FeedNetback
co-design for networked control systems

Project Final Report

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4.1 Final publishable summary report

4.1.1 Executive summary

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The revolutionary developments in microelectronics over the past decades have led to the production of cheap yet powerful devices that can communicate with one another, can sense and act on their environment and can be deployed in large numbers to deliver an abundance of data. Such devices and the networks they form (broadly grouped under the term wireless sensor networks) bring together communication, computation, sensing and control and have enabled monitoring and automation at an unprecedented scale. Especially challenging in this context are networked control systems, where feedback control loops are closed over networked, distributed communication platforms. To take full advantage of this technology novel design methods are necessary that transcend the traditional borders between disciplines, to apply the principles of feedback to complex, interconnected systems.

By focusing on wirelessly connected networks and leveraging on recent advances in sensor networks, the FeedNetback project studied networked control from a fundamental point of view, and extended the current scientific state-of-the-art toward the integration of additional components including communication, computation, energy and complexity. To demonstrate the potential of the new technology, the project has applied it to 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 components are essential in both as they require cooperation of distributed objects to achieve a common goal.

> The objective of the **FeedNetback** project was to generate a co-design framework, to integrate architectural constraints and performance trade-offs from control, communication, computation, complexity and energy management.
>
> FeedNetback contributed in mastering 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

Early in the project's schedule, as an element of our open approach, a set of roadmaps was developed to explore usage and applications areas for networked control systems in order to inform our designs and ensure “fitness for purpose”. The project conducted an ambitious plan dissemination activities including representation of the project in over 100 events, organisation of three annual workshops plus a workshop dedicated to junior researchers, course offerings to international schools and videos to illustrate the research undertaken. The results of the project were reported in over 250 conference and journal publications.

Impact. Scientific excellence and technical skills built during the project are being successfully incorporated in undergraduate and graduate courses. This will enhance the course quality offered by the academic participants but importantly benefit the student communities at those universities, and eventually industries employing those students. The FeedNetback’s co-design framework will enable application developers and programmers to fully use the potential of networked control in a wide set of industrial domains. The two test cases show that FeedNetback went beyond developing new technologies, but also applied them to areas of society where they protect the environment and improve people's safety, security and ultimately quality of life. Other areas where impact is expected in the future are the fields of factory automation, public infrastructure safety and security, transport and building maintenance.

4.1 Final publishable summary report

4.1.2 Project context and objectives

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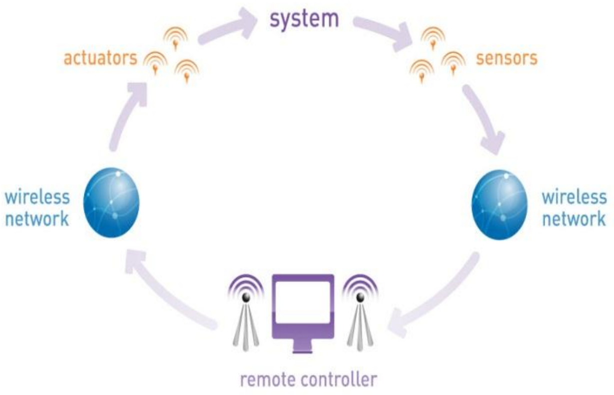


Telecommunication and wireless networks have been areas of spectacular growth for several decades. Fuelled by revolutionary developments in micro- and optoelectronics, networks have become a defining element of modern society and economy. More recent developments in miniaturization, such as MEMS- and nano-technologies, have enabled the development of Wireless Sensor Networks (WSN) which promises yet another revolution. It is widely believed that this type of pervasive networking technology will be transparent to the user, but at the same time will allow monitoring and automation to a scale previously unimaginable.

Figure 1: FEEDNETBACK, closing the loop over wireless networks.

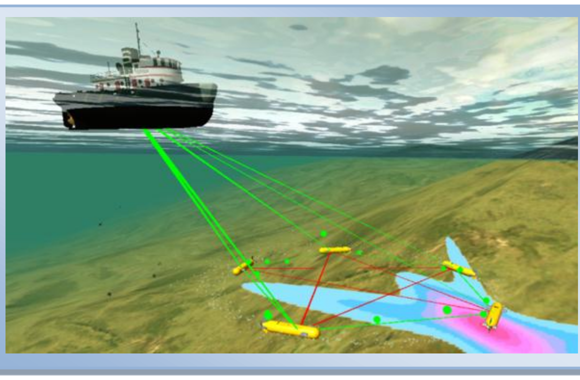
In addition to monitoring, surveillance and other information collection applications, networking technologies and especially WSN provide new opportunities for automation, i.e. closing control loops over wireless networks. Potential application areas of such Networked Control Systems (NCS) abound: In industrial automation, building management, intelligent transportation, and other areas there are many advantages to deploy wireless technologies. These advantages, however, can only be realized provided one can ensure that the resulting closed-loop control system offers appropriate safety and performance guarantees, and that the complexity of the design can be appropriately handled. This, in turn, requires the development of a novel design paradigm based on the cross-fertilization of communication and control to enable the joint consideration of sensing, computation, communication, energy and control requirements.

This potential for a new broad class of wireless control systems applications has sparked a considerable research effort in NCS. As a result, several techniques have been proposed to deal with specific problems that arise in NCS; examples include techniques for making controllers robust to time-varying network delays, or to packet loss. However, it is fair to say that there is still no coherent methodological framework to address NCS design problems. Moreover, most of the techniques developed so far treat the network properties as given constraints, to which the control design procedure must be adapted. For many emerging applications, this type of approach is bound to lead to very conservative designs, which do not fully exploit the potential of the networked system. A more productive approach would be (as addressed in the FeedNetback project) to develop a co-design procedure, where networking considerations enter the control design process but also control considerations affect the network design.

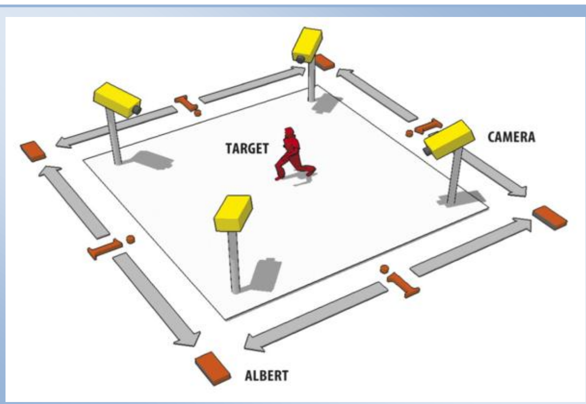
*In **FeedNetback** we have developed such a fundamental design framework for NCS. As illustrated in Figure 1, we close the control loop over wireless connections based on data collected by wireless mobile or stationary sensor nodes. At the heart of our methodology we had proposed a co-design procedure, which will allow the integration of communication, control, computation and energy considerations and a joint design of the networking and control systems.*

The two case studies have been selected to demonstrate the wide spectrum of possible applications of our methodology: from systems with relatively few, highly mobile nodes, communicating over a low bandwidth, unreliable network (underwater inspection systems); to systems with a very high number of immobile nodes, with high available bandwidth but also high communication requirements (smart camera network). In both test cases, the control component is essential as they demonstrate how distributed objects can cooperate to achieve a common goal.

