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Activity Report 2012

Project-Team NECS

Networked Controlled Systems

IN COLLABORATION WITH: Grenoble Image Parole Signal Automatique (GIPSA)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Modeling, Optimization, and Control of Dynamic Systems

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Project-Team NECS

Keywords: Distributed Algorithms, Network Modeling, Network Control, Quality Of Service, Robust Control, Nonlinear Control

Creation of the Project-Team: January 01, 2007 .

1. Members

Research Scientists
Carlos Canudas de Wit [Team Leader, Senior Researcher CNRS, HdR]
Federica Garin [Researcher INRIA]
Alexandre Seuret [Researcher CNRS (–> Jun. 2012)]
Daniel Simon [Researcher INRIA, HdR]

Faculty Members
Alain Kibangou [Associate Professor, UJF-CNRS Chair/IUT 1]
Hassen Fourati [Associate Professor, UJF/IUT 1]
Lara Briñón Arranz [ATER ENSE3 - (Sep. 2011 –> Aug. 2012)]
Antoine Lemarchand [ATER ENSE3 - (Oct. 2011 –> Aug. 2012)]

External Collaborator
Olivier Sename [Professor, Grenoble INP, HdR]

Engineers
Jonathan Dumon [Research Engineer - Hardware support]
Roger Pissard-Gibollet [Research Engineer - Software support]
Iker Bellicot [Engineer ADT-GTL]

PhD Students
Aida Makni [MENRT - (Oct. 2012 –> Sep. 2015)]
Abir Ben Khaled [IFPEN - (Jan. 2011 –> Dec. 2013)]
Dominik Pisarski [HYCON2 project - (Jun. 2011 –> May 2014)]
Gabriel Rodrigues de Campos [MENRT - (Oct. 2009 –> Sep. 2012)]
Giovanni de Nunzio [CIFRE-IFP-GIPSA-lab - (Oct. 2012 –> Sep. 2015)]
Luis Leon Ojeda [HYCON2 project - (Avr. 2011 –> Mar. 2014)]
Nicolas Cardoso de Castro [FeedNetBack project - (Sep. 2009 –> Sep. 2012)]
Patrick Jocelyn Andrianiaina [CIFRE-Airbus - (Apr. 2009 –> Mar. 2012)]
Ruggero Fabbiano [FeedNetBack project - (Dec. 2011 –> Nov. 2014)]
Thi-Minh Dung Tran [Vietnamese Government scholarship - (Jan. 2012 –> Jan. 2015)]
Valentina Ciarla [BDI CNRS/VOLHAND project - (Dec. 2010 –> Nov. 2013)]
Wenjie Lu [CSC-Scholarship - (Sep. 2011 –> Oct. 2012)]

Post-Doctoral Fellows
Alireza Esna Ashari [Chaire Inria-Schneider-Digiteo - (Nov. 2011 –> Oct. 2012)]
Fabio Morbidi [MoCoPO Project - (Nov. 2012 –> Oct. 2013)]

Administrative Assistant
Elodie Toihein [Assistant]

2. Overall Objectives

2.1. Introduction

The field of Networked Controlled Systems (NCS) refers to feedback systems controlled *over* networks, as shown in Fig 1. Such systems present 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 the number and variety of components), the distributed location of sensors and actuators, and computational constraints imposed by their embedded nature (i.e., embedded systems and systems on-chip). In this class of systems, 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 performance properties of the feedback controlled systems. Inversely, the already designed feedback system can be affected by the properties of the channel transmission (latency, fading, delay jitter, lost of data, etc.), and the way that the computational and energy resources are used.

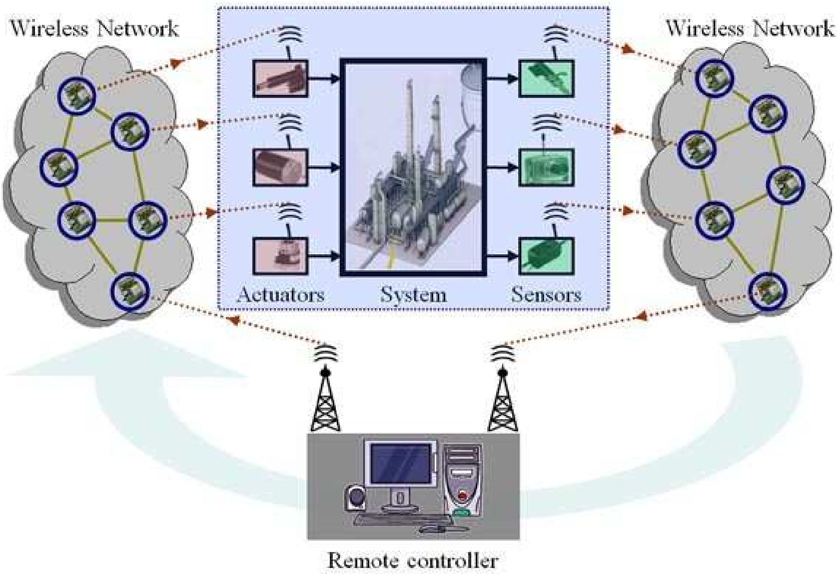

Figure 1. Overview of NeCS systems.

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 bi-located at Inria (Montbonnot) and at the GIPSA-LAB (at the Grenoble campus).

2.2. Highlights of the Year

The most relevant events for the NeCS team in 2012 are the following:

- Carlos Canudas de Wit has been elected as member of the Board of Governor (BoG) of the IEEE Control System Society (CSS)
- The team animated the In'Tech seminar on intelligent transportation systems in November 2012.

3. Scientific Foundations

3.1. Multi-disciplinary nature of the project

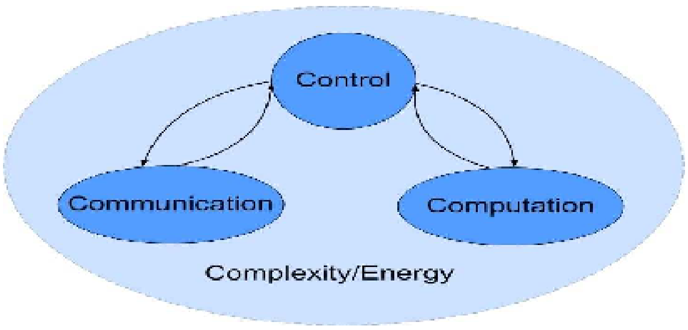

Figure 2. Relation of the NCS area with the fields of: Control, Communication, Computation.

The team's project is 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 systems 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, scaling with respect to a growing number of sensors. Energy management concerns in particular the efficient handling of energy in wireless sensors, and means an efficient way to handle both information transmission and computation.

3.1.1. (a) Control in Communication

This topic is the study of how control-theoretic methods can be applied in order to solve some problems found in the communication field. Examples are: the Power control in cell telephones, and the optimal routing of messages in communication networks (Internet, sensor networks).

3.1.2. (b) Communication in Control

This area concerns problems where communication and information theory interact with systems theory (control). As an example of a classical paradigm we can mention the stabilization problem under channel (communication) constraints. A key result here [75] 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

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

where the $\lambda_i's$ are unstable eigenvalues 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 sent 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). Networked controlled systems also constitute a new class of control systems including specific problems concerned by delays. In NCS, the communication between two agents leads unavoidably to transmission delays. Also, transmission usually happens in discrete time, whereas most controlled processes evolve in continuous time. Moreover, communication can induce loss of information. Our objectives concern 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 due to time-varying communication delays, asynchronous samplings, packets losses or lack of synchronization. All those phenomena can be modeled as the introduction of time-delays in the closed loop system. Even if these time-delay approaches can be easily proposed, they require careful attention and more complex analysis. In general, the introduction of delays in a controlled loop leads to a reduction of the performance with respect to the delay-free situation and could even make the systems unstable. Our objective is to provide specific modeling of these phenomena and to develop dedicated tools and methodologies to cope with stability and stabilization of such systems.

