Figure 4. Hierarchical control structure.

The task periods directly affect the computing load, they have been chosen as actuators. They can be implemented through software variable clocks. As timing uncertainties cannot be avoided and are difficult to model or measure, we currently design robust control algorithms using the H_∞ control theory, which have been successfully simulated and experimentally validated [8].

This methodology is supported by ORCCAD where a run-time library for multi-rate multitasking has been developed and integrated. It will be further improved using a QoS-based management of the timing constraints to fully benefit from the intrinsic robustness of closed-loop controllers w.r.t. timing uncertainties.

3.2. Main Research Directions

The main objective of the project is to develop a unified control, communication, computing co-design methodology explicitly accounting for all the components involved in the system controlled over a network. This includes quantifier properties, scheduling parameters, encoder/decoder, alphabet length, bandwidth of the transmission media (wire or wireless), delays, resource allocation, jitter, etc.

These components, including the control laws, should be designed so as to optimize performance/stability trade-offs resulting from the ceiling of the computing resources, the channel capacity limitations and the quality of the send/received information protocols.

In short the project is centered along the following 3 main axis:

1. **Control under Communications Constraints.** One well established topic along this axis concerns the coding and control co-design. That is, the design of new code alphabets simultaneously than the design of the control law. Or equivalent, the ability of designing codex containing information pertained to the system model and the control law. The objective being the improvements of the overall closed-loop performances. Besides this matter, additional improvements pertain to the field of the information theory are also in order.
2. **Control under Computational resources constraints.** The main objective here is the design of control loops by explicitly accounting for the network and/or the computing resources. Dynamic allocation of such resources depends on the desired controlled systems specifications. Keys aspects to be considered are: the design of controllers with variable sampling time, the robustness with respect time uncertainties such as the input/output latencies, the global control of resources and its impact over the performance and the robustness of the system to be controlled. We aim to provide an *integrated control and scheduling co-design* approach [9].
3. **Controlling Complexity** Design and control of partially cooperative networked (possible also multi-agent) systems subject to communication and computational constraints. Here, a large number of entities (agents), having each its own goal share limited common resources. In this context, if there is no minimum coordination, dramatic consequences may follow, on the other hand, total coordination would be impossible because of the lack of exhaustive, reliable and synchronous information. Finally, a local "network of strategies" that are based on worst-case assumptions are clearly far from being realistic for a well designed system. The aim of this topic is to properly define key concepts and the relevant variables associated to the above problem (sub-system, partial objective, constraints on the exchanged data and computational resources, level of locally shared knowledge, key parameters for the central level, etc).

4. Application Domains

4.1. Polling the domain

Keywords: *automotive*, *embedded systems*, *robotics*, *telecommunications*.

Closing feedback loops around Wireless sensor networks offers new challenges and new opportunities for the area of control. Several new application areas can be enabled, or enhanced if systematic methods are developed for the design of NCS. Examples include:

- Intelligent buildings, where sensor information on CO2 concentration, temperature, room occupancy, etc. can be used to control the heating, ventilation and air conditioning (HVAC) system under multi-objective considerations of comfort, air quality and energy consumption.
- Intelligent transportation systems, where traffic flow or density can be measured using novel wireless technologies and used to determine control inputs such as on-ramp metering schemes and variable message signs.
- Disaster relief operations, where data collected by sensor networks can be used to guide the actions of rescue crews and operate automated rescue equipment.
- Surveillance using swarms of Uninhabited Aerial Vehicles (UAVs), where sensor information (from sensors on the ground and/or on-board the vehicles) can be used to guide the UAVs to accomplish their mission.
- Environmental monitoring and exploration using schools of Autonomous Underwater Vehicles (AUVs), where underwater sensors and communication are used to guide the AUVs.
- Infrastructure security and protection using smart camera networks, where the images collected are shared among the cameras and used to control the cameras themselves (pan-tilt-zoom) and ensure tracking of potential threat.

In particular, the team is already involved in the areas described in detail below :

4.2. Transport and motion systems

4.2.1. Underwater systems.

Underwater systems, as presently used or intended by the offshore industry and marine research, are subject to severe technological constraints. In autonomous vehicles (AUV) the on-board power is limited and calls for both control and computing optimization. The links between the master and slave nodes use ultrasonic devices, which have a very low bandwidth and are subject to frequent transient loss, thus calling for sharing the decisional process among the nodes and for a robust implementation of the distributed control, taking into account the communication network features. These constraints together with the potential cost of failures make these systems good candidates for safe and flexible control, communication and computing co-design. The team already got a significant experience in this domain with a past collaboration with IFREMER and other EU projects. Currently, the project CONNECT deals with this type of problems. Details of this project are described in Section 8.1.2.

4.2.2. Car industry

Car industry has been already identified as a potential homeland application for networked controlled system [42], as the evolution of micro-electronics paved the way for introducing distributed control in vehicles. In addition, automotive control systems are becoming the more complex and iterative, as more on-board sensors and actuators are made available through technology innovations. The increasing number of subsystems, coupled with overwhelming information made available through on-board and off-board sensors and communication systems, rises new and interesting challenges to achieve optimal performance while maintaining the safety and the robustness of the total system. Causes of such an increase of complexity/difficulties are diverse: interaction between several control sub-systems (ABS, TCS, ESP, etc.), loose of synchrony between sub-systems, limitations in the computation capabilities of each dedicate processor, etc. The team had several past collaborations with the car industry (Renault since 1992, and Ford), and has recently initiate a new collaboration on observer design and fault diagnostics design for multi-sensor systems in Homogeneous Charge Diesel engines, in collaboration with the IFP.

4.2.3. Traffic

Throughout the world, roadways are notorious for their congestion, from dense urban network to large freeway systems. This situation tends to get worse over time due to the continuous increase of transportation demand whereas public investments are decreasing and space is lacking to build new infrastructures. The most obvious impact of traffic congestion for citizens is the increase of travel times and fuel consumption. Another critical effect is that infrastructures are not operated at their capacity during congestion, implying that fewer vehicles are served than the amount they were designed for. Using macroscopic fluid-like models, the NeCS team has initiated new researches to develop innovative traffic management policies able to improve the infrastructure operations. This activity is currently focused on automatic model calibration and traffic prediction, two important items to implement efficient Intelligent Transportation Systems (ITS) such as traffic responsive ramp metering and varying speed limit as well as producing relevant user information.

4.3. Telecommunications

4.3.1. System on chip

Achieving a good compromise between computing power and energy consumption is one of the challenge in embedded architecture of the future. This management is especially difficult for 45nm or 32nm known to be at the limit of the scalability. Automatic control loops have therefore to be designed in order to make the performance fit the requirement in order to minimize the energy loss in a context of highly unknown performance of the chip. The main objective is to control the computing power and the consumption using the voltage and frequency automatically according to the requirements of the OS. For this, appropriate sensors must be implemented on the chip and a high-performance repartition between hardware and software implementation must be made.

4.3.2. Server systems

Server systems (Internet, database, news, etc.) is a very active industry in the communication area. Tuning servers is currently done with the experience and the feeling of human operators with potential problems like under-optimality or even trashing phenomena in case of bad tuning. The NeCS team has started research on that subject in collaboration with the INRIA-Sardes team to use control theory tools to control in closed-loop server systems and especially their admission. This goes in the direction to fully autonomous servers in completely heterogeneous aggregation of servers.

5. Software

5.1. Orccad

Participants: S. Arias [SED], R. Pissard-Gibollet [SED], F. Boudin, D. Simon [contact person].