- **Underwater inspection systems based on fleets of Autonomous Underwater Vehicles (AUVs).** This refers here to the use of heterogeneous marine vehicles (surface and underwater vehicles such as autonomous crafts, AUVs or underwater gliders) to achieve a scientific mission composed of several phases (exploration and survey, scientific sensor data sampling). Fleets of autonomous vehicles are envisioned to optimize the operational mission time (several vehicles will perform faster the same mission than one) as well as to achieve mission goals that could not be accomplished with a single vehicle. A coordinated underwater inspection mission will require sharing of data (scientific payload data, or vehicle data) collected by the different vehicles resulting in a "sensing network" when the fleet seen as a global system.



- **Smart cameras for surveillance and motion capture.** Security is a major issue facing all of Europe and video surveillance systems are being installed everywhere. A large scale surveillance system integrated with access control, possibly equipped with heterogeneous sensors is, de facto, a complex system and the distributed intelligence poses the problems of designing global behaviour from local laws, coordination and self-organization of these multi-agent systems. Our industrial partners have expertise in the image capture and processing aspects which will allow the project to concentrate directly on the control and networking issues, without having to concentrate on machine vision and image processing issues



*The key contribution of the **FeedNetback** project has been to address this challenge by proposing an integrated co-design procedure for NCS, where the control and networking considerations are taken into account in a unified manner.*

Strategic objectives. The scientific and technological objectives of the FeedNetback project have been organized by 4 high level strategic objectives, and by a set of a series of detailed technological objectives. The general objectives are show in Fig.2

Figure 2 Project general objectives

The project objectives have challenged additional difficulties requiring a solid interdisciplinary effort. This includes

- **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 node topology.
- **Resource management**: The energy and computation capabilities of each sensor/transmitter element are generally limited.
- **Scalability:** WSN 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.

Detailed technological objectives

> ***FeedNetback** has proposed innovative methodologies to design control for systems in which signals are exchanged through a communication network with limited capacity*

Traditional control theory often disregards issues of connectivity, data transmission, coding and many other items of central importance to WSN. Also, the broadcasting nature of the wireless medium allows for sophisticated cooperative sensing, coding and transmission schemes, providing additional redundancy that a sophisticated control system can exploit for safety, predictability and robustness.

Challenge 1

Communication and control co-design: **Fundamental guidelines for closing the loop over wireless links.**

- How can control algorithms be designed together with the signal coding?
- What are the mutual interdependencies?
- How can one overcome the limitations of the wireless medium by appropriate controller design?
- How can one exploit its strengths?

Challenge 2

Computation and control co-design: **Fundamental guidelines for closing the loop under computational limitations.**

- How can control algorithms be designed so that they can be deployed with limited computational capabilities?
- Can the control design be made robust with respect to computational load variations and asynchronous samples?
- What are the mutual interdependencies between controller design and computational implementation?

Challenge 3

Energy and control co-design: **Fundamental guidelines for closing the loop using energy limited devices.**

- A focused effort in achieving energy-efficiency in applications with battery-driven nodes.
- What is an optimal way to accomplish the control tasks so as to minimize the energy use of each sensors/node?
- How can the life time of the entire closed loop system be extended by appropriately distributing tasks among the nodes?

Challenge 4

***Complexity and control co-design*:** **Fundamental guidelines for dealing with system complexity.**

- How does the complexity of NCS design methods and the resulting controllers scale with the size of the underlying network?
- When is a decentralized design advantageous over a centralized one?
- How can the control design accommodate large scale complex systems?

4.1 Final publishable summary report

4.1.3 A description of the main S&T results/foregrounds:

A)-Selected results on the FeedNetback application domains

Surveillance Camera Networks

Today *Tomorrow*

Security and surveillance are an ever crucial concern in our society. Surveillance systems can be found everywhere: in transport systems from buses to the underground, from lonely streets to highways, from small stores to stadiums. Video surveillance is a powerful solution to **crime prevention** and the number of surveillance cameras is constantly growing everywhere. Unfortunately, as a drawback, security guards working in front of several monitors are overwhelmed by too many video feeds. It is known that the attention of a security guard watching videos decreases drastically after few dozens of minutes when nothing happens. One of the conclusions of a study by the US National Institute of Justice into the effectiveness of human monitoring of surveillance video is that "[...manually detecting events in surveillance video, even when assigned to a person who is dedicated and well-intentioned, will not support an effective security system.]". The lack of a proper analysis and understanding process applicable to video streams provided by **huge security camera networks** could seriously jeopardize the effectiveness in terms of crime prevention of ever growing video surveillance installations. To deal with such very critical issue, modern surveillance systems use smart cameras performing automatic **video content analysis** (VCA) in order to select and display to security guards only relevant videos which are likely to show suspicious or criminal activities. Unfortunately, although smart cameras are pretty useful for some applications, their capabilities are still quite limited. As a consequence, **todays' commercial surveillance** systems present the following limitations:

- **Poorly utilized:** the VCA capability of understanding a monitored scene is not comparable to human cognition especially in complex scenarios. Today's VCA usage in terms of security is mainly limited to motion detection and tracking in not crowded scenes. Object classification is also possible but it is usually based on simple features such as target size and velocity. A further limitation is that smart cameras are not designed to "play" and "talk" together and cooperate as a team. Although the term "distributed architecture" is widely used, it just means that video analysis is moved from central servers to "edge devices" (smart cameras). In practice a modern surveillance system is still based on a classic **centralized architecture.**
- **Supervised approach and high use of human resources:** videos are visually inspected mostly by humans. Even when automatic video content analysis is applied, all final decisions about suspicious events and consequent actions are always taken by humans. The number of security guards involved in surveillance systems must increase almost linearly with the number of cameras. As a final consequence the overall cost can become really too high discouraging investments on security infrastructures. Moreover performance issues related to loss of human attention remain.
- **Expensive installation and maintenance**: surveillance of large areas requires large set of fixed cameras resulting in very expensive systems. Moreover, the configuration process comprises many time consuming operations: camera calibration, configuration in terms of data storing and streaming, detection/repairing/replacement of malfunctioning cameras, optimal positioning of cameras. The lack of a proper level of intelligence implies that all such operations are carried out manually resulting in high installation and maintenance costs.

To overcome these limitations **next generation surveillance systems need to achieve a paradigmatic shift** in the design approach:

- **Advanced smart cameras:** by replacing several fixed cameras with few pan-tilt-zoom (PTZ) cameras, the coverage of the surveillance system is dynamically preserved and the cost reduced. However, in order this change to be effective, cameras need to be smart. Furthermore, more intelligence and capabilities are needed in order to proactively communicate, cooperate and take decisions. These needs require at the same time the definition of new interfaces, communication and interoperability standards.