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 controllers need to be re-designed as to account for non-uniform sampling times resulting in this framework. Questions 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 low 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 tries to regulate the total computation load to a prefixed value. Here, the system to be regulated is the process that generates and uses 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 Fig. 3, 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 applications [64]. 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 Fig. 3

a hierarchical control structure: besides the usual process control loops we add an outer control loop whose 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. 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 [74]. This methodology is supported by the software ORCCAD (see Section 5.1) 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.

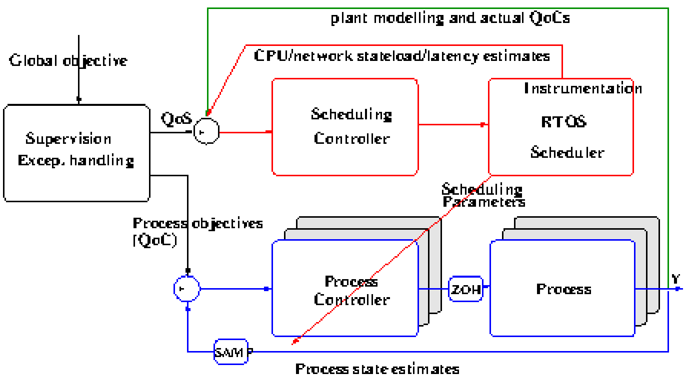

Figure 3. Hierarchical control structure.

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. More informations about the main research directions of the team can be found in [1], [3],[2], [4] [5], [6], [7], [8], [9] and [10].

In short, the project is centered along the following 3 main axes:

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 equivalently, the ability of designing codes 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 to 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 [1].

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 is 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. Application domains

Closing feedback loops around Wireless sensor networks offer 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 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.
- Intelligent buildings, where sensor information on CO_2 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.
- 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. Vehicular transportation systems

4.2.1. Car industry

Car industry has been already identified as a potential homeland application for NCS [67], 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). In addition, in the ANR project VOLHAND, in progress, the team works on developing a new generation of electrical power-assisted steering specifically designed for disabled and aged persons. More recently, a grant with IFP has been signed with the aim of studying the potential in terms of energy saving and traffic improvement of communicating vehicles.

4.2.2. Intelligent transportation systems

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. The team is currently setting up a consortium with local authorities involved in traffic management to build to a demonstrator called GTL (Grenoble Traffic Lab). One target of this activity is to transfer part of the developed technology to a start-up named Karrus.

4.3. Underwater systems

Underwater systems, as presently used or intended by the offshore industry and marine research, are subject to severe technological constraints. In AUVs, the on-board power is limited and calls for both control and computing optimization. The links between the master and slave nodes use acoustic 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. The projects CONNECT and FeedNetBack dealt with this type of problems (see 8.3.1.1).

4.4. Systems 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.

5. Software

5.1. ORCCAD

Participants: Daniel Simon [correspondant], Soraya Arias [SED], Roger Pissard-Gibollet [SED].

ORCCAD is a software environment that allows for the design and implementation of the continuous and discrete time components of complex control systems, e.g. robotics systems which provided it first ground [59]. It also allows the specification and validation of complex missions to be performed by the 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, mode switching). ORCCAD offers a complete and coherent vertical solution, ranging from the high level specification to real-time code generation. 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). Current targets are Linux (Posix threads) and Xenomai, a real-time development framework cooperating with the Linux kernel (http://www.xenomai.org). 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 Safenecs 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 team. Web page: http://orccad.gforge.inria.fr.

5.2. MASim

Participants: J. Dumon [contact person], P. Bellemain [GIPSA-Lab], S. Nicolas [PROLEXIA], N. Maciol [PROLEXIA], F. Martinez [ROBOSOFT], J. Caquas [ROBOSOFT].

MASIM is a tool that has been adapted from our former multiagent simulator MUSim (MUSim=MASim + ConnectSim + ConnectIHM). It integrates agent's models, communication media including their limitations, heterogeneous network, and all the variants of the multi-agent control strategies. Besides the models and simulation engine, the simulation can be replayed through a GUI, an interactive graphical interface which is used to visualise and interpret the state of the multi-agent control system and communication topology. The validation scenario is a real-size application enough complex to enforce the pertinence of our results. The simulator MASim is now being used as an open research tool for various applications in the field of multi-agents networked systems, particularly within the FeedNetBack project (see Fig. 4).

Web page: http://www.gipsa-lab.grenoble-inp.fr/projet/connect/simulator.php

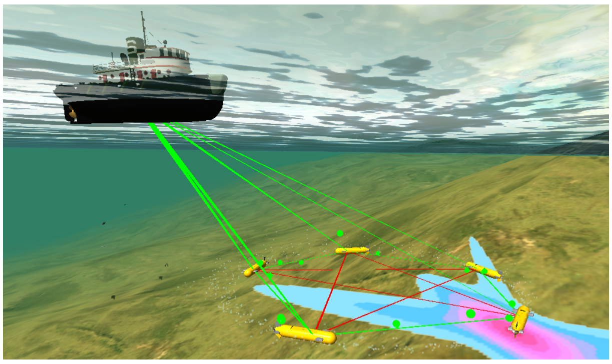

Figure 4. A scenario's view obtained with MASIM.

5.3. GTL

Participants: C. Canudas de Wit [contact person], I. Bellicot [contact person], L. Leon Ojeda, D. Pisarski.

The team has created a software demonstrator to have a showcase including cutting-edge model developments. This software is a global services platform for end-user traffic use, providing accurate density calculation on traffic color vision, and integration of estimator and prediction motor for travel-time calculation. GTL (Grenoble Traffic Lab) is a real-time traffic data center platform intended to collect traffic road infrastructure information in real-time with minimum latency and fast sampling periods. The main elements of the GTL are: a real-time database, a show room, and a suit of traffic forecasting software. Sensed informations come from a dense wireless sensor network providing macroscopic traffic signals such as flows, velocities, densities, and magnetic signatures. This sensor network was set in place in collaboration with Inria spin-off Karrus-ITS, local traffic authorities (DIR-CE, CG38, La Metro), and specialized traffic research centers.

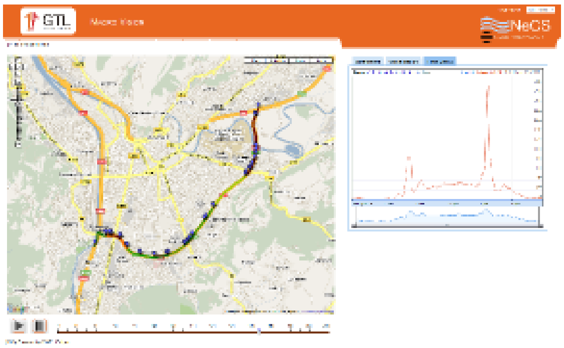

Figure 5. The GTL Macro-simulator.

6. New Results

6.1. Communication and control co-design for networked systems

6.1.1. Energy-aware communication and control co-design in wireless networked control systems

Participants: C. Canudas de Wit [Contact person], N. Cardoso de Castro, F. Garin, D. Quevedo [Newcastle Univ., Australia].

This work is the topic of the PhD thesis of N. Cardoso de Castro [12]. We have considered an event-based approach to energy-efficient management of the radio chip in the sensor node of a wireless networked control system.. Indeed, as we had pointed out in the review paper [63], the radio is the main energy consumer, and intermittent data transmission allows one to reduce the use of the radio. While the existing literature in the control community on event-based control only addresses policies using two radio-modes (Transmitting/Sleep), our work follows some considerations on the radio-chip modes well-known in the communication networks literature, and introduces various radio-modes: different 'idle' non-transmitting modes, where only part of the radio-chip is switched off (thus consuming more energy than 'Sleep', but allowing for faster transition to transmission), and various transmitting modes, with different power levels. We propose an event-based radio-mode switching policy, which allows to perform a trade-off between energy saving and performance of the control application. To this end, a switched model describes the system, taking into account control and communication. The optimal switching policy is computed using Dynamic Programming, considering a cost either over an infinite time-horizon [31] or over a finite receding horizon [32].

6.1.2. System-theoretic analysis of modern error correcting codes (serial turbo codes)

Participants: F. Garin [Contact person], G. Como [Lund Univ., Sweden], F. Fagnani [Polit. Torino, Italy].