ORCCAD [1] is a software environment that allows the design and implementation of the discrete and continuous components of complex control systems, e.g. robotics systems which provided it first ground ([26]). It also allows the specification and validation of missions to be realized by this system. It is mainly intended for critical real-time applications, in which automatic control aspects (*servo loops*) have to interact narrowly with the handling of discrete events (*exception handling*). ORCCAD offers a complete and coherent vertical solution, ranging from the high level specification to real-time code generation. ORCCAD is supported by the *Support Expérimentations & Développement (SED)* service of INRIA-Rhône-Alpes. ORCCAD is used by the experimental robotics platforms of INRIA-Rhône-Alpes and by the SAFE_NECS ANR project in a real-time simulator of a X4 drone. New functionalities and updates are developed jointly by the *SED* service and researchers of the NECS and POP ART teams.

Although it has been developed years ago, the basic concepts upon which the ORCCAD architecture relies still appear to be solid in the field of software development for robot control [62], and compares well with other tools dedicated for real-time control implementation [67]. However the ORCCAD V3 software was designed with proprietary tools that moreover are now becoming obsolete. ORCCAD V4 is currently deeply re-engineered to be compliant with open-source and free software tools (Java/Eclipse/XML). Current targets are Linux (Posix threads) and Xenomai, a real-time development framework cooperating with the Linux kernel (http://www.xenomai.org).

6. New Results

6.1. Stability and control design of asynchronous interconnected systems

Participants: C. Canudas-de-Wit [contact person], N. Marchand, S. Durand.

Networked and embedded control systems are usually operated under variable resources like communication rates and computational loads. This results in an asynchronous sub-systems interconnection, as the sampling time may be adapted *on the fly* as a function of the available resources at the moment. Examples of these systems can be found in many application fields such as remotely-operated systems, interconnected vehicle control loops, and more generally in component-based control design where synchronous exchange of information is not feasible.

6.1.1. Passivity design for asynchronous feedback-interconnected systems

In this topic we have studied the passivity properties of asynchronously non-uniformly sampled systems. The idea of studying these systems comes from the necessity of developing theoretical tools for the analysis of systems that are asynchronously interconnected. Imposing certain passivity properties to each sub-system it is possible to design a local controller each sub-system disregarding the particular characteristic of the other system (modular design).

[1] http://sed.inrialpes.fr/Orccad/

In particular we have studied the following items. First we introduce the notion of (MASP) *MAximum Sampling time preserving Passivity* for linear systems; given a continuous-time system with some dissipation properties specified, the notion of MASP give a maximum sampling time, T^* after which passivity is lost. A second aspect studied here concern the case of a system locally asynchronous but globally synchronous feedback interconnected systems. The notion of globally synchronous comes from the fact that we limit this study to samples T_i of each i-subsystem that are multiple integers among them, nevertheless we allows the sampling time of each individual sub-systems to be time-varying. Finally, we use these results as a design guidelines for the control design, and we propose a numerical algorithm to compute local feedback loops providing a MASP compatible with the maximum sampling-time upper-bound of each sub-system. Details are given in [17].

Further studies consider systems that are either Input/Output Strictly passive (IOSP), or systems which have bounded L_2-gains less than one. The analysis is performed by using the concept of MAximum Sampling time preserving Dissipation (MASD), for each interconnected system. We investigate the impact of using the scattering transformation in the computation of the MASD, and we provide a numerical algorithm (based on a set of LMI's) that allows to choose the most suitable configuration for the interconnection (see [47])

6.1.2. Event-based control design

Asynchronicity is becoming more and more meaningful in modern control architectures and some new control strategies are being developed by some research teams in the world. The principle of these control laws is to compute the control law only when some event occurs, this event characterizing a change in the system and therefore a need for a new control. These approaches are supposed to reduce the number of times the control is computed and to remove the real-time hard constraint on the computational system. In this domain, our contribution is twice. First, based on [49], we proposed a fully asynchronous control scheme (without any time information) for chain of integrators that insures the global stability of the system with only measures when the states cross a priori defined level. This work presented at the IFAC world congress in Korea [5]. Secondly, we removed the safety limit condition introduced by K-E. Årzén in his event-based PID controller [69]. This safety limit was added to prevent the system to be sampled less than what Shannon theorem requires. This work therefore reveals that the Shannon sampling condition is no more needed in the context of event based systems. This was submitted to the next European Control Conference [36].

6.2. Communication and control co-design in feedback systems

Participants: C. Canudas-de-Wit [contact person], C. Siclet, J. Jaglin, M. Alamir, O. Sename, A. Seuret.

Traditional control theory often disregards issues of connectivity, data transmission, coding and many other items of central importance in wireless sensor networks. In this topic we study new methodologies to design control for systems in which signals are exchanged through a communication network with limited capacity. Some of the general questions addressed here are:

- How the signal (source) coding algorithm can be designed jointly and simultaneously with the control law ?
- What are the mutual inter-dependencies between the control and communication design?
- How can one overcome the limitations of the wireless medium, and
- How energy of the sensors and the associated transmission media, can be optimized, by the appropriated energy-aware design of the coding and the control

More specifically, we have studied the following problems:

- Differential Coding for networked controlled systems [37], [46],
- Energy-aware and entropy coding in NCS [32], [31],
- Passivity design for asynchronous interconnected systems [17],
- Stabilization under Communication Networks [7][23] [58], [6].

6.2.1. *Differential Coding for networked controlled systems*

In a networked controlled system, the output signals have to be digitalized before transmission. Our objective is then to use the minimum quantization bits necessary to maintain stability on the closed loop system, that is to say the minimum bandwidth.

Several quantization methods have already been proposed during the last decade. Delta modulation is one alternative to minimize the numbers of bits to be coded. The reason is that innovation increments (with a granularity depending on a quantization factor Δ) are coded rather than the absolute value of the signal. Recent works in [2] have re-adapted the standard form of the delta modulation structure to their use in a feedback setup. One advantage of this type of strategy is that the coding algorithm can be built in a methodological and simple manner. A limitation is that re-synchronization may be needed, if the signal track is lost. Inspired by this approach several variants of [2] have been studied as for example gain scheduling 2-bit coding [45]. Except for the trivial case of diagonalizable multi-variable system that can be reformulated as a set of n-scalar ones, all these works deal exclusively with scalar system.

We have generalized the delta-modulation coding presented in [2], to MIMO systems in [18]. In particular we have introduced a vector coding structure for *multi-variable centralized* linear systems. The notion of centralization refers here to the fact that both the encoder-decoder and the control law use the full available information from all sensors. The idea is shown in Fig. 5, where we can see that all the sensed system outputs are collected in a *central* point, then transformed into a different coordinate-basis (using a transform matrix) before they are coded using a vector-coding algorithm. At the receiver side, it is similarly assumed that the transmitted information arrives to a central receiver, then decoded, and finally the control is computed using this centralized information. It is worth to notice that *decentralized* case is clearly much more constrained, even in absence of a coding process. We have also shown that this fixed-gain simple and methodical coding strategy results in a ultimately uniformly (local) stability. We have also provided an estimation of the attraction domain, and a new method to tune the coding gains, resulting in closed-loop precision improvements. Simulation results have also been presented validating the proposed approach.

Previously, in [3] authors have presented a quantization method based on a one-bit-adaptive Δ modulation. The interest of this technique is that it permits global stability in the scalar case provided that the open loop eigenvalue λ is such that: $|\lambda| < 1.3$. Nevertheless it can be shown that in this case (one bit quantization) it is theoretically possible to just have $|\lambda| < 2$. That is why we have introduced a new adaptive Delta modulation variant called D-ZIZO (Dwell Time Zoom In Zoom Out)(not yet published). This algorithm is inspired by the contributions of Liberzon [28] and [59] (ZIZO algorithm). D-ZIZO needs the previous and the actual information but constraints the maximal open loop eigenvalue. We have determined how many past information we need (dwell time) to assure that for any open loop eigenvalue it is possible to ensure global stabilization.