- **Cooperative and decentralized architecture:** large scale systems with hundreds of cameras are feasible only if part of the current human duties is **automatically** accomplished by the camera network itself. Although the humans can never be totally removed in this kind of applications, some tasks like suspicious event detection or automatic visual tracking by multiple cameras can be performed automatically. However, in order to reduce the number of false alarms and mis-detected events, cooperation among multiple cameras is ought.
- **Real-time multi-tasking assignment in distributed architectures:** in distributed smart camera networks, cameras not only can accomplish tasks like tracking an object, patrol an area, storing a recording, streaming a video, but can themselves issue such tasks and compete with other cameras for the same tasks. This requires the development of multi-agent architectures where task assignment is performed automatically as much as possible, while still preserving the possibility for the humans to intervene. Moreover, no global task queue should be present to increase robustness to cyber-attacks and scalability.
- **Automatic calibration and configuration:** cameras can be hardly placed in optimal location or might simply be poorly installed, yet with hundreds of cameras in place, they need to automatically self-calibrate themselves, discover their neighbors both in terms of communication network and physical topology. These can be achieved only though cooperation and once again should be at much as possible an automatic procedure.
- **Automatic fault or cyber-attack detection and compensation:** besides improving the scalability, a multi-agent distributed architecture has the advantage to be more difficult to attack since information is not concentrated in a single hub. Also possible malfunctioning or attacked cameras can be compensated by neighboring cameras. This however requires some **redundancy** in the system and **plug/unplug-and-play** mechanisms that allow the surveillance systems to reconfigure automatically.
- **Virtual reality:** humans should be presented only with relevant information and videos. Ideally, they should be able to virtually explore the camera networks and interact with it to ask for additional information. This requires new human-machine interfaces as well as standards for information representation formats that fuse both visual and non-visual content.

Key points of the advance

Within the FeedNetback project we tackled some of the previous objectives and in particular we focused on:

1. **Cooperative multi-camera self-calibration and configuration:** The objective was to develop centralized and distributed algorithms such that smart-cameras (both static and PTZ) can self-calibrate themselves, i.e. they can recover their orientation and position with respect to the same 3D world frame. The calibration is obtained only though local relative position orientation of pairs of neighboring cameras which can share part of the same field of view. Most of today's multi-camera calibration systems are for single pairs (stereo calibration) and are obtained using structured objects like chess boards. New algorithms had to be developed for calibration in potentially unstructured environments and with hundreds of interconnected cameras. Similarly, self-configuration in terms of discovery of the neighboring cameras and the topological vicinity, need to be performed automatically. The construction of the communication graph and the topology graph obtained with this procedure can be continuously updated based on a plug/unpug-and-play spirit.
2. **Real-time tracking with PTZ cameras:** a first tracking algorithm has been developed in [1] where camera inputs, i.e. zoom, pan and tilt angles, have been computed in order to guarantee a minimum probability of targets detection at the next time instant while at the same time minimizing variation w.r.t. previous cameras inputs and maximizing target resolution, i.e. "zoom in" value. This algorithm provides good performance and has been implemented in a test-bed at ETH [Video1] and in the final demo. Even if the developed algorithm resulted in good tracking performance we worked on the development of a more general framework able to deal with other objectives besides tracking. We consider the problem of maximizing the probability of satisfying safety (tracking), reachability (target acquisition), and reach-avoid (one target tracking while acquiring another) objectives. The solution of the safety, reachability, and reach-avoid tasks are computed via dynamic programming resulting in an optimal control policy for the PTZ camera [2].
3. **Cooperative multiple-target PTZ tracking in 3D scenarios:** we addressed the problem of tracking multiple targets in a 3D scenario. We developed a tracking system presenting the following features which are not present in any current commercial surveillance system:
   - **Automatic hand-off** of a tracked target from one PTZ camera to other PTZ cameras. Today very few companies propose basic target hand-off strategies but such strategies are limited to only two PTZ units and moreover target hand-off must take place in a predefined and still PTZ state.
   - **Multi-target tracking guaranteed:** each target is tracked by at least one camera and the systems is guaranteed to track all targets if their number is smaller than the number of cameras, i.e. it is not possible

that there are two cameras tracking the same target, while a target is left untracked. Today PTZ tracking is confined mainly to the case of one pan tilt zoom unit tracking autonomously a single target.

- The system is also **robust to targets cross-over,** i.e. cameras can coordinate when two targets get close to each other and then they separate apart so that targets are always locked-in.

4. **Real-time PTZ multi-camera optimal perimeter patrolling:** we addressed the problem of patrolling a perimeter maximizing the probability of detecting an intruder. Cameras might have different speeds and visible portions of the perimeter, but extra redundancy is included so that each point in the perimeter can be seen by at least two cameras. Each camera is an autonomous agent capable of communication and independent decision making. The goal was to provide an algorithm capable of achieving optimal partitioning of the perimeter for patrolling, i.e. the time of last visit of each point by a camera is minimized. Although this is a global objective function which involves all cameras, we were able to propose an algorithm that has the following features:
   - It is **distributed**, i.e. each camera runs the same code whose complexity in terms of memory requirement, bandwidth and computational complexity, does not depend on the number of cameras
   - It is **optimal**, i.e. it is guaranteed to achieve asymptotically the global optimum
   - It is **asynchronous**, i.e. cameras do not need to communicate and update their patrolling region at strict time instants but only sufficiently often
   - It is **parallelizable**, i.e more cameras can communicate and update their patrolling region except for some rarely data collision
   - It is **half-duplex**, i.e. does not require bidirectional communication and coordinated updates of patrolling regions
   - It is **adaptive**, i.e. if a camera fails or is engaged in target tracking, the remaining patrolling cameras optimally take care of the unpatrolled region of the tracking camera(s)
   - When cameras are in tracking mode, they update the neighbouring cameras on the expected time of intercept via a **Kalman Filter**
5. **Certification of patrolling in a 2D environment:** we proposed a method to evaluate the performance of autonomous patrolling systems. The problem of maximizing the probability that the evader successfully completes an intrusion objective while avoiding capture by the cameras is considered and posed as a stochastic reach-avoid problem. Several patrolling strategies have been analyzed and compared. Among them, patrolling strategies based on probabilistic pursuit-evasion games seem to be very promising.

These algorithms has been proved to be theoretically correct and verified on extensive simulations including dozens of cameras. An experimental test with a smaller number of cameras using Videotec PTZ cameras has been implemented showing remarkable stability, robustness and performance. **It is very impressive to watch the reaction of the system** built in our lab when a PTZ unit gets disconnected from the network: each remaining PTZ unit changes its path to take care of the areas left uncovered by the disconnected unit. The continuous motion of the PTZ units is more suitable for large areas patrolling and the visual feeling for the end user is much better

The cooperative PTZ patrolling developed by the FeedNetback team is revolutionary: today PTZ units performing patrolling simply act as independent players scanning a predefined discrete set of PTZ states. The cooperative PTZ tracking developed by the FeedNetback team is definitely a big step forward. Such a level of automation overcomes the performances of today's automation and of security guards as well. A security guard cannot deal with such critical situations controlling many PTZ units at the same time. Several security guards could not reach such level of coordination.