Serial turbo codes are a family of codes for error correction in point-to-point digital communication. The encoder can be described as the composition of three linear maps, the intermediate one being a permutation (called interleaver) while the inner and outer one are convolutional codes, i.e., linear dynamical systems where state, input and output belong to a vector space over the finite field $GF(2)$. The decoding is performed with iterative low-complexity algorithms which give a good approximation of the optimal maximum-likelihood (ML) decoder. Using system-theoretic properties of the constituent convolutional codes and probabilistic arguments, we study the average and the typical behavior of ensembles of such codes (with fixed convolutional codes, and random interleaver), asymptotically in the block-length [18]. We disprove the common conjecture that the typical behavior concentrates around the average: indeed, the average error decays polynomially in the block-length N, while the typical code has a faster error decay (exponential in some fractional power of N); however, the typical-code analysis confirms the same design parameters for the convolutional codes that were already suggested by the study of the ensemble average: free distance of the outer encoder, and effective free distance of the inner encoder.

6.2. Networked systems and Graph analysis

6.2.1. Observability in consensus networks

Participants: A. Kibangou [Contact person], C. Commault [Gipsa-Lab].

Studying the observability problem of a system consists in answering the question: is it possible, for a given node, to reconstruct the entire network state just from its own measurements and those of its neighbors ?

Studying observability for arbitrary graphs is particularly a tough task. Therefore, studies are generally restricted to some families of graphs. For instance, recently, observability has been studied in [70] for paths and circular graphs where the study was carried out based on rules on number theory. Herein, we have considered families of graphs admitting an association scheme [62] such that strongly regular graphs and distance regular graphs. The regularity properties of these kinds of graphs can particularly be useful for robustifying the network as for cryptographic systems [79]. Based on the so-called Bose-Mesner algebra [60], we have stated observability conditions on consensus networks modeled with graphs modeled with strongly regular graphs and distance regular graphs. For this purpose, we have introduced the notion of local observability bipartite graph that allows characterizing the observability in consensus networks. We have shown that the observability condition is given by the nullity of the so-called local bipartite observability graph. When the nullity of the graph cannot be derived directly from the structure of the local bipartite observability graph, the rank of the associated bi-adjacency matrix allows evaluating the observability; the bi-adjacency matrix of the so-called local bipartite observability graph must be full column rank for guaranteeing observability. From this general necessary and sufficient condition, we have deduced sufficient conditions for strongly regular graphs and distance regular graphs. In particular, we have shown that observability is ensured in such graphs only if $DK \geq N - 1$ where D is the number of classes of the association scheme, N the number of nodes, and K the valency of the graph, i.e. the cardinality of the neighborhood.

6.2.2. Distributed graph discovery

Participants: A. Kibangou [Contact person], F. Garin [Contact person], C. Commault [Gipsa-Lab], D. Tran, D. Varagnolo [KTH], K.H. Johansson [KTH].

We have studied the problem of estimating the eigenvalues of the Laplacian matrix associated with a graph modeling the interconnections between the nodes of a given network. Two approaches have been developed. For the first one [38], based on properties of the observability matrix, we have shown that Laplacian eigenvalues can be recovered by solving a local eigenvalue decomposition on an appropriately constructed matrix of observed data. Unlike FFT based methods recently proposed in the literature (see [65], [73]), in our proposed method we are also able to estimate the multiplicities of the eigenvalues. However, this method is only applicable to networks having nodes with sufficient storage and computation capabilities. That's why we have proposed a second method requiring much less computation and storage capabilities in [76]. Based on a recent result showing that the average consensus matrix can be factored in D Laplacian based consensus matrices, where D stands for the number of nonzero distinct Laplacian eigenvalues [40], we have shown how carrying out such a factorization in a fully distributed way. The proposed solution results on a distributed solution of a constrained consensus problem.

The availability of information on the communication topology of a wireless sensor network is essential for the design of the estimation algorithms. In the context of distributed self-organized sensor networks, there is no central unit with the knowledge of the network, and the agents must run some distributed network-discovery algorithms. This is particularly difficult in the case when the agents do not have or do not want to disclose their identifiers (IDs), either for technological reasons (in time-varying self-organized networks, assigning unique identifiers to agents is a challenge) or for privacy concerns. In a recent work [78] the authors proposed an algorithm which allows each agent to find an estimate of the number of agents in the network, in an anonymous way. Such an algorithm is based on the generation of pseudo-random numbers, on some consensus algorithms (for distributed computation either of average or of maximum), and on statistical inference. In our work [37], we show how the same algorithm, with some minor modifications, can provide more information: approximations of each node's eccentricity, of the graph diameter and of the graph radius. We study the quality of such approximations, providing tight bounds on the error.

6.3. Distributed methods for control

6.3.1. Distributed control

Participants: A. Seuret [Contact person], G. Rodrigues de Campos, L. Brinon-Arranz, D.V. Dimarogonas [KTH], K.H. Johansson [KTH].

Another particular effort has been provided to the design of distributed control laws for multi-agents systems. Three main contributions have been produced and can be summarized as follows.

In [44], a new consensus algorithms for heterogeneous multi-agent systems is provided. A control strategy based on a consensus algorithm which is decoupled from the original systems is proposed. Consequently, its major advantage remains in the separation of the stability analysis of each subsystem and the distributed control algorithm. It is shown that our method allows using classical distributed consensus algorithms such as simple integrator consensus (with or without delay) and distributed consensus filter algorithms.

For many multi-robot applications it is interesting to impose a particular configuration for the robotic agents. This paper discusses the design and analysis of a distributed algorithm for the compact deployment of agents, where the behavior of each vehicle is only dependent on local information. The objective of the paper [72] is to achieve the most compact formation possible. To solve this problem we propose, in a first step, two uncorrelated controllers: one designed for dispersion with connectivity maintenance and a second designed to minimize inter-agent angles. An improved controller including variable gains, particularly designed to avoid singular configurations, is also provided. Lastly, we propose a sequential strategy composed of the two previously mentioned controllers and a stability analysis based on hybrid systems theory. Finally, some simulation results for different configurations supporting our theoretical results are presented.

6.3.2. Collaborative source seeking control

Participants: C. Canudas [Contact person], R. Fabbiano, F. Garin.

The problem of source localization consists in finding the point or the spatial region from which a quantity of interest is being emitted; this goal can be pursued by one or several agents possibly cooperating each other. Source-seeking agents can be fixed sensors, that collect and exchange some information about the signal field and try to identify the position of the source (or the smallest region in which it is included), or moving devices equipped with one or more sensors, that physically reach the source in an individual or cooperative way.

Within the FeedNetBack European project, we have addressed the problem of collaborative source seeking with a fleet of autonomous underwater vehicles (UAVs). This topic was explored in the PhD thesis of Lara Brinon [61], where a solution was proposed, based on circular formations with the center of the formation following a 2-dimensional movement in the direction of the gradient of the source. The gradient computation was achieved through an approximation using the point-wise measurements from the various vehicles.

In a more recent work [29], we leave temporarily aside all issues of coordination and communication failures well-addressed in [61], and we focus on the gradient computation formula. Under some assumptions on the source emission (isotropic diffusive source in steady-state, whose solution satisfies the Laplace equation), we show that there is an exact integral formula (based on the Poisson integral of harmonic functions) for the computation of the gradient at the center of a circle, using pointwise measurements along the circumference. This approach has two main advantages: it can be generalized in three (or more) dimensions, and it allows to compute also higher-order derivatives, which allow to find higher-order control laws, useful e.g. for non-holonomic vehicles. A relevant property is that such an integral formula exploits mathematical properties of the source density distribution (the fact that it is harmonic), but does not require the knowledge of an explicit expression for the density function. This makes our approach different from the main source-seeking techniques present in the literature, which either are based on a specific knowledge of the solution of the diffusion process, or make use of an extremum-seeking approach, exciting the system with a periodic signal so as to explore the field and collect enough information to reconstruct the gradient of the quantity of interest.

The latter work is part of the research of Ruggero Fabbiano during his Ph.D. studies.