Even if the essence of the algorithms is the same, it seems that the dwell time phase permits to have some improvements. This comparison could be summarized with these following items.

- This change of coordinates and the quantization steps tuning method enable D-ZIZO to obtain the minimum bandwidth on the communication channel for all linear systems whereas ZIZO *may* sometimes reach the theoretical limit for certain classes of linear systems.
- ZIZO generates high frequencies on the quantization noise though this signal is smoother for D-ZIZO.
- For same regulation detection, D-ZIZO is faster than ZIZO. Moreover, with the same convergence rate, the detection is faster for D-ZIZO.
- One drawback for D-ZIZO is the generalization to non-linear systems that seems difficult. Without the change of coordinates which is the key point of D-ZIZO, it is impossible to obtain an adaptive algorithm in D-ZIZO case. With ZIZO, the issue is solved.

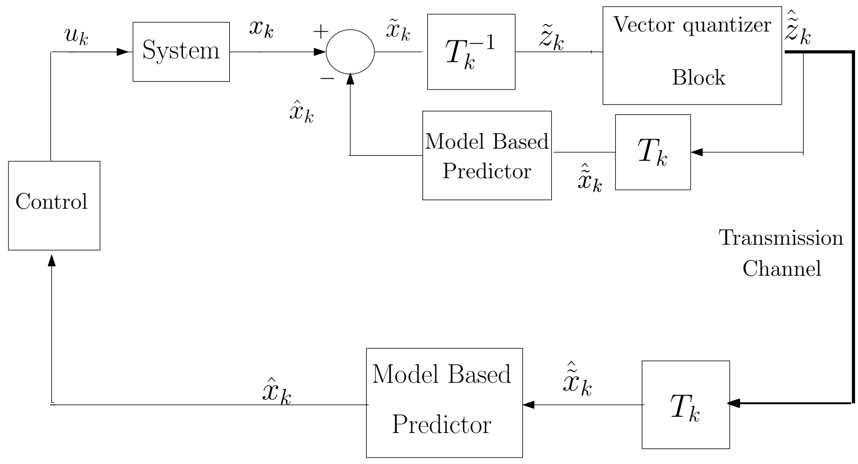


Figure 5. Schematic representation of the system in our study.

6.2.2. Energy-aware and entropy coding in NCS

Wireless low-cost sensor networks are an expanded technology in many new and varied areas such as: traffic monitoring and control (urban, highways), undersea monitoring/exploration, environment sensing (forest, farms, etc.), building services, large instruments with distributed sensing and actuators (Tokamak, telescopes), etc.

In this context, future generation of this type of sensors are expected to be packaged together with communication protocols, RF electronics, and energy management systems. Therefore, the development of such integrated sensors will be driven by constraints like: low cost, ease of replacement, low energy consumption, and energy-efficient communication links. In turn, these constraints bring new problems to be considered in the exploitation of this information. For instance, low cost will induce sensors with low resolution (binary sensors, at the extreme) advocating for minimum bit coding strategies, low consumption will impose issues on efficient sensor energy management (sleep and wake-up modes, differentiation of stand-still event), ease of replacement will imply the system ability to keep safe operation in a failure of one or several sensors, and finally communication links and protocols should be designed to account for energy savings, information loss, and varying fading characteristics.

The objective of our work published in [11] is specifically to treat aspect related to the energy management, in relation with the particular code to be used. To this aim, we have proposed to use a coding strategy based in the following 3 main ingredients:

- **Differential coding** encodes the differences (error prediction) between successive samples rather than the samples themselves. Since differences between samples are expected to be smaller than the actual samples amplitudes, fewer bits are required to represent the differences. However, in its standard form no specific distinction is made for the stand-still events.
- **Event-based coding** has the ability to quantify and to differentiate stand-still signal events from changes in the source (level crossing detector). Coding is effectuated by defining at least 3-valued alphabet for the minimum bit case, and $(2L+1)$-valued alphabet for a general case with a precision inversely proportional to $L \in \mathbf{Z}^+$. Hence, the stand-still signal event is modulated with a low-power signal, whereas the changes of levels will be modulated with a high-power one.
- **Entropy coding** can be added to improve the energy use by assigning a probability distribution to the events. In that way, the mean transmission energy can be substantially improved for systems

where the stand-still events may have high probability to occur (i.e. stable systems).

A pre-requisite for the entropy coding strategy is to design a mechanism with the ability to quantify and to differentiate stand-still signal events, from changes in the source (level crossing detector, denoted here as φ_{LD}). For instance, this can be done by defining an alphabet where the source signal information is contained in the time interval between level crossing and in the direction of the level crossing. We assign strings of the 2-tuple 00 to represent the time between signal level crossing, and 01 and 10 to denote the direction of level crossing, the output of the level crossing detector contains a high probability of the 0 symbol which makes it suitable for an entropy encoder to attain a "good" overall compression ratio, and hence (as it will be shown here), a substantial improvements of energy saves. A fundamental difference with the classical Differential algorithm (i.e. delta modulation, see [2]) is that the error is coded on the basis of a 3-valued alphabet rather than a 2-valued one. If the levels are uniformly spaced and constant then the signal prediction precision, and hence the resulting closed-loop behavior, will be limited by the size of the level spacing. Instead, we propose here to increase the number of levels to $2L+1$, where $L \in \mathbf{Z}^{+}$, so as to match the required precision. This leads to a $2L+1$-word alphabet, which can still be combined with a energy-efficient variable length (VLE) entropy coding to improve the use of energy for cases and systems where the stand-still events have a substantial probability to arise.

6.2.3. Stabilization under Communication Networks: A Time-Delay Approach

The networked control systems constitute a new class of control systems including specific problems such as delays, loss of information and data process. The problem studied here concerns the stabilization of systems where the sensor, actuator and system are assumed to be remotely commissioned by a controller that interchanges measurements and control signals through a communication network. Additional dynamics are introduced in the system due to the wireless communications such as time-varying communications delays, asynchronous samplings, packets losses or lake of synchronization.

In [10], and in [68], we proposed to use a time-varying horizon predictor to design a stabilizing control law that sets the poles of the closed-loop system. The computation of the horizon of the predictor is investigated and the proposed control law takes into account the average delay dynamics explicitly. The resulting closed loop system robustness with respect to some uncertainties on the delay model is also considered. Tele-operation subject to time-varying delays has been considered in [6]. In [58] and [23], we also proposed an observer-based controller to ensures the stabilization of networked controlled systems. The main interest of such a controller concerns the potential to take into account the additional dynamics induced by the networks cited above. Further developments will take into account the quantification and the coding of the transmitted data packets.

Another effort has been devoted to the problem of controlling a set of agents, cooperating under communication constrains. It is well-known that introducing a delay generally leads to a reduce of the performance or to instability. Thus, investigating the impact of time-delays in the consensus problem is an important issue. In our research, we assume that each agent receives instantaneously its own output information but receives the information from its neighbors after a constant delay τ. The setup we considered leads to study the following equation $\dot{x}(t) = -\mu x(t) + Ax(t-\tau)$, where $\mu > 0$ and A is the classical adjacency matrix. These corresponds to a more realistic setup than the one usually considered in the literature [51]. More especially, in [7] and [57], we investigate the influence of the communication on the location of the agreement point and on the convergence rate, which is not straightforward when delays appear in the network. First, we proved that whatever the delay and whatever the graph, the set of agents will reach a consensus. The consensus equilibrium depends on the delay and on the initial conditions taken in an interval is given by

$$x_{eq} = U_2 \left(\lim_{s \to 0} s \frac{x(0) + \mu e^{-\tau s} \int_{-\tau}^{0} x(u) e^{-us} du}{s + \mu(1 - e^{-\tau s})} \right) \vec{\mathbf{1}}.$$

where U_2 is a vector depending on the communication graph. Then, based on Lyapunov-Krasovskii techniques and LMI representation, an estimate of the convergence rate is provided. Figure 6 shows the examples of four communications graphs and Figure 7 shows the corresponding convergence rate.