Scientific results

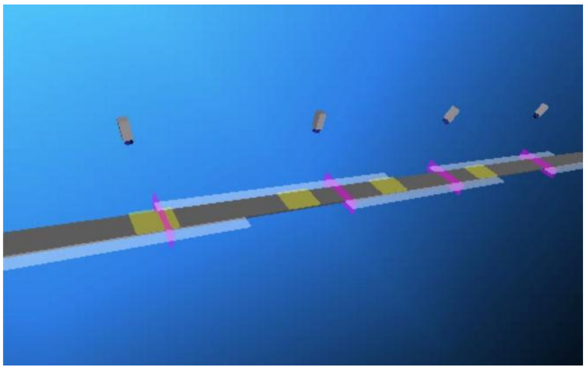
Beyond the definition of new algorithms, the research activity on distributed reconstruction has yielded interesting results in the following contexts:

- **distributed optimization with asynchronous communication and constraints**: The problem of optimal perimeter patrolling has been abstracted into a distributed optimization problem subject to constraints and with asynchronous communication and updates. This is a rather unexplored and challenging area of research and we provided real-time distributed algorithms with guaranteed converge to the global optimum. [6]

- **stochastic reachability**: The problem of detecting a smart evader in a 2D/3D environment has been cast a problem of stochastic reachability. In the stochastic reachability framework we analyze the probability of stochastic systems to satisfy stochastic objectives. We can pose the problem of maximizing or minimizing the probability of an uncertain process to satisfy objectives by using the knowledge of the mechanism governing the evolution of the uncertainty in time

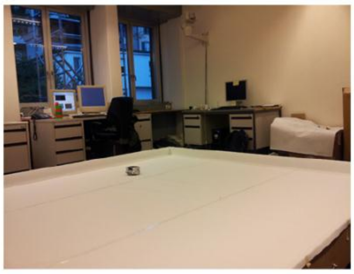
Software development

In this context, two main algorithms have been designed and tested:



Multi PTZ-camera perimeter patrolling and partitioning:

The algorithm is developed for any number of cameras patrolling and tracking a predefined perimeter. Cameras need to communicate and coordinate only with the preceding and the following cameras along this perimeter. Each camera has limited mobility in terms of PTZ maximum angles and speeds. The cameras are pre-calibrated. Once in place, they can optimally cooperate to partition the perimeter in segments each of which requires the same minimal time to patrol. The patrolling is guaranteed to detect any intruder and cameras are able to reconfigure the partitioning of the perimeter when one or more cameras go in tracking mode or simply they are subject to faults.



Tracking with pan-tilt-zoom cameras

Surveillance tasks of target tracking and acquisition in the form of a probabilistic pursuit evasion game have been considered. Here the objective is to maximize the probability of target tracking and acquisition. The optimal decision policy for the cameras is computed by dynamic programming. The maximum probability of successfully completing the considered surveillance objectives can be useful when making high level decisions (e.g. track a single evader or two evaders), especially when considering a scenario involving multiple cameras where this information may be valuable to exchange between cooperating cameras.

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Source seeking control using a fleet of AUVs under communication constraints

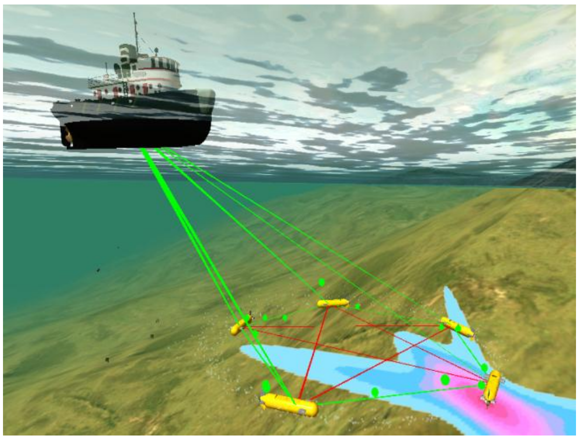


Fig. 1: Heterogeneous marine vehicles (surface and AUVs) collaborate for achieving a scientific mission such as source seeking.

Summary.

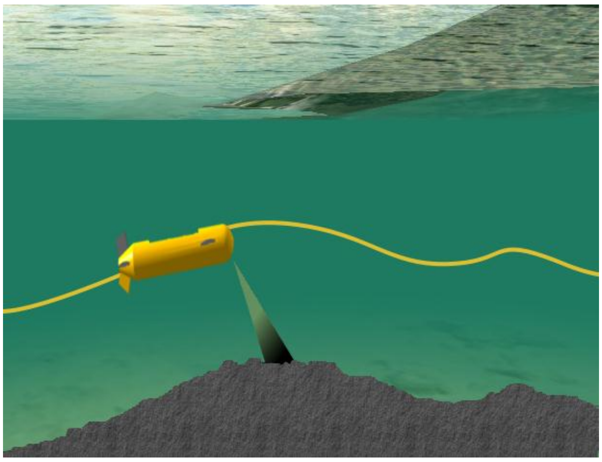
A collaborative source seeking mission necessitates several levels of control. First a local controller is derived so that macroscopically the AUV can be approximated with a kinematic unicycle model. Second, the fleet of vehicles is to be controlled in a distributed way. Such coordination is made through a communication channel with limited capacity. Third a collaborative source seeking approach using coordinated fleets is derived.

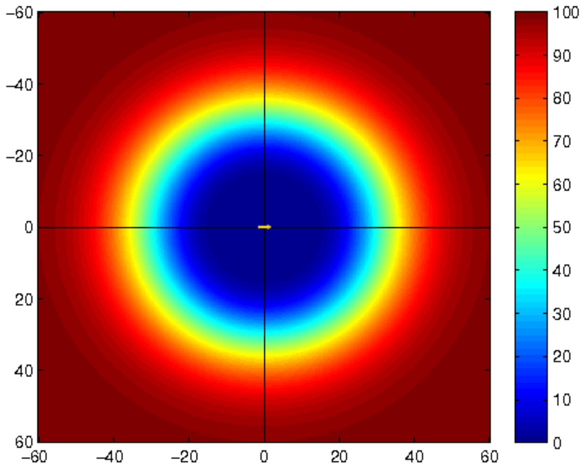
Objective: Spring water or pollutant source detection by gradient search and tracking using a fleet of Autonomous underwater vehicles (AUVs).

Motivation: A fleet of AUVs can optimize the operational mission time (several vehicles will perform faster the same mission than a single one) as well as to achieve mission goals that could not be accomplished with a single vehicle. A coordinated underwater inspection mission will require sharing of data (scientific payload data, or vehicle data) collected by the different vehicles resulting in a "sensing network" when the fleet is seen as a global system. This case study encompasses several challenges such as the need to coordinate the actions of the vehicles over channels with limited capacity and decentralized control strategies.

Main achievements

- Control & Complexity: Distributed algorithms for formation control and source seeking.
- Control & Communication: New methods for acoustic transceivers with robust Doppler estimation and compensation using OFDM signals.
- Control & Computation: LFT/Hinfinity varying sampling control for Autonomous Underwater Vehicles.