6.3.3. Distributed real-time Simulation of numerical models

Participants: D. Simon [Contact person], A. Ben Khaled [IFPEN], M. Ben Gaid [IFPEN].

The need of quick innovation in the automotive domain made simulation necessary at early stages of the development cycle. Vehicles and powertrains are complex systems where different domains are involved. Representative phenomenological models of powertrains have been developed and have been used in the design phase under domain dedicated tools. However, their use for controls validation using Model-In-the-Loop (MIL) and Hardware-In-the-Loop (HIL) was prevented due to performance limitation of widely used single-solver/single-core simulation approaches.

Multicore simulation for complex systems has been studied with a focus on simulation duration speedup. The methodology of parallelization across the model has been selected for such problem where strong interactions between the model components are observed. The current study showed that decoupling the model parts by relaxing their data dependencies is promising in term of simulation speed (by increasing the parallelism) and results accuracy. Besides, tests results on engine model showed that, with the model partitioning, it is possible to use efficiently variable-step solvers thanks to the decrease of the number of discontinuities, so the number of integration interrupts, in each subsystem [26].

Further work will investigate in the combination of the use of variable-step solvers in split model with the use of multicore architecture for parallel computing, in order to improve the simulation speedup while keeping results accuracy under control.

6.4. Distributed average consensus algorithms

6.4.1. Finite-time average consensus protocols

Participants: A. Kibangou [Contact person], D. Tran.

Nowadays, several distributed estimation algorithms are based on the average consensus concept. Average consensus can be reached using a linear iterations scheme where each node repeatedly updates its value as a weighted linear combination of its own value and those of its neighbors. The main benefit of using a linear iterations scheme is that, at each time-step, each node only has to transmit a single value to each of its neighbors. Based on such a scheme, several algorithms have been proposed in the literature. However, in the majority of the proposed algorithms the weights are chosen so that all the nodes asymptotically converge to the same value. Sometimes, consensus can be embedded as a step of more sophisticated distributed. Obviously, asymptotic convergence is not suitable for these kinds of distributed methods. Therefore, it is interesting to address the question of exact consensus in finite-time. For time-invariant network topologies and in the perfect information exchange case, i.e. without channel noise nor quantization, we have shown that the finite-time average consensus problem can be solved as a matrix factorization problem with joint diagonalizable matrices depending on the Graph Laplacian eigenvalues [40], [39]. Moreover, the number of iterations is equal to the number of distinct nonzero eigenvalues of the graph Laplacian matrix. The design of such a protocol requires the knowledge of the Laplacian spectrum, which can be carried out in a distributed way (see [65], [73], [76]). In [77], the matrix factorization problem is solved in a distributed way. In particular a learning method was proposed and the optimization problem was solved by means of distributed gradient backpropagation algorithms. Unlike the method in [40], the factor matrices are not necessarily symmetric and the number of these factor matrices is exactly equal to the diameter of the graph.

6.4.2. Quadratic indices for performance evaluation of consensus algorithms

Participants: F. Garin [Contact person], S. Zampieri [Università di Padova], E. Lovisari [Università di Padova and Lund Univ.].

Traditional analysis of linear average-consensus algorithms studies, for a given communication graph, the convergence rate, given by the essential spectral radius of the transition matrix (i.e., the second largest eigenvalues' modulus). For many graph families, such analysis predicts a performance which degrades when the number of agents grows, basically because spreading information across a larger graph requires a longer time. However, when considering other well-known quadratic performance indices (involving all the eigenvalues of the transition matrix), the scaling law with respect to the number of agents can be different. This is consistent with the fact that, in many applications, for example in estimation problems, it is natural to expect that a larger number of cooperating agents has a positive, not a negative effect on performance. It is natural to use a different performance measure when the algorithm is used for different purposes, e.g., within a distributed estimation or control algorithm. Examples of various relevant costs can be found in the book chapter [66] and in the references therein.

We are interested in evaluating the effect of the topology of the communication graph on performance, in particular for large-scale graphs. Motivated by the study of wireless sensor networks, our main objective is to understand the limitations which arise when agents are limited to truly local interactions, i.e., the neighborhoods are determined by being 'near' in a geometric (Euclidean) way, differently from graphs with few but possibly 'distant' connections, such as in small world models. At first [19] we consider graphs which are regular lattices (infinite lattices, or grids on tori, or grids on hyper-cubes), which are examples of geometrically local interactions, but also have a very rich structure: their symmetries allow to exploit powerful algebraic tools, such as the discrete Fourier transform over rings, to compute their eigenvalues, and then find bounds on the associated costs. Then, we extend the results to a more general class of graphs, thus showing that the behavior of lattices is mainly due to the local nature of interactions and not to the spatial invariance (the richness of the automorphism group). To do so, we exploit the analogy between reversible Markov chains and resistive electrical networks, which allows to study some perturbed grids, with less regularity but still exhibiting the same dimension-dependent asymptotic behavior. This latter work is part of the Ph.D. thesis of E. Lovisari at University of Padova, Italy, and the topic of a journal paper in preparation.

6.5. Distributed Estimation and Data fusion

6.5.1. Distributed joint state and input estimation

Participants: A. Kibangou [Contact person], F. Garin [Contact person], A. Esna Ashari.

Three consensus-based distributed algorithms have been developed for joint state and input estimation in discrete-time systems. The methods are proper substitutes for distributed Kalman filter in the case in which there are additive faults to the system. Previously developed centralized estimation methods have been reformulated so that the estimator can be used for distributed sensor networks. These new forms are similar to the information form of Kalman filter [34], [35]. The new forms can be used to propose distributed algorithms based on the consensus of the nodes on calculation of some matrices and vectors. Also a second algorithm is proposed, based on the consensus of the local estimators on local state estimations. This algorithm has less computation effort than the first, but gives a sub-optimal solution in the sense of covariance error. Finally, a third method based on covariance intersection method for diffusing local estimations was proposed in addition. This method also provides a sub-optimal solution. Compared with the second approach, the diffusion of local data is less complicated, however it requires more message communication between nodes.

6.5.2. Data fusion approaches for motion Capture by Inertial and Magnetic Sensors

Participants: H. Fourati [Contact person], A. Makni.

We are interested to motion capture (or attitude) by fusing Inertial and Magnetic Sensors. In [17], we present a viable quaternion-based Complementary Observer (CO) which is designed for rigid body attitude estimation. We claim that this approach is an alternative one to overcome the limitations of the Extended Kalman Filter (EKF). The CO processes data from a small inertial/magnetic sensor module containing tri-axial angular rate sensors, accelerometers, and magnetometers, without resorting to GPS data. The proposed algorithm incorporates a motion kinematic model and adopts a two-layer filter architecture. In the latter, the Levenberg Marquardt Algorithm (LMA) pre-processes acceleration and local magnetic field measurements, to produce what will be called the system's output. The system's output together with the angular rate measurements will become measurement signals for the CO. In this way, the overall CO design is greatly simplified. The efficiency of the CO is experimentally investigated through an industrial robot and a commercial IMU during human segment motion exercises. These results are promising for human motion applications, in particular future ambulatory monitoring. The estimated attitude is used to reconstitute the linear acceleration, linear velocity and finally the 3D position from a usual integration procedure (in the case of foot motion) [36]. The problem of attitude estimation is also recently studied within the PhD thesis of Aida Makni. Our goal is to develop a new attitude estimation methods in the case of aerial vehicles (hexa-rotors) by the use of intermittent measures of gyroscopes with the goal to reduce the energy consumption and to gain in the autonomy of the battery.

6.6. Stability and control design of asynchronous interconnected systems

6.6.1. New approaches for stability analysis of time-delay systems

Participants: A. Seuret [Contact person], F. Gouaisbaut.