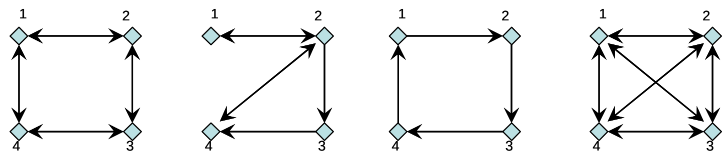


Figure 6. Four agents connected through various communication graphs

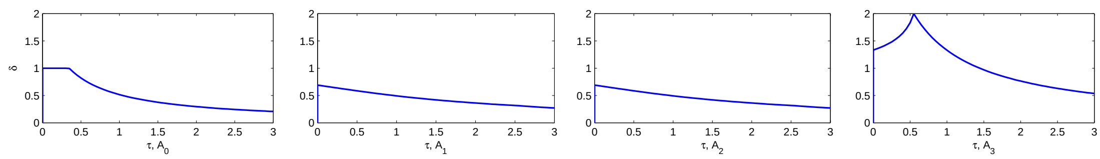


Figure 7. Evolution of the convergence rate δ with respect to the delay τ for various communication graphs

It can be seen that the convergence rate strongly depends on the connection. Note that an interesting phenomena concerning the full connected network is pointed out. It is now well known that for some systems, delays could improve the performance and even lead to stability [13]. It thus appears that a set of full connected agents is one of those systems.

6.2.4. Tele-operated system

NecsCar is an electrical vehicle (scale 1/3) to be used as an experimental platform to study improvement of new control architectures. The vehicle is designed to be remotely tele-operated from our active steering wheel platform, ant it will be equipped of a 3D vision system to provide the operator with stereo vision capabilities. Bilateral teleoperation can be performed using wheel contact torque measurements, feed back for force deflection. Wireless connection will allows us to test coding algorithms, resource sharing, and robustness against transmission delays. First experiments were conducted this summer and visible at http://necs.inrialpes.fr/

6.3. Underwater communications

Participants: C. Siclet [contact person], C. Canudas-de-Wit, M. Mossi Idrissa, G. Gomez.

CONNECT (CONtrol of NEtworked Cooperative sysTems) is a project granted by the ANR. In collaboration with IFREMER, GIPSA-lab, PROLEXIA, and PGES, CONNECT aims at studying the problem of multi-agent control (AUVs) and coordination with heterogeneous networks, including underwater communication. In this context, we will interest to underwater acoustic communication.

Current underwater acoustic modems are based on very classical single-carrier modulation with a very low bit rate. In the same time, wireless radio-communications have been significantly improved during the latest ten years, in particular thanks to multi-carrier modulations. These modulations are indeed now used in several high rate applications (ADSL, DVB-T [56], IEEE 802.11a/g, ...). These applications are all based on the same modulation, OFDM (Orthogonal Frequency Division Multiplex). Thanks to the use of a guard time [52] (or cyclic prefix), it is possible under certain conditions to simplify considerably the equalization step, so that OFDM is particularly performing. That is why OFDM has also recently been considered for underwater communications : the underwater acoustic channel [43], [64] is indeed particularly frequency selective, so that OFDM is a potential interesting solution [30].

In spite of its advantages, OFDM also suffers from several drawbacks : the guard time induces a spectral efficiency loss, and, what is more, the pulse shape used for each carrier is rectangular, and therefore badly frequency located. This spectral efficiency loss remains small if we use long duration symbols, but it may cause inter-carrier interferences if the transmission channel is not stationary during a symbol interval. Compensation techniques have then to be studied [39]. Lastly, the modulated signal has an amplitude which may by very high which is problematic for linear amplification.

Several alternatives have been proposed to solve these problems, among them oversampled OFDM/QAM modulations [61] and OFDM/OQAM modulations [40], [63], and their bi-orthogonal extensions (BFDM) [60]. For each of these types of modulation, it is possible to use non rectangular pulse shapes, optimized according to a given criterion (time-frequency localization, frequency localization...). They appear then to be promising and give more freedom degrees in their conception than classical OFDM. Nevertheless, the equalization is more complex (in the OQAM case) and their implementation more expensive (in terms of computational complexity).

Our objective is to study multi-carrier modulation systems (OFDM, oversampled OFDM/QAM, OFDM/OQAM as well as their bi-orthogonal extensions) and to determine the corresponding receptors, in the framework of underwater acoustic communications. We will then have develop a complete communication chain using and comparing these different modulations to classical underwater communication systems. We will thus interest to various problems : channel estimation, equalization, synchronization, non-linearity of digital to analog and analog to digital converters.

Further investigations are currently conducted in order to extend this results in the case of more sophisticated multi-carrier modulations and more realistic UWA communication channel (OFDM/QAM and OFDM/OQAM).

6.4. Modeling and control of web servers

Participants: N. Marchand [contact person], L. Malrait, S. Bouchenak [SARDES].

This work focuses on the design of a server model, the design of admission control laws that allow the server to satisfy different Service Level Objectives, and the implementation of the latter. This work is in collaboration with SARDES team of the INRIA.
The first part of the work consists in designing a continuous time model using a fluid flow approach. Inherent non-linearities of such systems are taken into account. We validate model with different experimental data sets, under different conditions. Results show the relevancy of the model, which is accurate on a wide range of load. Then it is used for control purposes. We build theoretical control laws that ensure a maximum latency on the server or a maximum client rejection rate. We implemented them on a real system which is supposed to emulate an e-business environment. Fig. 8 show the experimental results obtained with a hard workload of one class of requests. A publication has been submitted to the next European Control Conference [48] and a patent is pending.

6.5. Observers design for multi-sensor systems: application to HDI engines

Participants: C. Canudas-de-Wit [contact person], R. Ceccarelli.

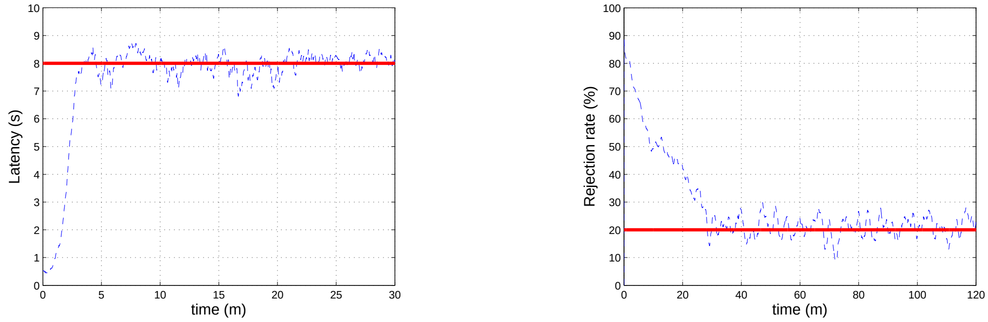


Figure 8. Evolution of the latency and the client rejection rate (dashed line) for references $8s$ *for the latency and* 20% *for the client rejection rate (solid line).*

Collaboration with IFP (Institut Français du Petrole).