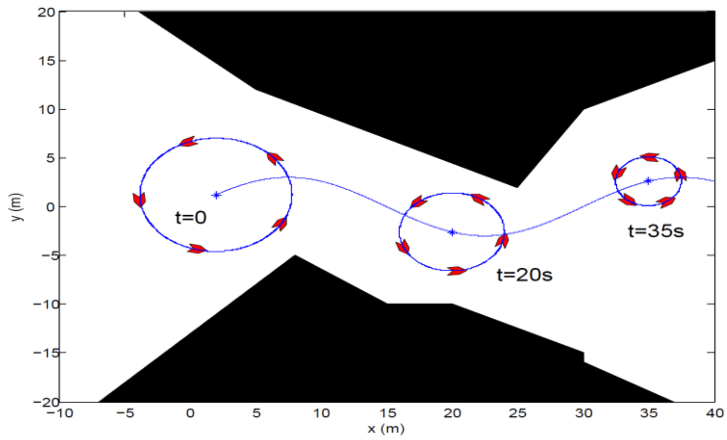


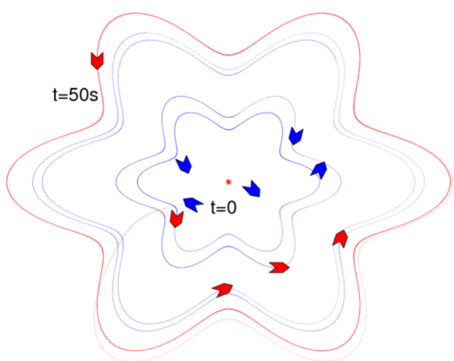
AUV are in general subject to strong perturbations. H∞ controllers developed in [1] allow controlling the vehicle in three dimensions with respect to the marine environment and other vehicles in the fleet with the guarantee of tracking a given trajectory. *For fleet coordination,* the available bandwidth is severely limited (few bits per second). In addition, communication is subject to long and variable propagation delays, Doppler, multi-path, fading and high bit error rates. The figure above (right) depicts the packet loss rate according to the communication range that can be improved using technics derived in [2].

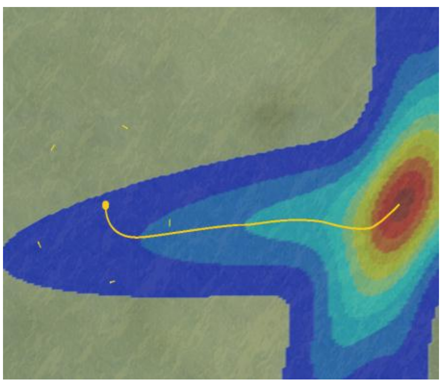
AUV Fleet control under limited communication capabilities

The purpose, here, is to design a control law in order to stabilize the AUV fleet to time-varying formations which are circular or more general. This is achieved by applying a sequence of affine transformations such as translations, rotations and scaling. Along with this stabilization goal, the new algorithm also distributes the AUVs along the formation by taking into account the communications constraints. Owing to this algorithm, the formation can be adapted to the marine environment or to the contour of the source.

In the context of source seeking, it is relevant to constrain the agents in an appropriate shape to avoid unnecessary waster of energy waste. Moreover, ensuring that the agents are uniformly distributed along the formation is more adequate to produce efficient search motions. Therefore, an additional component of the control law is also added to distribute of the agents along the *elastic formation*. This is achieved by taking into account the communication graph between the agents. The collaborative control law stands for the case of range dependent graph. The figure below depicts the changing of the radius of a circular formation to adapt to the environment







Collaborative estimation of gradient direction

The source seeking problem has been first solved by using only direct signal measurements work in a all-to-all communication scheme. Then, a fully distributed algorithm with more realistic communication constraints has been derived. In particular, we have shown how a group of AUVs uniformly distributed in a circular formation, is able to approximate the gradient direction of the signal propagation to steer the formation towards the source location. To achieve this objective under limited communication, each AUV estimates its own direction based on its neighbors' concentration measurements. A consensus algorithm is used for converging to the same desired gradient direction.

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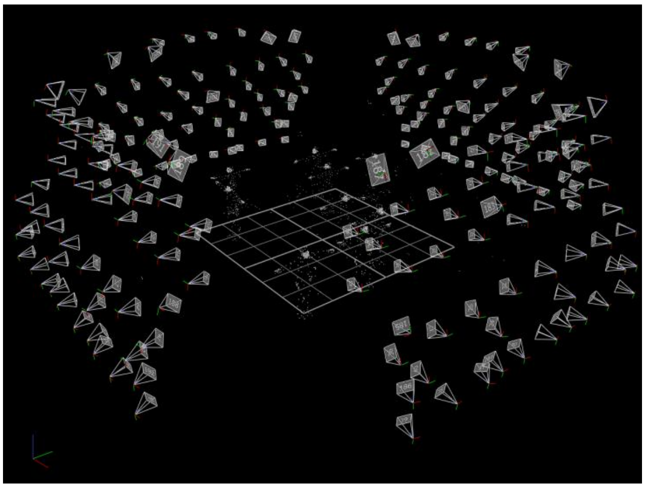
Motion Capture Networks

State of the art and project innovations:

Context:



Typical scenarios in a motion capture systems consist of tens/hundreds of cameras and several hundreds of unlabelled markers.

The commonly used reconstruction algorithm is summarized as follows:

- ***matching****: For each pair of cameras the information on the image planes is compared, searching for correspondences through geometric triangulation;*
- ***back-projection****: When a pair of measurements is found to be compatible, a "temporary" target is created in the 3D space and it is back-projected onto the other cameras image planes;*
- ***reconstruction****: When more image plane measurements from different cameras are found compatible with each other, they all contribute to reconstruct a "real" target in the 3D space.*

Motion capture networks are networks of smart cameras used to record and estimate the motion of an actor, a patient or any physical object of interest. These systems are attractive because they provide accurate measurements with minimal intrusion and burden. Today's motion capture relies on a fixed network of cameras observing a volume where the objects to be captured can move freely.

Clearly, there are some limitations to this approach that we would like to alleviate. For example, because the cameras have a limited field of view as the size of the volume increases, the number of cameras required to obtain reliable motion capture data increases and can become completely non-realistic for very large volume, both in terms of costs and current technical capabilities. If the system is composed by a limited number of cameras and targets, the classical reconstruction algorithm based on geometric triangulation can be implemented in a centralized fashion on a single machine to track the targets in real time. On the other hand, when considering the envisaged large system scenarios, the reconstruction cannot be done in real time by a single machine. In actual fact, the current and next generation of motion capture camera networks are made of devices either with embedded computational capabilities or supported by a cluster of PCs for computations, and it is therefore a challenge and an opportunity to distribute the computations among the processing nodes to achieve high accuracy, low latency and high throughput.

On the other hand, there are however many application scenarios where the number of cameras could be dramatically reduced if these cameras had the ability to track the objects of interest as they travel within the capture volume. The cameras can be mounted on Pan-Tilt motorized head and can be controlled automatically to ensure that the objects are always in the field of view.

Key points of the advance:

- The exploitation of the network as both a computational and communication grid suggests the exploration of a distributed approach to 3D reconstruction: ***How to design a reconstruction algorithm that allows to scale with the number of cameras and markers?***
- Also, the tracking abilities of cameras bring new challenges: ***how to keep an accurate camera calibration (position and orientation) required to triangulate the 3D positions of the objects of interest? How to control the Pan-Tilt motors to the keep always or as much as possible the objects in the field of view?***

These are questions we addressed in FeedNetback to enable new application scenarios and markets of motion capture networks [2]

a. Distributed reconstruction: the power of the network

In the centralized classical approach the reconstruction algorithm runs on a single core, scaling badly with both the number of cameras and the number of markers. Conversely, if adapted to work in a distributed fashion on the computational grid formed by the camera network, a huge speed up of the whole reconstruction can be achieved. The rationale is that cameras that allow to reconstruct more targets has to be matched first, in such a way that most of the 2D measurements are deleted quickly (in the first step of the reconstruction procedure).