A particular attention has been paid to the stability analysis of time delay systems. Indeed delays represent a classical phenomenon which appears in networked control systems cite. This corresponds to the fact that data are not transmitted instantaneously from one node to its neighbors. In this context some effort has been provided in order to reduce the conservatism of the stability conditions. This works represents some fundamental researches to develop accurate stability conditions to networked control systems. More especially we produced a paper [45] which addresses the stability problem of linear time delay system. In the literature, the most popular approach to tackle this problem relies on the use of Lyapunov-Krasovskii functionals. Many results have proposed new functionals and techniques for deriving less and less conservative stability conditions. Nevertheless, all these approaches use the same trick, the well-known Jensen's inequality which generally induces some conservatism difficult to overcome. In light of those observations, we propose to reduce the conservatism of Lyapunov-Krasovskii functionals by introducing new classes of integral inequalities called Wirtinger's inequalities. This integral type inequality is firstly shown to encompass Jensen's inequality and is then employed to derive new stability conditions. To this end, a slightly modified Lyapunov functional is proposed. Several examples illustrate the effectiveness of our methodology. Further efforts on this topics have been provided and several improved articles are now submitted to servals journals.

6.6.2. Stability and control of asynchronous sampled-data systems

Participants: A. Seuret [Contact person], C. Briat [ETHZ], J. Gomes Da Silva Jr. [UFRGS], M. M. Peet [Illinois Institute of Technology].

Sampled-data systems have been extensively studied in the literature and the references therein. It is now reasonable to design controllers which guarantee the robustness of the solutions of a closed-loop system under periodic samplings. However the case of asynchronous samplings still leads to several open problems. This corresponds to the realistic situation where the difference between two successive sampling instants is time-varying. Several articles drive the problem of time-varying periods based on a discrete-time approach, input delay approach using the framework of Lyapunov-Krasovskii theorem, using the small gain theorem or the analysis of impulsive systems. These last approaches are very relevant to this problem because they cope with time-varying sampling periods as well as with uncertain systems in a simple manner. Nevertheless, these sufficient conditions are still more conservative than discrete-time approaches. In [24], we proposed a novel approach to assess stability of continuous linear systems with sampled-data inputs. The method, which is based on a particular type of functionals, called 'looped-functionals' provided easy tractable stability conditions for the continuous-time model. This method has been extended to various cases dealing with sampled-data systems. Indeed a method to constructs such class of functionals using the Sum of Squares framework was developed in [23]. Another extensions was also proposed in order to include saturations in the actuators [21]. Extensions to the case of communication delays and asynchronous samplings was also provided in [22].

Based on this new type of Lyapunov functional, several works have been provided in the more general context of hybrid system. Indeed sampled-data systems can be seen as a particular type of hybrid systems. This has been provided in several study done by A.R. Teel, Dragan Nesic and many other researchers. Thus the idea was to show that the previous approach was also able to provide efficient stability conditions for impulsive systems [16], [27], [28], [54] or switched systems [53].

6.6.3. Event-based control

Participants: A. Seuret [Contact person], N. Marchand [Gipsa-Lab], C. Prieur [GIPSA-Lab], S. Durand [CINVESTAV].

Usually feedback laws are implemented in a periodic fashion on digital hardware. The main reason for using this periodicity in the hardware comes from the difficulties to analyze the stability of aperiodic or asynchronous systems. However it also seems natural to hold the same control input longer if the system behaves in a suitable way or shorter if the system requires an updated input. In [9], an algorithm is suggested to sample the control input based on the behavior of a Lyapunov-like function. This algorithm is called event-triggered since the Lyapunov-like function directly depends on the state of the systems. Using a Lyapunov-like function, two algorithms for the design of event-triggered algorithm are designed. It is assumed that a stabilizing controller for the continuous control system is given. Both event-triggered algorithms need to consider a closed-loop system with a mixed discrete/continuous dynamics (namely this is a hybrid system). Some numerical simulations illustrate the stability properties of both algorithms. In a future work, the performance issue should be analyzed. It is remarked that the event-triggered algorithms have a different performance. The first one seems to ensure a good speed of convergence on numerical simulations, whereas the second event-triggered algorithm allows less jumps and thus needs to compute less often the control variables. The advantages and disadvantages of each algorithm will be studied more precisely in a future work, for a theoretical point of view (e.g. by estimating a priori the number of switches), or on applications (to understand which algorithm is better depending on the application). Regarding this remark a journal paper has been submitted to IMA Journal of Mathematic Control and Information lately in 2012.

6.6.4. Feedback under slacken real-time

Participants: D. Simon [Contact person], A. Seuret, P. Andrianiaina [AIRBUS].

Robustness in control usually deals with the plant's parameter uncertainties, but the insensitivity or adaptability w.r.t. timing deviations from the theoretical pattern, such as jitter or deadlines misses can be exploited. The interesting point is that a feedback control system which is robust w.r.t. the plants parameters uncertainties is also robust, to some extent, w.r.t. timing deviations. Hence a feedback control system is not as hard as it is often considered in the literature, but should be better considered as *weakly hard*, i.e. able to tolerate specified timing deviations without leaving its requested performance [46].

A weakened implementation scheme for real-time feedback controllers is proposed to reduce the conservatism due to traditional worst-cases considerations. To save wasted computing resources, new real-time scheduling scenarios allowed for reducing the time slots allocated to control tasks below the value of the Worst Case Execution Time which is traditionally used to implement embedded control software. The stability of the control system under occasional deadlines miss is assessed using robustness arguments, using Lyapunov-Krasovskii functionals and LMIs solving based on [10]. The methodology has been successfully assessed for a fighter aircraft pitch controller, which show that the stability of the plant can be kept (and even improved) using the new scheduling schemes using less computing resources than traditional implementations [25], [11].

6.6.5. Varying sampling for LPV systems

Participants: D. Simon [Contact person], O. Sename, E. Roche.

In the context of network-controlled systems the idea of using varying control intervals naturally arises when the available computing power devoted to feedback control is limited, e.g. in embedded systems. It can be easily shown that decreasing the control frequency directly decreases the amount of computing needed for control. However, the stability of the feedback controller under varying sampling must be assessed for all the allowed variations of the sampling intervals [8].

The Linear Fractional Transform (LFR) formulation is widely used in robust analysis to study the influence of the plant's uncertain parameters on the stability and performances of a closed-loop system. Usually it is used to build a parameter dependent model of a dynamical system, depending on a known set of parameters. Here the set of varying parameters has been extended with the sampling interval of the control system, thus allowing to handle both varying sampling and plants uncertainties in a single framework (Figure 6).

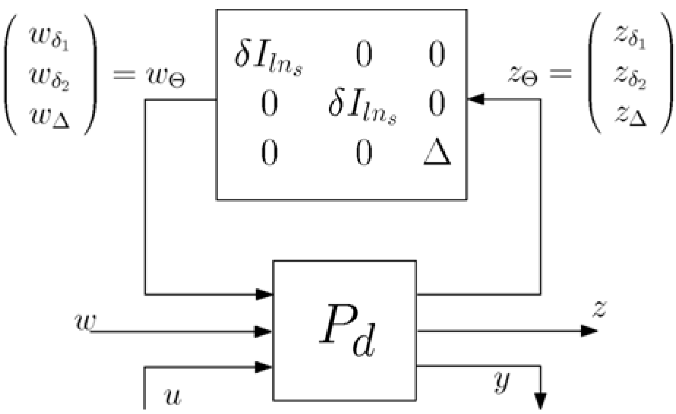

Figure 6. LFR system depending on system parameters and sampling interval variations

Here, P_d is a on-line discretized model of the plant, Δ represents the uncertain parameters of the plant and δ is the variation of the sampling interval around its nominal value. From this model a robust controller can be synthesized, enforcing the control system stability for all variations of the sampling interval inside a predefined range.

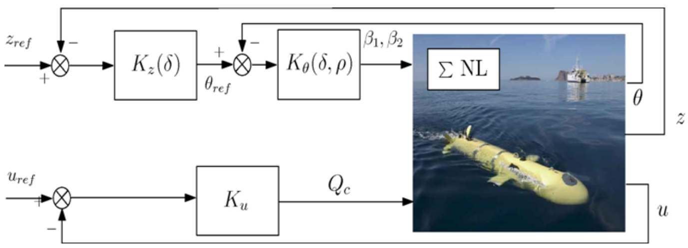

Figure 7. Control of an AUV

The approach have been successfully applied to the pitch and altitude control of a non-linear autonomous underwater vehicle, where the source of sampling variations comes from the altitude ultrasonics sensors [43]. However the approach still suffers from conservatism for which improvements using full block multipliers, or parameter-dependent Lyapunov functions, have been investigated [58].