Research activity in vehicle industry targets pollutant emission reduction. Homogeneous charge compression engine ignition (HCCI) is an interesting alternative to this problem. New European community laws impose new stringer constraints to pollution, and as a consequence, forces the car industry to realize on board diagnosis system in order to detect engine failures that may result in an increase in the engine pollution. The control of pollutant emission, in diesel engine, is ensured by exhaust gas recirculation system (EGR). Its functioning is very important and a fault detection and isolation system (FDI) is necessary in order to ensure good performances and poor emissions. Exhaust gas could be taken before or after compressor: respectively called high and low pressure EGR.

In this project carried out in collaboration with the IFP (Institut Français du Petrole), we aim at developing model-based observer allowing to identify several types of engine failures, like: gas leakage in the low and high pressure recirculation circuits, ill functioning of some of the sensors, and actuators (valves).

First year has been dedicated to system modeling with respect to leakage detection and estimation. In a first phase, leakage in intake receiver has been studied by the mean of two different nonlinear adaptive observers. The observers have been tested on a AMEsim - Simulink co-simulation environments.. For this first application, no differences come out from the use of these two observers. The second part of the work (current task) is dedicated to the design of a variable threshold in order to be less conservative and avoid false alarms. For this purpose I am investigating a study of possible causes (modeling and measures error) whose effect drive leakage estimation away from the correct value [33].

6.6. Energy-aware control for systems on-chip

Participants: C. Canudas-de-Wit [contact person], C. Albea-Sanchez, N. Marchand, D. Simon, S. Durand, Y-B. Zhao.

The NECS team is involved in the ARAVIS project (see 7.1 at http://www.minalogic.com/posters/aravis.pdf) : the high level of integration in future chips will lead to heterogeneity in the performance of the various integrated components. It appears that introducing control loops at different levels of these chips will be necessary to be compliant with heterogeneous circuits.

6.6.1. Adaptive Control of the Boost DC-AC Converter

The control of boost DC-AC converters is usually accomplished tracking a reference (sinusoidal) signal. The use of this external signal makes the closed-loop control system to be non-autonomous and thus, making its analysis involved. Here we follow a different approach consisting in the design of a control law in order to stabilize a limit cycle corresponding to the desired oscillatory behavior. In that way, no external signals are needed. In [21], we have proposed some adaptive control laws for the nonlinear boost inverter in order to cope with unknown RL load, that is, the two parameters: R and L are adapted at the same time. These adaptive controls are accomplished by using some state observers for some of the converter variables even when the state variables are measured. The stability properties are derived by resting to via singular perturbation analysis.

6.6.2. Advanced Control Design for Voltage Scaling Converters

In low-power electronics, achieving a high energy efficiency has great relevance. Nowadays, Global Asynchronous Local Synchronous Systems enables to use a Local Dynamic Voltage Scaling architecture, this technique allows achieving a high energy efficiency. Moreover, Local Dynamic Voltage Scaling can be implemented using different approaches. One of them is Vdd-Hopping technique. Different controllers are designed for a Vdd-Hopping searching a better performance in terms of dissipated energy reduction [22].

A controller which is principally focused on energy-aware, dealing with maximal current peak constraints is designed. It improves considerably the system efficiency, achieves the desired objective in short time and reduces the current peaks. Stability analysis of the closed-loop system is achieved. This controller is patent pending with the name Energy-Aware Control (ENARC).

6.6.3. Energy aware computing power control

The aim of this work is to achieve a good compromise between computing power and energy consumption. This management is especially difficult for 45nm or 32nm known to be at the limit of the scalability. Therefore automatic control loops are designed in order to make the performance fit the requirement.

A patent is currently pending on the energy control of a single node subject. A second one is in preparation for the multi-node energy control.

6.6.4. QoS control

An application software deployment based on a static and worst case point of view is no longer effective for such heterogeneous chips and more flexible designs must be used. It appears that closed-loop control can be integrated at several hardware and software levels of the chips to provide both adaptivity to the operation conditions and robustness w.r.t. variability.

On top of the nodes power control and computing speed control layers, the outer application layer will include a closed-loop controller of the application quality of service (QoS) under constraints of computing and energy resources availability. This loop uses the scheduling parameters provided by the operating system to regulate the application's QoS. In the context of ARAVIS the computing speed of each integrated node is assumed to be controllable and is also a possible control actuator used by the application level. A first step will be devising a formal definition of the required control performance and stating cost functions to formally associate the QoS with the usable scheduling parameters.

6.7. Control and scheduling co-design

Participants: D. Simon [contact person], O. Sename, E. Roche, M. Ben Gaid [IFP].

We propose here a control/scheduling co-design approach. We aim to provide an *Integrated control and scheduling co-design* approach. Indeed closing the loop between the control performance and the computing activity seems to be promising for both adaptivity and robustness issues.

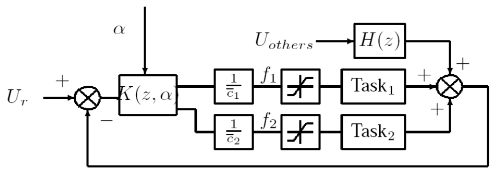
6.7.1. A LPV approach to control a robot arm

Optimization of computing resources in computer-controlled systems is a challenging problem. Current solutions consist in on-line changing the algorithm or adapting the sampling period in order to increase the flexibility by adaptation of the processor utilization.

Methods to design sampling period dependent controllers have been already proposed, e.g. in [53] for RST controllers and in [54] using the LPV/H_∞ control approach for polytopic systems. However in these studies the variation of computing resources is linked to the real-time system performance only and not to the plant expected performances. In this section we provide a methodology to design a feedback scheduling controller which will make the resource utilization vary on line according to the resource availability and to the plant trajectory.

Feedback scheduling is a dynamic approach allowing a better usage of the computing resources, in particular when the workload changes (e.g. due to the activation of an admitted new task). Here the CPU activity will be controlled according to the resource availability by adjusting scheduling parameters (i.e. period) of the plant control tasks. However the use of computing resources should also be linked to the dynamical behavior of the plant(s) to be controlled. Indeed while controlling different subsystems in a single computer it is natural to ensure the resource availability when large transient behaviors occur.

The main result given in this section consists in deriving a new feedback scheduling controller which will depend on the plant trajectory in view of an "optimal" resource sharing [19]. It is designed in the LPV/H_∞ framework for polytopic systems. Following previous results in [8], the feedback scheduling is illustrated in Fig 9 as a dynamical system between control task frequencies and processor utilization.



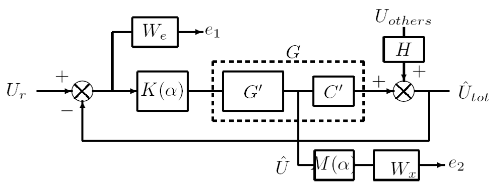


Figure 9. a: Feedback scheduling bloc diagram b: Control scheme for CPU resources

In figure 9a the interval of frequencies is limited by the "saturation" block, α represents a set of real parameters $\{\alpha_1, \alpha_2, ..., \alpha_n\}$ dedicated to the set of control tasks $\{U_1, U_2, ..., U_n\}$. These parameters will be used to make the resource sharing vary according to the plant trajectory. For instance, in a 2 control-tasks system, where $U = U_1 + U_2$, we will require that:

$$\begin{aligned} U_1 &= \alpha U \\ U_2 &= (1-\alpha)U \end{aligned} \tag{1}$$

α being a varying parameter.

In figure 9b, G' is the model of the scheduler, the output of which is the vector of all task loads. To get the sum of all task loads we use $C' = [1\ \ ...1]$. The H transfer function represents the sensor dynamical behavior which measures the load of the other tasks. It may be a first order filter. The template W_e specifies the performances on the load tracking error.