According to the requirements defined in WP1 [1], a distributed algorithm is proposed that uses a binary tree structure to spread the calculation on different nodes/cameras, in such a way to tackle the issue of computational complexity when scaling up in the number of cameras/targets [4]**Erreur ! Source du renvoi introuvable.** Also, in order to apply this strategy efficiently, it is of paramount importance to find a strategy to pair cameras efficiently, namely to define and compute a suitable affinity measure between cameras: A large affinity score indicates that cameras allow for good reconstruction of a large number of targets, and should be paired first. The derivation of such an affinity measure has been completed by taking into account two often complementary factors: The number of reconstructed targets and the quality of reconstruction. As shown [5], the simulations prove that a huge speed-up of the whole procedure is attained, and the approach based on the camera affinity score also yields a fairly complete reconstrution in very limited time, so as to allow a preliminary evaluation of the whole reconstruction at an early stage of the procedure.

b. Continuous automatic camera calibration: autonomicity

As stated above, a moving camera needs to be continuously calibrated in order to provide useful measurements for the triangulation. To do so, we rely on static background markers for which the 3D position is known, and we relate these markers to their 2D images to estimate the pose and orientation of the camera in space. Cameras external calibration parameter estimation (also known as camera re-sectioning) is a well-established robust optimization procedure when the correspondences between the image data and the 3D markers are known. Unfortunately, these correspondences are unknown in the motion capture case, and their computation is a combinatorial search problem that explodes when the number of 3D markers is large.

We therefore split the calibration task into two processes running in parallel, namely a tracking process and a detection process. In the tracking process, we rely on the previous estimated pose to drastically eliminate correspondences. A non-linear least square optimization is then ran to obtain a maximum likelihood estimate of the camera pose [5].

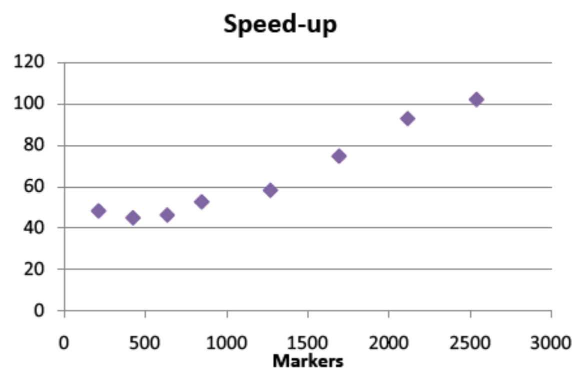
A key feature of the algorithm is that its complexity scales very well with the number of marker clusters; moreover, although the detection phase is twice as slow as the tracking, it is still able to provide a good initialization when the tracking is lost.

c. Background marker 3D estimation: a novel approach!

The calibration described above relies on the knowledge of the 3D position of the background markers. An original method has been devised to achieve this: A camera is waved in the volume and captures images of the background markers from different angles. Since the intrinsic parameters of this camera are known, it is possible to recover a metric reconstruction of the 3D background (given a length measurement in the real scene) via structure from motion algorithms **Erreur ! Source du renvoi introuvable.**: The approximate relative camera poses are then combined into a non-linear optimization problem whose solution provides camera trajectories and marker positions.

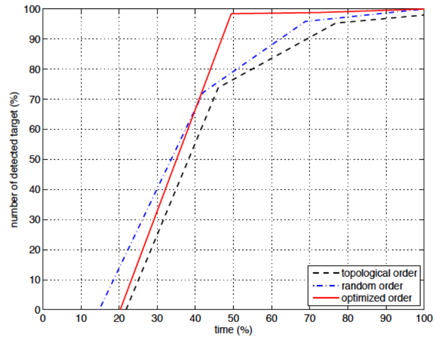
d. Pan-Tilt control in the 3D tracking case: enter camera dynamics!

The problem of Pan-Tilt control is formulated as an optimization problem, in terms of object coverage (i.e. the number of cameras seeing the object) that is an easy quantity to measure and check. Although a real-time performance could not be achieved using the best performing method for computational reason, a greedy suboptimal procedure turned out to give acceptable results in a more realistic computation time [3]



Over 40x faster by exploiting parallel computing, and scaling up with the number of markers!

Speed-up obtained using the distributed reconstruction procedure procedure for different number of markers, w.r.t. the centralized approach.



Over 90% of reconstructed markers in the first half of the run by exploiting smart camera association!

Number of detected targets vs the computational time, obtained using the topological (neighboring cameras are associated), random (random cameras are associated), and optimized reconstruction order (most affine cameras are associated).

Software development

In this context, two main algorithms have been designed and tested:

Distributed reconstruction algorithm:

The algorithm is based on a binary tree structure, where at each level the nodes are paired and their information (2D information on the image planes and partial reconstruction of the 3D targets) is fused. The algorithm is organized into three steps, namely the fusion of partial 3D target reconstructions, the contribution of 2D information to already existing partial 3D targets, and the creation of new 3D targets from 2D data. The sequence of the three phases guarantees convergence and correctness of the reconstruction procedure. [4]

PTZ control:

The algorithm is designed to perform concurrent calibration and tracking, using a partition of the 2D points on the camera image planes to estimate the current camera calibration, while the remainder of the 2D data are used for tracking purposes to compute the pose and location of the objects of interest and a new target position for the motorized Pan-Tilt heads [4].

Scientific results

Beyond the definition of new algorithms, the research activity on distributed reconstruction has yielded interesting results in the following contexts:

- **derivation of a camera affinity functional**: The affinity among cameras can be formally computed in terms of 3D mean reconstruction error when using their image plane information. This formula can be used to compute the *k-1* cameras that allows the best reconstruction when associated to a specific chosen camera or, similarly, to compute the *k* cameras that allow the best reconstruction [8];
- **study of complexity**: A strategy to compute the theoretical complexity of the algorithm is defined, according to different reconstruction scenarios (clustered and sparse scenes) [6];
- **reconstruction algorithm performance**: A typical design requirement for a camera system is that of reconstructing targets' positions with a certain accuracy; the conditions for an adequate reconstruction have been defined, e.g. how many cameras have to be used to make sure that the reconstruction error's standard deviation is lower than a given threshold [7].