6.7. Vehicular transportation systems

6.7.1. Traffic estimation and prediction

Participants: C. Canudas de Wit [Contact person], A. Kibangou, L. Leon Ojeda, F. Morbidi.

Reconstructing densities in portions of the road links not equipped with sensors constitutes an important task in traffic estimation, forecasting, and control problems. Among many other approaches, model-based observers is one popular technique to build this information. They can also be understood as *virtual sensors* deployed inside of the cells not equipped with *true sensors*. They are used to better track, in real-time, density variations with a fine degree of granularity in the space, as the *virtual cells* can be selected as small as desired. In [30], a graph constrained-CTM observer was introduced. It allows reconstructing rather accurately the internal states (densities) of a road portion not equipped with sensors. This strategy for real-time density estimation was applied on Grenoble South Ring. Simulation results exhibit that the measured densities obtained from the traffic simulator Aimsun and the estimated densities agree closely. In [69], this observer has been associated with an adaptive Kalman filtering approach for traffic prediction in terms of travel time. The adaptive Kalman filtering approach was also been used for predicting input flows in [68].

6.7.2. Traffic control

Participants: C. Canudas de Wit [Contact person], D. Pisarski.

The problem of equilibrium points for the Cell Transmission Model was studied in [42]. The structure of equilibrium sets was analyzed in terms of model parameters and boundary conditions. The goal was to determine constant input flows, so that the resultant steady state of vehicle density was uniformly distributed along a freeway. The necessary and sufficient conditions for the existence of one-to-one relation between input flow and density were derived. The equilibrium sets were described by formulas that allow to design a desired balanced density. A numerical example for the case of a two-cell system was presented. In [41], the problem of optimal balancing of traffic density distributions was explored. The optimization was carried out over the sets of equilibrium points for the Cell Transmission Traffic Model. The goal was to find the optimal balanced density distribution, that maximizes both the Total Travel Distance and the total input flow. The optimization was executed in two steps. At the first step, a nonlinear problem to find a uniform density distribution that maximizes the Total Travel Distance was solved . The second step was to solve a quadratic problem reflecting the trade-off between density balance and input flow maximization. At both steps, decomposition methods were used. The computational algorithms associated to such a problem were given. Finally, in [71], the application of the idea of optimal balancing of traffic density distribution was presented. It was implemented to the Grenoble South Ring in the context of the Grenoble Traffic Lab. The traffic on the ring is represented by the Cell Transmission Model that was tuned by using real data and Aimsun micro-simulator. A special attention was paid to the calibration of a flow merging model. A large-scale optimization problem was solved by using advanced combinatorial procedures. The main difficulties in the implementation as well as the limitations of the designed software were highlighted. Finally, the results of different traffic scenarios on the Grenoble South Ring were presented.

6.7.3. Vehicle control for disabled people

Participants: C. Canudas de Wit [Contact person], V. Ciarla, J. Dumon, F. Quaine [UJF], V. Cahouet [UJF].

The typical architecture of an Electric Power Assistance Steering (EPAS) system includes a static map to provide the correct amplification to the drivers exerted torque. In literature, it is generally known as booster curve. This work concerns the study of the amplification criteria, that are commonly used to these booster curves. The basic concepts of the Electric Power Steering (EPS) systems with a realistic model for the friction contact, that acts on the wheels are discussed. A relation between the assistance and the driver's torque is provided, under the hypothesis of a position-oriented control of the movement and the Stevens' power law [33]. In current works, we want to modify the general architecture of the EPAS system for people driving with two arms. For this purpose, we insert two additional blocks: the first one provides an estimation of the gravitational torque due to the weight of the driver's arm while the second gets as inputs the total driver's torque and the estimated gravitational torque in order to update the driver's torque with the gravitational torque. The updated measure is then given as input to the booster curve for deriving the correct assistance.

6.7.4. Control of communicating vehicles in urban environment

Participants: C. Canudas de Wit [Contact person], G. de Nunzio.

For a given vehicle there are different ways to travel on a given distance in a given time, corresponding to different levels of energy consumption; therefore, there is an energy-optimal trajectory. Advising the driver via a suitable interface can reduce the energy consumed during the travel, and thus improve the energy efficiency: this is the principle of eco driving. In urban areas, the optimal trajectory of the vehicle depends on interactions with other vehicles, but also on passive signs (panels, priorities, etc.) and active signs (traffic lights); in each case, constraints are imposed on the command (vehicle speed). From the infrastructure perspective, traffic control in urban areas consists in determining the state of traffic signals in order to solve an optimization problem, for example minimizing travel time of vehicles in the road network. If all the vehicles can communicate with one another and with the active infrastructure (traffic lights), we can imagine benefits for each of the two problems which can be considered as a whole: on the one hand, for vehicles, more information is available that can be integrated into the online optimization problem; on the other hand, there are new measures and new commands available to control traffic. Indeed, the estimation of the traffic is no longer necessary, as the position and speed of approaching vehicles is known. More importantly, the traffic manager can send instructions to the vehicle. The aim of the research is to evaluate the potential in terms of energy saving and traffic improvement made possible by communicating vehicle. This work is carried out in collaboration with IFP in the framework of a CIFRE thesis.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. KARRUS start-up

The NeCS team is continuing its activity in road traffic modeling and control. The expected scientific contribution of NeCS in this field concerns the development of new estimation prediction and identification algorithms based on the measurements collected through sensor networks installed on freeways. The team study also the problems of time-to destination and control algorithms for ramp metering. The team is currently setting up a consortium with local authorities involved in traffic management to build a demonstrator called

GTL for Grenoble Traffic Lab. One target of this activity is to transfer part of the developed technology to a start-up named Karrus and led by Denis Jacquet (http://www.karrus.fr/). The start-up was created in January 2010.

7.2. Bilateral Grants with Industry

7.2.1. AIRBUS

Accompanying PhD contract with AIRBUS in the framework of the CIFRE PhD grant of P. Andrianiaina. The goal of this PhD thesis is to study flexible implementation methods for real-time controllers, aimed at reducing the conservatism induced by the current approach purely based on worst case considerations.

7.2.2. IFPEN

Accompanying PhD contract with IFPEN (IFP Energies Nouvelles), in the framework of the PhD grant of A. Ben Khaled. The thesis explores new architectures and flexible scheduling methods to enhance the trade-off between the integration accuracy and the simulation speed of distributed real-time (hardware-in-the-loop) simulators, in particular in the framework of automotive power-trains.

Accompanying PhD contract with IFPEN (IFP Energies Nouvelles), in the framework of the PhD grant of Giovanni de Nunzio. The thesis explores eco-driving for comunicating vehicles in urban environment.

8. Partnerships and Cooperations

8.1. Regional Initiatives

The 12-months post-doctoral stay of Alireza Esna Ashari has been funded by Inria-Schneider Endowed Chair on Foundations of Component-based Design for Embedded Systems. A. Esna Ashari has been working on distributed estimation and fault detection using wireless sensor networks, under the supervision of F. Garin and A. Kibangou.

8.2. National Initiatives

8.2.1. ANR

8.2.1.1. ANR VOLHAND

VOLHAND (**VOL**ant pour personne âgée et/ou **HAND**icapée) is a project funded by the ANR (National Research agency). This project, started in October 2009, is a result of collaboration between C. Canudas de Wit and Franck Quaine/Violaine Cahouët (from the biomechanical team of GIPSA-Lab). The project aims at developing a new generation of Electrical power-assisted steering specifically designed for disabled and aged people. Our contribution is to work out new assisted laws that accomodate to the specific mechanical characteristics of this particular driver population. The consortium is composed by: LAMIH, CHRU, Fondation Hopale, GIPSA-Lab, INRETS and JTEKT. More information can be found on-line: http://www.univ-valenciennes.fr/volhand/.