The resource distribution is realized through the $M(\alpha)$ matrix. To associate the use of computing resources with the robot trajectory, the contribution of each of 3 robot control sub-tasks (namely computing the Inertia matrix, the Coriolis forces and the Gravity forces) to the closed-loop system performances has been evaluated as a function of their execution period. Cost function has been evaluated through simulations of a particular robot trajectory (see Figure 10).

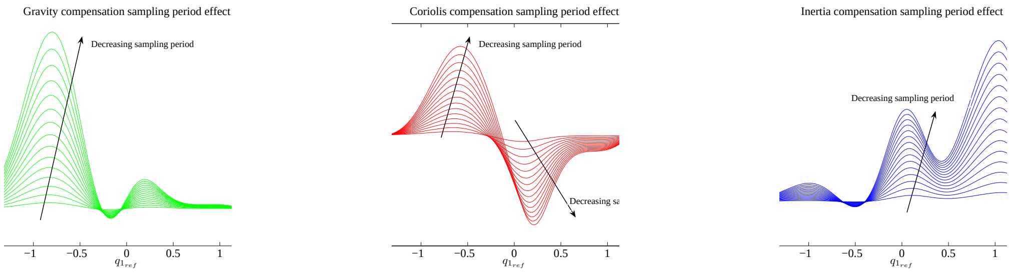


Figure 10. Cost variations due to varying sampling rates for Gravity, Coriolis and Inertia compensation task

While it is difficult to infer the relations between the compensation tasks execution period and the trajectory tracking performance, simulation using the TrueTime toolbox ([34]) shows that the loads of the compensation tasks (Gravity, Coriolis and Inertia) vary on line as expected according to the parameter α_I, and that the adaptive LPV case (α varying) leads to a smaller cost function compared with the constant case ($\alpha = 0.375$), which was already efficiently tuned (Figure 11).

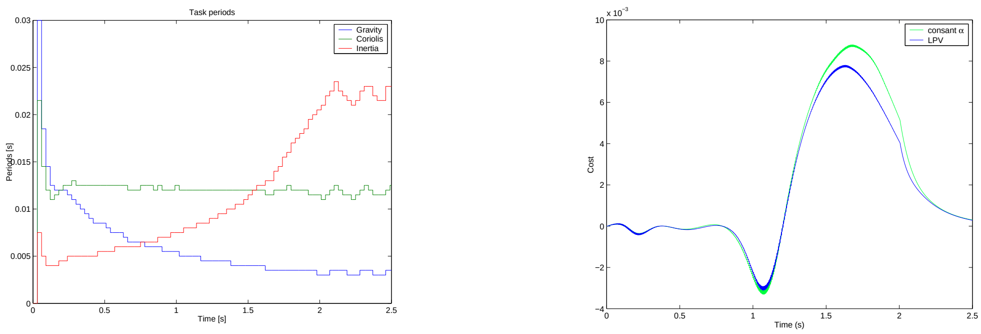


Figure 11. Task periods and control cost

6.7.2. Process state based feedback scheduling based on convex optimization

Existing approaches for state-feedback optimal scheduling (e.g. as in [38], [50], [65], [44])did not exploit or investigate the possible convexity properties of the optimal state-feedback based resource allocation problem. In fact, in these approaches, the solutions were based on rather generic optimization methods or special heuristics. However, in optimization, convexity is an interesting property that considerably simplifies the obtained solutions. Convex optimization problems have in general efficient solutions. In the context of the on-line state-feedback scheduling, the complexity of the scheduling algorithm is a crucial point for its effectiveness.

Instead of approximating the cost as a function of the sampling period, we suggest a sampling-period approximation of the different coefficients of the Riccati equations solutions, which are involved in the LQ control design.

The problem has been stated in [15] for a collection of N continuous-time LTI systems $\{\mathcal{S}_i\}_{1\le i\le N}$ described by $\dot{x}_i(t) = A_i x_i(t) + B_i u_i(t)$ associated with an infinite horizon continuous-time cost functional J_i, defined by $J_i(x_i,u_i) = \int_0^\infty \left(x_i^T(t)Q_i x_i(t) + u_i^T(t)R_i u_i(t)\right) dt$. A global cost functional $J(x_1,...,x_N,u_1,...,u_N)$, defined by $J(x_1,...,x_N,u_1,...,u_N) = \sum_{i=1}^{N} \omega_i J_i(x_i,u_i)$ is associated to the entire system, allowing the evaluation of its global performance. Constants $\{\omega_i\}_{1\le i\le N}$ are weighting factors, representing the relative importance of each control loop.

An interesting property in optimal LQ sampled-data control is that the cost functional $J_i(t_i(k),x_i,u^*_{i,h_i})$ may be characterized by a unique positive definite matrix $S_i(h_i)$ of size $n_i \times n_i$, which is the solution of the associated Riccati equation.

On several benchmarks, e.g. LQ control of an unstable pendulum, an active car suspension and the quadrotor drone described in section 6.7.4, it has been observed that the control performance penalty due to sampling, compared with the continuous case, has a convex shape. More precisely, Figure 12 plots the elements of $(S(h) - S^c)$ where S^c is the solution of the Riccati equation in the continuous case, and $(S(h)$ its solution for increasing values of the sampling period h : in all these cases the sampling penalty can be accurately approximated by quadratic functions.

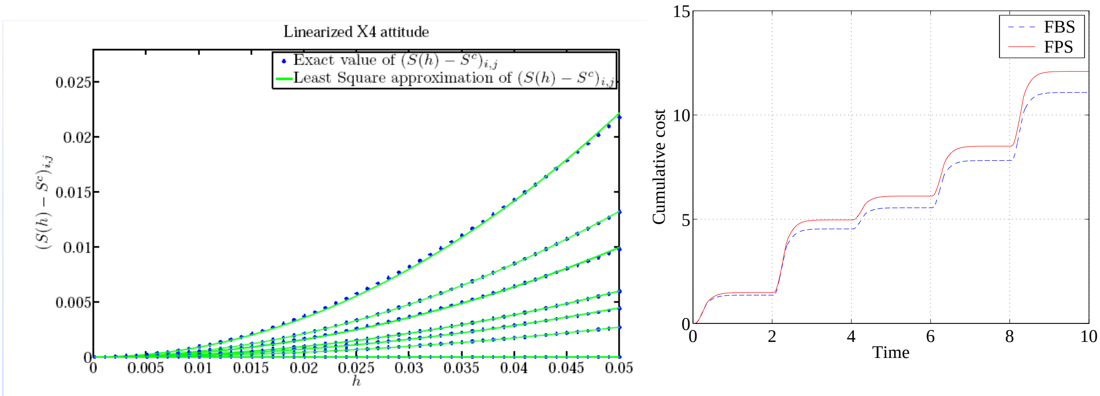


Figure 12. X4 quadrotor : cost coefficients vs. sampling period - final cost index

In that case the problem of finding optimal solutions (i.e. sampling rates) to solve the problem of minimizing $J(x_1,...,x_N,u_1,...,u_N)$ is feasible and can be computed analytically (in bounded and moderate time) using the Karush-Kuhn-Tucker (KKT) conditions. [27].

Simulations have been setup using a plant made of two unstable pendulums sharing a unique computing resource. Each pendulum is disturbed by different king of disturbance. The state-based feedback-scheduler (FBS) automatically allocates more computing power to the system subject to the highest disturbance, so that a global performance index is made better than in the case of a traditional fixed periods scheduling (Figure 12b).

6.7.3. Robust control of underwater vehicles

For system with important non-linearities and large uncertainties on parameters, the use of a robust control, such as the $\mathcal{H}_\infty$, may not be sufficient to obtain good performances for the closed loop system over all the parameters variation range. The Linear Parameter Varying (LPV) theory, based on robust control, improves the method by taking into account the non-linearities and variations of the system at design time [29]. The obtained controller is then parametrized by a set of parameters, and is on-line adapted at the working points.