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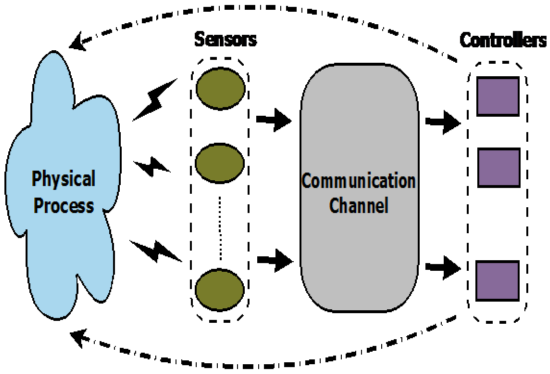
4.1 Final publishable summary report

4.1.3 A description of the main S&T results/foregrounds:

B)- Success stories in control co-design

Control & Communications

Closed-loop Stabilisation over Gaussian Communication Networks



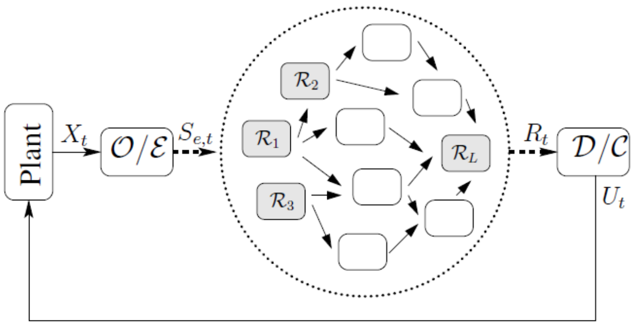
Consider the scenario where an unstable physical process (plant) is being controlled/stabilized by remotely located control units. The sensor nodes measure the physical process and communicate these measurements to the remote controllers, which then take appropriate actions to stabilize the system in the desired way. The communication links from the sensors to controllers and from the controllers to the actuator or the plant can be wired or wireless depending on the application. The sensor and the controller nodes can be decentralized or have limited cooperation among them. Different nodes in this closed-loop network can have different communication capabilities and resources. Therefore it is important to study various topologies in the remote control setup.

In this work the plant is modeled as a linear time invariant system with an unknown initial state. We assume that the signals received signals at the various nodes are corrupted by additive white Gaussian noises. The communicating nodes have average transmit power constraints. We propose to use delay-free schemes to stabilize the system in mean square sense and thereby derive conditions for mean square stabilization in some centralized and distributed settings.

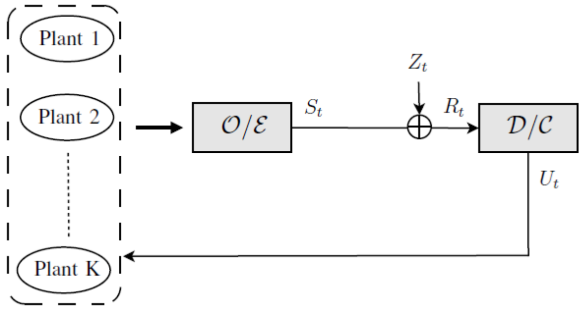
Key Contributions:

- We derive necessary and sufficient conditions for mean square stabilization of a linear time invariant plant in various centralized and distributed settings.
- We introduce the idea of using relay nodes within the communication medium to improve the system performance.
- We analyze delay-free schemes for stabilization and provide useful insights on optimal sensing schemes in various network topologies.
- The results reveal relationship between the communication parameters and achievable stability region of the LTI plant.

Stabilization Over a Relay Network



Stabilization of Systems Over a Single Channel

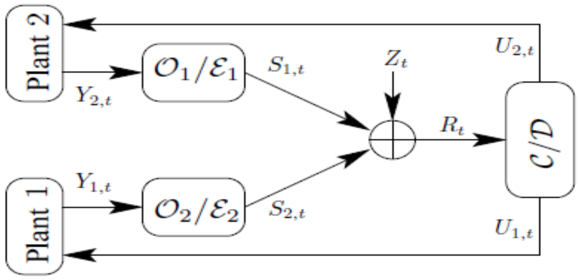


Stabilization Over Relay Network: In this setup, there is a network of intermediate nodes (known as relays) to help communication from the sensor to the controller. We consider some basic network topolgies such as orthogonal, non-orthogonal, cascade, and parallel networks, which are basic buildiung blocks of a general communication network. We also study half-duplex and full-duplex relays with an overall transmit power constraint and derive necessary and sufficient conditions for stabilization.

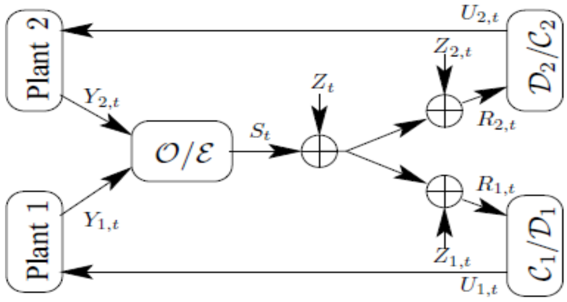
Stabilization of Many Systems Over a Single Channel: A group of dynamical systems are being monitored by a single sensor which communicates its observation to the controller using a uni-dimenisonal Gaussian channel. We show that linear time invariant schemes are not sufficient in general for stabilization. However one can always stabilize the group plants by employing a linear time variant sensing scheme as shown in [6]. We also derive an optimal linear time varying scheme for finite horizon stabilization.

Stabilization Over Multi- User Communication Channels

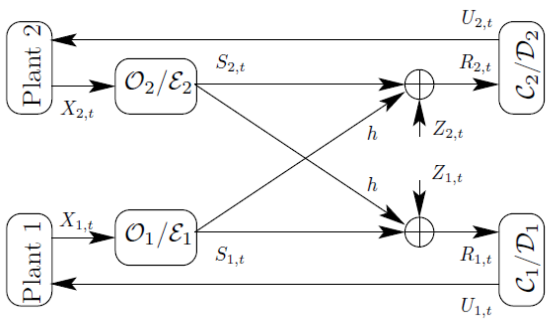
Stabilization Over Gaussian Multiple-Access Channel: There are two LTI plants which are separately sensed by two sensors. The sensors transmit their measurements over a single Gaussian channel to the controller, which then takes actions to stabilize both systems. This is the distributed sensing joint control setup for which we propose a linear transmission scheme and derive achievable region for mean square stabilization under average transmit power constraints.



Stabilization Over Gaussian Broadcast Channel: There are two LTI plants whose states are separately observed by a single sensor node. The sensor transmit its measurements over Gaussian channels to two separate controllers, which then take actions to stabilize the two systems. This is the joint sensing distributed control setup for which we propose a linear transmission scheme and derive conditions for mean square stabilization under average transmit power constraints.



Stabilization Over Gaussian Interference Channel: There are two LTI plants whose states are separately sensed by a two separate sensors. The two sensors transmit their measurements over Gaussian inerference channel to two separate controllers, which then take actions to stabilize the two systems. This is the separate sensing distributed control setup with cross-talk between the communicating nodes for which we propose a linear transmission scheme and derive achievable region for mean square stabilization under average transmit power constraints.



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Control & Computation

AUV control under execution resources constraints

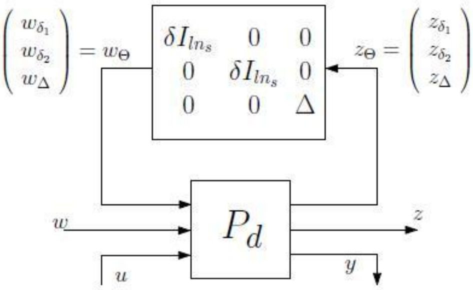
Autonomous underwater vehicle

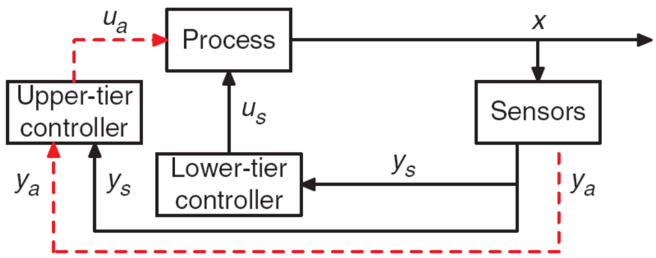
Embedded control systems are subject to execution resources related constraints such as limited computing power, asynchronous sensing, preemption, jitter and un-measured communication delays.
It is now recognized that computing devices can be also objects that can be controlled using feedback, hence the design of feedback schedulers based on various components of the rich control toolbox.
It is also recognized that control loops are robust not only w.r.t. the plant parameters variations, but also w.r.t. deviations of the real-time scheduling parameters. Therefore it is possible to design new “weaklyhard” real-time control algorithms based on various kind of asynchronies , e.g. using varying sampling rates.