8.2.2. PREDIT

8.2.2.1. MoCoPo

The MOCoPo project (Measuring and mOdelling traffic COngestion and POllution) is funded by the French Ministry in charge of Transport (MEDDTL), through the PREDIT (Research and Innovation in Land Transport Program). The project began in January 2011 and will end up in December 2013. Various research institutes and universities, some teams of the MEDDTL and pollution measurements associations are involved in the project: LICIT (Transport and Traffic Engineering Laboratory, joint unit of IFSTTAR and ENTPE), LTE (Transports and Environment Laboratory, IFSTTAR), LEPSIS (Laboratory for Road Operations, Perception, Simulators and Simulations, IFSTTAR), IM (Infrastructures and Mobility Department, IFSTTAR), MACS (Monitoring, Assessment, Computational Sciences, IFSTTAR), Inria-NECS, Atmo Rhône Alpes, DIR-CE (Center-East Direction of Roads), LRPC Angers (Regional Laboratory of Angers), CERTU (Center for Cities and Urban Transportation), and CEREA (Center of Teaching and Research in Atmospheric Environment, laboratory Ecole des Ponts ParisTech / EDF Research and Development). NeCS is particularly involved in tasks devoted to travel time estimation and prediction. For this purpose one post-doc (Fabio Morbidi) has been recently hired. More information can be found on-line:http://mocopo.ifsttar.fr/.

8.3. European Initiatives

8.3.1. FP7 Projects

8.3.1.1. FeedNetBack

Title: FeedNetBack

Type: COOPERATION (ICT)

Defi: Networked embedded and control systems

Instrument: Specific Targeted Research Project (STREP)

Duration: September 2008 - January 2012

Coordinator: Inria (France)

Others partners: ETH Zurich (CH), Universidad de Sevilla (ES), KTH Stockholm (SE), Universita di Padova (IT), Ifremer (FR), Videotec (IT), OMG (GB), Vitamib (FR).

See also: http://feednetback.eu

Abstract: 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 enabled the development of more efficient, robust and affordable networked control systems that scale and adapt with changing application demands. The project extend the current scientific state-of-the-art in networked control and develop a set of software tools to support the co-design framework.

8.3.1.2. Hycon2

Title: Highly Complex and Networked Control Systems

Type: COOPERATION (ICT)

Defi: Engineering of Networked Monitoring and Control Systems

Instrument: Network of Excellence (NoE)

Duration: September 2010 - August 2014

Coordinator: CNRS (France)

Others partners: Inria (France), ETH Zurich (Switzerland), TU Berlin (Germany), TU Delft (Netherlands) and many others

See also: http://www.hycon2.eu

Abstract: Hycon 2 aims at stimulating and establishing a long-term integration in the strategic field of control of complex, large-scale, and networked dynamical systems. It focuses in particular on the domains of ground and aerospace transportation, electrical power networks, process industries, and biological and medical systems.

8.4. International Initiatives

8.4.1. Inria International Partners

- H. Fourati has started a new collaboration with the Kazakhstan National Technical University (KazNTU). He curretly co-advises with Pr. Olga Shiryayeva in KazNTU, Zarina Samigulina PhD student in KazNTU. He also submitted an European project "LA STRADA" with two teams and an SME: Istituto per le Applicazioni del Calcolo "M. Picone" (Università di Roma), the Mathematical Modeling and Scientific Computing Research Group (University of Mannheim) and Karrus (SME).
- F. Garin has collaborations with University of Padova, Italy (S. Zampieri), University of Newcastle, Australia (D. Quevedo), with Lund University, Sweden (G. Como and E. Lovisari), and with KTH Stockholm, Sweden (D. Varagnolo)

8.4.2. Participation In International Programs

8.4.2.1. TeMP

TeMP (Tensor-based Information modelling and Processing) is a project funded in the framework of the French-Brazilian bilateral collaboration program (FUNCAP-Inria). It started from August 2011 for a duration of two years and is coordinated for the French part by A. Kibangou. This project aims to study, analyze, propose and evaluate new models and techniques for digital communication systems using tensors and multilinear algebra tools, through in-depth theoretical analysis of mathematical models, optimization algorithms, and computational simulations. Indeed, new models should be developed for generalizing existing tensor models in order to allow the modeling of a wider class of communication systems for more realistic propagation channels including the cooperation among multiple nodes of a communication network (users or sensors). Due to dynamic change of parameters, tensor-based filtering algorithms need to be developed for information retrieval systems in cooperative communication. These algorithms should be distributed for avoiding network vulnerability and for a better management of computation and storage resources.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Maria Guinaldo Losada, PhD Student, UNED, Madrid, Spain, 2 months visit (Oct. and Nov. 2012).
- André L.F. de Almeida, Associate Professor, UFC, Brazil, visit within the framework of the TeMP project (January 2012).
- Joao Cesar M. Mota, Professor, UFC, Brazil, visit within the framework of the TeMP project (January 2012).
- Zarina Samigulina, PhD student, Kazakhstan National Technical University (KazNTU), two weeks visit (November 2012).

8.5.2. Visits to International Teams

- H. Fourati spent two weeks in Kazakhstan National Technical University (KazNTU), Dec. 2012.
- F. Garin spent three weeks in Lund University during the LCCC focus period on Information and Control in Networks, Oct. 2012.
- A. Kibangou spent three weeks in UFC, Brazil, in two stays (May and Oct. 2012).

- C. Canudas de Wit visited universities of Berkeley (USA), Lund (Sweden), Madrid, Sevilla, and Valencia (Spain).

9. Dissemination

9.1. Scientific Animation

- Carlos Canudas de Wit has been an European project evaluator (STREPs and IPs) on the following programs: Cognitive systems and Robotics (FP7-ICT 2002) and Chat (http://www.ict-chat.eu/). He was elected as member of the Board of Governors of the IEEE Control System Society. He is vice-president of the European Control Association (EUCA) and member of the steering committee in charge of redefying the new EUCA constitution. Since 2010, He is Editor of the Asian Journal of Control.
- H. Fourati has been a peer-reviewer for international journals (IEEE Sensors Journal, IEEE/ASME Transactions on Mechatronics).
- D. Simon was member of the ETFA'12 (IEEE Int. Conference on Emerging Technologies and Factory Automation), CIFA'12 (Conference Internationale Francophone d'Automatique) and CAR'12 (Control Architecture of Robots) program committees, and of the IFAC Joint Conference (Grenoble, february 2013) organization committee. Involvement within the API (Automatique Pour l'Informatique) PEPS headed by E. Rutten (SARDES). Peer reviewer for the ICSCS'12, MED'12 and ECC'13 international conferences. Scientific direction of the farewell robotics seminar given in honour of Bernard Espiau.
- F. Garin has been a peer-reviewer for international journals (IEEE Trans. Automatic Control, IEEE Trans. Inform. Theory, Automatica) and conferences (CDC 2012, NecSys2012, ECC 2013) and for a chapter in a book in Springer LNCS.
- A. Kibangou has been a peer-reviewer for international journals (Automatica, IEEE Trans. on Control Systems and Technology, Elsevier Signal Processing, IEEE Trans. on Signal Processing, Electronics Letters, Int. J. of Adaptive control and Signal Processing, and System control letters) and conferences (CDC 2012, CIFA 2012, ACC 2013, ECC 2013). Locally, he is the organizer of seminars for the Control Department of GIPSA-LAB.
- A. Ben Khaled gave a talk at the "Logicels de Modélisation et de Calcul Scientifique" day (LMCS 2012) organized at Paris la Défense by EDF, IFPEN, Acsystème and Esilv in December.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence: H. Fourati, Informatique Industrielle, 100h, L1, IUT 1 (GEII2), University Joseph Fourier, France;

Licence: H. Fourati, Automatique, 24h, L2, IUT 1 (GEII2), University Joseph Fourier, France;

Licence: H. Fourati, Automatismes industriels et réseaux, 90h, L1 et L2 et 2, IUT 1 (GEII2), University Joseph Fourier, France.

Doctorat, Master: H. Fourati, Network Theory, 20h, Kazakhstan National Technical University (KazNTU), Kazakhstan.