In the framework of the Connect project (8.1.2) the $\mathcal{H}_\infty$ approach for LPV system is again applied to an Autonomous Underwater Vehicle (AUV) ([55]). The control of these vehicles is made difficult by numerous non-linearities, due to cross-coupled dynamics and hydrodynamic forces. Moreover the knowledge about the vehicles parameters is very poor. On the other hand the performance required by the payload may be high, e.g. the roll and pitch velocities must be kept inside tight bounds to perform high quality imaging using a side-scan sonar. Hence robust control is necessary to perform safely autonomous missions.

In a preliminary approach, the mass of the vehicle M is chosen as the unique varying parameter. Indeed, the mass is one of the parameter varying during the navigation (because of the water-added terms uncertainty, or due to the casting off of payloads during a mission). The choice of this unique varying parameters allows for keeping the controller reconstruction simple. More complex sets of varying parameters could be chosen in future studies to enlarge the set of operating conditions, such as the speed of the vehicle like in [24] for missile control. The $\mathcal{H}_\infty$ problem for the LPV system is first solved considering a variation of $+$ or $-$ 20% with regards to the nominal mass of the vehicle. In that case simulations show that the LPV (adaptive) controller is always better than a purely $\mathcal{H}_\infty$ robust controller. For higher variations of the AUV's mass (upto 70%), the LPV controller is still able to stabilize the system, provided that the mass can be roughly estimated.

These first results foster ongoing research to better understand how the LPV approach can be used to efficiently and robustly control such autonomous vehicle. In particular it is intended to combine several uncertain parameters, including computing and communication resources related disturbances like computing and networking induces delays.

6.7.4. Hardware-in-the-loop simulation of a quadrotor drone

In the framework of the SafeNECS project (see 8.1.1), a hardware-in-the-loop experiments using ORCCAD has been set up to provide a safe environment for both algorithms and software validation, prior to experiments with the real (expensive and fragile) quadrotor.

Figure 13 describes the control and diagnostic setup used for testing purpose [25]. In this block-diagram the blue boxes represent the user-provided modules (i.e. functions) interconnected by their input/output ports (respectively blue/red). From the real-time point of view, each module is implemented by a real-time task possessing its own programmable timer. Therefore all the modules can be run asynchronously at their own (possibly varying) sampling frequency. In this diagram one of the modules implements a feedback scheduler: it monitors the controller's real-time activity and may react by setting on-the-fly the tasks scheduling parameters, e.g. their firing intervals. For example it is may used to implement a (m,k)-firm dropping policy ([41]), accelerable tasks ([16]) or any one of the scheduling control algorithms described in the previous sections.

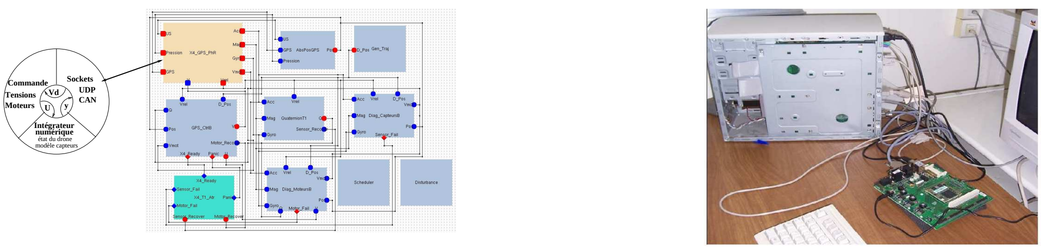


Figure 13. Control and diagnosis block-diagram - Experimental set up

To set up a "hardware-in-the-loop" real-time simulator, the multitasks controller running on the embedded target is connected via a Can (or Ethernet) link running a numerical integrator, calling a model of the drone, of its sensors and of its actuators. This setup allows for ultimate tuning of the control algorithms before launching the real and fragile system. It is also provided with a disturbing daemon allowing to simulate various failures and to check the validity of the diagnosis and recovery procedures defined in the Safe-Necs project.

7. Contracts and Grants with Industry

7.1. Pôle de compétitivité Minalogic/ARAVIS

ARAVIS (Architecture reconfigurable et asynchrone intégrée sur puce) is a project sponsored by the Minalogic Pole, started for 3 years in October 2007 (http://www.minalogic.com/posters/aravis.pdf). It will investigate innovative solutions needed by the integration of 32 nano-meter scale future chips. It is headed by STMicroelectronics, the other partners are CEA-Leti, TIMA laboratory and the SARDES and NECS teams at INRIA.

7.2. IFP

Accompanying contract with IFP (Institut Français du Pétrole), in the framework of the CIFRE PhD grant of Riccardo Ceccarelli (2007-2010). The goal sought with the Control Engine Dept. of IFP is the development of a model-based observer allowing to identify several types of engine failures. First year has been dedicated to system modeling with respect to leakage detection and estimation. In a first phase, leakage in intake receiver has been studied by the mean of two types of nonlinear adaptive observers. The observers have been tested on a AMEsim - Simulink co-simulation environment. For this first application, no differences come out from the use of this two observers. The second part of the work (current task) is dedicated to the design of a variable threshold in order to be less conservative and avoid false alarms. For this purpose we are investigating the possible causes (modeling and measurement error) whose effects drive leakage estimation away from the correct value.

7.3. Technology transfer towards start-up creation

The NeCS team started with the recruitment of Denis Jacquet in November 2008 a new activity in road traffic modeling and control. The expected scientific contribution of NeCS in this field concerns the development of new estimation and identification algorithms based on the measurements collected through sensor networks installed on freeways. The team is currently setting up a consortium with local authorities involved in traffic management to build to demonstrator called GTL for Grenoble Traffic Lab. One target of this activity is to transfer part of the developed technology to a start-up currently incubated at GRAIN (Grenoble incubator for high tech start-ups).

8. Other Grants and Activities

8.1. National actions

8.1.1. ARA-SSIA Safe_NECS

SAFE_NECS is an « Action de Recherche Amont - Sécurité, Systèmes embarqués et Intelligence Ambiante » funded by the ANR and started in December 2005 http://safe-necs.cran.uhp-nancy.fr/. The research topic is fault tolerant control of distributed process and the project focuses on both diagnosis and robust control under execution resources constraints. It gathers teams from CRAN and LORIA (Nancy), LAAS (Toulouse), and GIPSA-LAB and NECS (Grenoble). The project deadline has been extended upto June 2009.

8.1.2. ANR PsiRob CONNECT

The CONNECT proposal (**CON**trol of **NE**tworked **C**ooperative sys**T**ems) deals with the problem of controlling multi-agent systems, i.e. systems composed of several sub-systems interconnected between them by an *heterogeneous* communication network. The control of a cluster of agents composed of autonomous underwater vehicles, marine surface vessels, and possibly aerial drones will be used as a support example all along the proposal. The partners are the NECS team, Ifremer robotics lab. and the PGES and Prolexia companies. It started for 3 years in May 2007 (http://www.lag.ensieg.inpg.fr/connect/).

8.1.3. Collaborations inside Inria

- The development of Orccad raises collaborations between NeCS, POP ART and SED. Support about its use is provided to the TRIO team at Nancy in the framework of the SafeNecs project.
- Collaborations with the SARDES project-team have been initiated along two axis. The modeling and closed-loop control of web servers involves a shared PhD student. The QoS control of multimedia application based on the Think operating system is investigated in common to be the external layer of the ARAVIS project.