Licence: A. Kibangou, Automatique,62h, L2, IUT1 (GEII1), University Joseph Fourier, France.

Licence: A. Kibangou, Mathématiques, 14h, L2, IUT1 (GEII1) , University Joseph Fourier, France.

Licence: F. Garin, Automatique, 32h, L2, IUT1 (GEII1), University Joseph Fourier, France.

Doctorat, Master: C. Canudas de Wit, Advanced control for transportation and vehicular systems, University of Sevilla, Spain.

Doctorat, Master: C. Canudas de Wit, Vehicular transportation, 20h, University of Valencia, Spain.

Doctorat, Master: C. Canudas de Wit, Modeling and forecasting of Traffic Systems : HYCON2 case study, 6h, University of Madrid, Spain.

9.2.2. Supervision

PhD: Patrick Jocelyn Andrianiaina, Robust control under weakend realtime constraints, Grenoble University, October 26 2012, co-advised by D. Simon and A. Seuret.

PhD: Nicolas Cardoso De Castro, Energy-aware control and communication co-design in wireless Networked Control Systems, Grenoble University, October 4th 2012, co-advised by C. Canudas de Wit and F. Garin.

PhD: Gabriel Rodrigues de Campos, Agreement strategies for multi-robot systems, Grenoble University, November 23th 2012, co-advised by A. Seuret and C. Canudas de Wit.

PhD in progress : Valentina Ciarla, Commande d'un système de puissance électrique pour personne âgée et/ou handicapée, Grenoble University, Sept 2010-Sept 2013, co-advised by C. Canudas de Wit, F. Quaine, and V. Cahouet.

PhD in progress : Abir Ben Khaled, Distributed real time simulation of numerical models: application to powertrain, Grenoble INP, Jan. 2011 - Dec. 2013, co-advised by D. Simon and M. Ben Gaid (Institut Français de Pétrole Energies Nouvelles).

PhD in progress : Luis Leon Ojeda, Modélisation macroscopique, estimation de la demande et prédiction du flux pour les systèmes de transport intelligents, Grenoble University, April 2011-March 2014, Co-advised by C. Canudas de Wit and A. Kibangou.

PhD in progress : Dominik Pisarski, Contrôle d'accès collaboratif : application à la Rocade Sud de Grenoble, Grenoble University, June 2011-May 2014, Advised by C. Canudas de Wit.

PhD in progress: Ruggero Fabbiano, Distributed source seeking control, Grenoble University, Dec. 2011 - Nov. 2014, by C. Canudas de Wit and F. Garin.

PhD in progress : Thi-Minh Dung Tran, Consensus en temps fini et ses applications en estimation distribuée pour les systèmes de transport intelligents, Grenoble University, co-advised by A. Kibangou and C. Canudas de Wit, Jan. 2012-Jan. 2015.

PhD in progress : Giovanni de Nunzio, Control of communicating vehicles in urban environnement, Grenoble University, co-advised by C. Canudas de Wit and P. Moulin (IFPEN), Sep. 2012-Aug. 2015

PhD in progress : Aida Makni, Estimation multi-capteurs et commande temps-réel tolérante aux fautes d'un drone aérien, Grenoble INP, Oct. 2012 - Sep. 2015, co-advised by H. Fourati, A. Kibangou and C. Canudas de Wit.

9.2.3. Juries

- D. Simon (reviewer and member) : J.-B. Chaudron, Jan. 25 2012, Onera and ISAE, Toulouse University;
- D. Simon (member) : Ch. Fiter, Sep. 25 2012, Lagis, Lille University ;
- D. Simon and A. Seuret (members) : P.J. Andrianiaina, Oct. 26 2012, Grenoble University;
- A. Seuret (member) : G. Rodrigues de Campos, Nov. 2012, Grenoble University.
- C. Canudas de Wit (member): S. Martin, Nov. 2012, Grenoble University.
- C. Canudas de Wit (member and reviewer): D. Efimov, HDR, Nov. 2012.

9.3. Popularization

- D. Simon has been involved in the ISN programme for the training of highschool teachers in Computer Science.

- C. Canudas de Wit animated the In'Tech seminar (Grenoble, Nov. 2012).
- C. Canudas de With animated seminars in CPS London Oct 2012 (http://controls.ame.nd.edu/mediawiki/index.php/London_CPS_Workshop#Participants) and Lund workshop (http://www.lccc.lth.se/index.php?page=workshop1210program).

10. Bibliography

Major publications by the team in recent years

[1] C. AUBRUN, D. SIMON, Y.-Q. SONG. *Co-design Approaches for Dependable Networked Control Systems*, ISTE Wiley, 2010, 314, http://hal.inria.fr/inria-00443847/en/.

[2] C. CANUDAS DE WIT, F. GOMEZ-ESTERN, F. RUBIO. *Delta-Modulation Coding Redesign for Feedback-Controlled Systems*, in "IEEE Transactions on Industrial Electronics", 2009, vol. 56, n^o^ 7, p. 1-20, http://hal.archives-ouvertes.fr/hal-00394981/en/.

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[8] D. ROBERT, O. SENAME, D. SIMON. *An H_∞ LPV design for sampling varying controllers : experimentation with a T inverted pendulum*, in "IEEE Transactions on Control Systems Technology", 2010, vol. 18, n^o^ 3, p. 741-749, http://hal.archives-ouvertes.fr/hal-00448496/en/.

[9] A. SEURET, C. PRIEUR. *Event-based sampling algorithms based on a Lyapunov function*, in "50th IEEE Conference on Decision and Control and European Control Conference (IEEE CDC-ECC 2011)", Orlando, Floride, United States, December 2011, 6, http://hal.inria.fr/hal-00610542/en.

[10] A. SEURET. *A novel stability analysis of linear systems under asynchronous samplings*, in "Automatica", October 2011, http://hal.inria.fr/hal-00610561/en.

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] P. J. ANDRIANIAINA. *Robust control under slackened real-time constraints*, Université de Grenoble, spécialité Automatique Productique, October 2012.

[12] N. CARDOSO DE CASTRO. *Energy-aware control and communication co-design in wireless Networked Control Systems*, Université de Grenoble, spécialité Automatique Productique, October 2012.

[13] R. CECCARELLI. *Diagnostic à base de modèle de la boucle d'air des moteurs Diesel*, Institut National Polytechnique de Grenoble - INPG, September 2012, http://hal.inria.fr/tel-00757525.

[14] L. MALRAIT. *Modeling and control of server systems*, Université de Grenoble, spécialité Automatique Productique, July 2012.

[15] G. RODRIGUES DE CAMPOS. *Agreement strategies for multi-robot systems*, Université de Grenoble, spécialité Automatique Productique, November 2012.

Articles in International Peer-Reviewed Journals

[16] C. BRIAT, A. SEURET. *A looped-functional approach for robust stability analysis of linear impulsive systems*, in "Systems and Control Letters", September 2012, vol. 61, n° 10, p. 980-988 [*DOI :* 10.1016/J.SYSCONLE.2012.07.008], http://hal.inria.fr/hal-00724545.

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[24] A. SEURET. *A novel stability analysis of linear systems under asynchronous samplings*, in "Automatica", January 2012, vol. 48, n^o 1, p. 177-182, http://hal.inria.fr/hal-00610561.

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[26] A. BEN KHALED, M. E. M. BEN GAÏD, D. SIMON, G. FONT. *Multicore simulation of powertrains using weakly synchronized model partitioning*, in "E-COSM'12 IFAC Workshop on Engine and Powertrain Control Simulation and Modeling", Rueil-Malmaison, France, October 2012, http://hal.inria.fr/hal-00746968.

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[50] A. SEURET, K-H. JOHANSSON. *Networked control under time-synchronization errors*, in "Time Delay Systems: Methods, Applications and New Trends", R. SIPAHI, T. VYHLÍDAL, S.-I. NICULESCU, P. PEPE (editors), Lecture Notes in Control and Information Sciences, vol. 423, Springer, 2012, p. 369-383, Softcover, ISBN 978-3-642-25220-4, http://hal.inria.fr/hal-00677291.

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Other Publications

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