8.1.4. Cooperations with other laboratories

- Carlos Canudas-de-Wit has a collaboration with University of Sevilla about NCS.
- C. Siclet has collaborations with L. Ros, C. Baras and J-M. Brossier at Gipsa-lab, and with P. Siohan at Orange Lab in Rennes.
- Strong collaborations have been established with KTK (Stockolm), ETH (Zurich), University of Sevilla and Padova as core partners of the FeedNetBack European project.

8.2. European actions

8.2.1. FeedNetBack

The FEEDNETBACK proposal has been accepted as a STREP project at the FP7-ICT-2007-2 call in October 2007. It is coordinated by Carlos Canudas-de-Wit and gathers researchers from academia (INRIA-NeCS, ETH Zurich, Universidad de Sevilla, KTH Stockholm, Universita di Padova) and from industry (Ifremer, Vodera, Vitamib, Intellio and OMG).

The main objective of the FeedNetBack project is to generate a rigorous co-design framework that integrates architectural constraints and performance trade-offs from control, communication, computation, complexity and energy management. The goal is to master complexity, temporal and spatial uncertainties such as delays and bandwidth in communications and node availability. This approach will enable the development of more efficient, robust and affordable networked control systems that scale and adapt with changing application demands. The project will extend the current scientific state-of-the-art in networked control and develop a set of software tools to support the co-design framework. To demonstrate the potential and limitations of the new technology, FeedNetBack will apply it on two industrial test cases of realistic complexity and scale: underwater inspection systems based on fleets of Autonomous Underwater Vehicles (AUVs), and surveillance systems using a network of smart cameras. The control component is essential in both test cases as they require cooperation of distributed objects to achieve a common goal (http://feednetback.eu/). Specific issues that will be addressed in the project include:

- Heterogeneity: The sensor hardware and the communication means may be of different nature (different noise, bandwidth, resolution characteristics, etc.).
- Mobility: Sensor location may not be fixed. Dynamic location of sensors will lead to varying topologies.
- Resource management: The energy and computation capabilities of each node are generally limited.
- Scalability: Wireless sensor networks may comprise hundreds or thousands of nodes. It is therefore crucial that the complexity of the design procedures and the resulting controllers scale slowly with the number of nodes.
- Asynchrony: Information exchange between sensor/control units may not be synchronous in time.

Since in NCS the goal is to ensure satisfactory performance of the overall closed loop system, these problems are treated holistically through sets of performance constraints.

The co-design framework aims at controlling more complex systems with a fraction of the effort, while increasing availability and reliability. The framework will enable application developers, programmers and systems integrators to fully use the potential of networked control in a wide set of industrial domains. Examples of areas where an impact is expected are the fields of factory automation, public infrastructure safety and security, transport and building maintenance.

FeedNetBack will go beyond developing new technologies, but will also apply these technologies to areas of society where they protect the environment and improve people's safety, security and ultimately quality of life.

9. Dissemination

9.1. Scientific community

- Francisco Rubio from Univ. Sevilla has been invited from September until October 2008.
- Carlos Canudas-de-Wit organized an invited session at IEEE Conference of Decision and Control (Advances in networked controlled systems) and the IFAC Word Congress at Seul, Korea, in June 2008. He was chair of invited session IEEE Conference on Control Applications,Singapore (Coding with minimal information). Member of program committees at the 2008 IEEE Conference on Decision and Control, Guest editor of a special issue of the International journal of Robust & Nonlinear Control on "Control with Limited Information". Member of the working group on Vehicle control, and systems and networks, of the GdR MACS.

  He is a member of the STL committee, of the COST (Inria) and of the AERES evaluation panel for the Rocquencourt CRI.

  He has been reviewer and examiner for the PhD thesis of Nicoleta Minoiu-Enache (Univ. of Evry) and Samer Riachy (Lille), and for the HDR of Franck Plestan (IRCCyN, Nantes).
- M. Alamir is a member of the "Nonlinear Systems" IFAC technical committee and co-animator of the "Nonlinear Predictive Control" group of GDR-MACS. He is Associated Editor for the IFAC World Congress (South Korea, 2008) and editor of a Special issue of International Journal on Robust and Nonlinear Control. He was in the PhD jury of M. Porez (IRCCyN Nantes), A. Donze (VERIMAG, Grenoble) and G. Gallot (IRCCyN, Nantes).
- N. Marchand is co-animator of the "Nonlinear Predictive Control" group of GDR-MACS. He is member of the scientific committee of the IEEE ASME Advanced Intelligent Mechatronics (AIM).
- D. Simon is a member of the RTNS'08 (international conference on Real Time and Network Systems) program committee. He co-organized an invited session about safe networked control systems at the 16th IEEE Mediterranean Conference on Control and Automation, Ajaccio, July 2008. He is reviewer for the PhD thesis of Ning Jia, Loria, Nancy, to be defended in January 2009.
- O. Sename is member of the IFAC Technical committees 'Linear systems'and 'Automotive control'. He is Associated Editor of the European Control Conference 2009. He was reviewer of the PhD Thesis of Wilfried Gilbert (Toulouse), Matteo Corno (Politecnico di Milano), and of the HDR of Nicolas Langlois (Univ. Rouen). He is responsible of the Master and PhD programs in Automatic Control.

9.2. Teaching

9.2.1. Courses

- Olivier Sename and Cyrille Siclet teach several courses in control and signal processing inside Grenoble INP schools; O. Sename teaches Robust Control (20h) in the M2R Automatique Master at Grenoble INP; Olivier Sename is responsible of the 2-years engineering program in Automatic Control, Systems and Information Technology.

- Nicolas Marchand : *Nonlinear control systems*, Master PSPI, Université Joseph Fourier. *Control of Embedded systems*, Filiere SLE, ENSIMAG, Grenoble-INP.

9.2.2. Advising

Post-docs:

- Yun-Bo Zhao (ARAVIS project - from September until December 2008), PostDoc advised by D. Simon
- Brandon Moore (CONNECT project - from September 2008), PostDoc advised by C. Canudas de Wit
- Jiri Zikmund (CONNECT project - from November 2008),(Connect project - from September 2008) , co-advised by M. Alamir and D. Simon

PhDs:

- Lara Briñon Arranz co-advised by C. Canudas de Wit and A. Seuret, INRIA, FeedNetBack project - 2008/2011,
- Emilie Roche, co-advised by O. Sename and D. Simon, INRIA,FeedNetBack project - 2008/2011,
- Jonathan Jaglin, co-advised by C. Canudas and C. Siclet, INPG, 2006-09
- Sylvain Durand, co-advised by N. Marchand and D. Simon, INPG, 2007-2010.
- Luc Malrait, co-advised by N. Marchand and S. Bouchenak (SARDES), INPG, 2007-2010.
- Carolina Albea-Sanchez, co-advised by C. Canudas and F. Gordillo (Univ. Sevilla)
- Riccardo Ceccarelli, co-advised by C. Canudas and A Sciaretta (IFP)

Masters:

- Moctar Mossi Idrissa (University of Rennes I), Gorka Gomez Garnika (University of Pamplona), advised by C. Siclet
- Emilie Roche, co-advised by O. Sename and D. Simon, M2R EEATS, ENSIEG
- Lara Briñon Arranz, advised by C. Canudas de Wit, M2R EEATS, ENSIEG

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Articles in International Peer-Reviewed Journal

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[12] C. CANUDAS-DE-WIT, F. RUBIO, M.-A. CORCHERO. *D-OSKIL: A New Mechanism for Controlling Stick-Slip Oscillations in Oil Well Drillstrings*, in "IEEE Transactions on Control Systems Technology", vol. 16, n^o 6, November 2008, p. 1177-1191.

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Invited Conferences

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