- The LPV approach enables to capture sampling rates as varying parameters of the plant model.
- Robust H_∞ control can be synthesize from this model for a predefined range of control intervals.
- Sampling rates can be controlled by a MPC based outer feedback scheduler to manage the computing or sensing costs.

Hierarchical design:

- the inner loop uses a LPV/H∞ controller is fast enough to stabilize the plant, but have limited capabilities to handle non-linearities
- the outer loop based on MPC handles non-linear behaviours, e.g. actuators saturation and cpu management, at a slower time scale



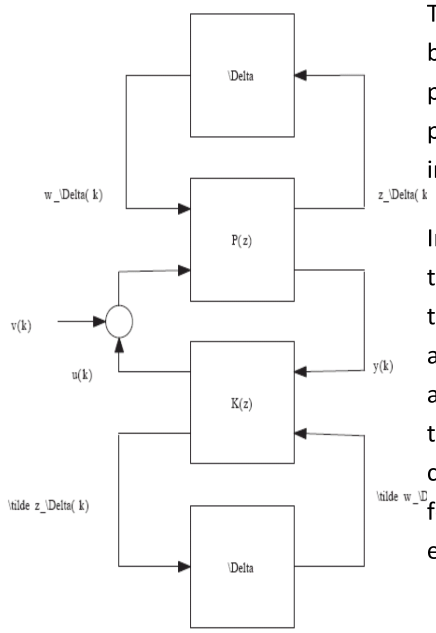


Left figure: In the LPV model the uncertainty block handles both the plant's uncertainties (Δ) and the sampling rate deviations w.r.t. its nominal value (δ). A robust H∞ is designed upon this model, using the varying measured parameters as additional inputs.

Right figure: A lower-tier control system relies on point-to-point communication and continuous measurements to stabilise the closed-loop system. A Lyapunov-based model predictive control is used to design an upper-tier networked control system to profit from both the continuous and the asynchronous measurements as well as from additional networked control actuators.

The fast LPV/H∞ can be used as the lower-tier controller

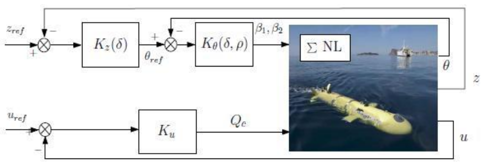
Combining LFT/H∞ (inner loop) and MPC (outer loop)

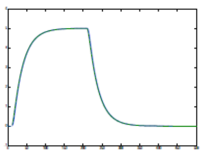


The LFR formulation is used to keep some varying parameters in the model. The Δ block contains the varying part of the model, which depends on the linearization point. The model is then discretized and the sampling interval is added in the Δ parameters block. Compared with previous approaches, the new one shows an improved range of efficiency as it handles some non-linearities of the plant.

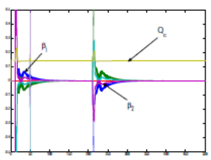
In the two-tier control architecture, the upper-tier controller decides the trajectory of the additional input between successive samples and the lower-tier controller decides the original input using the continuously available measurements. Due to the asynchronous nature of the measurements, the upper-tier controller has to take into account that the time interval between two consecutive samples is unknown and there exists the possibility of an infinitely large interval. In the case of the advance control of the AUV the two-tier MPC controller over the LFT/H_∞ controller is designed for time varying sampling times. This will allow the controller to take constraints explicitly into account.

Altitude control of the AUV

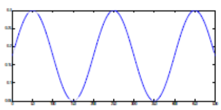




Altitude control



Actuators



Sampling rate

Stability of the closed-loop system

Combining the information from a hybrid communication system may lead to losing the stability properties of the lower-tier controller. The resulting closed-loop system is an asynchronous system and studying the stability of this class of systems is in general a difficult task. This implies that the design of the upper-tier controller is also a difficult task. In this work, we propose to follow a Lyapunov-based approach. The main idea is to compute the input applied to the system in a way such that it is guaranteed that the value of the Lyapunov function at asynchronous time steps is a decreasing sequence of values with a lower bound. This guarantees the practical stability of the closed-loop system.

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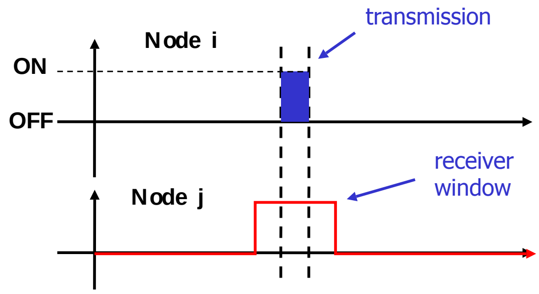
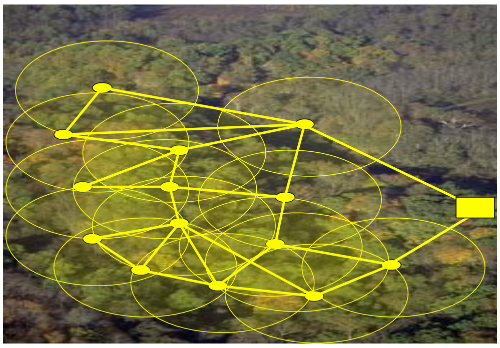
Control & Complexity

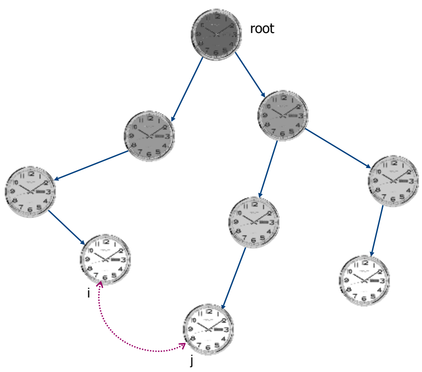
Consensus Based Networked Clock Synchronization for Wireless Sensor Networks

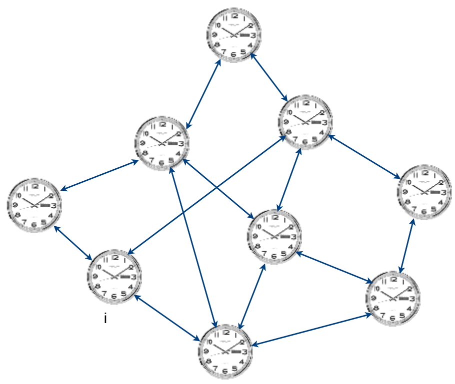
Wireless sensor networks (WSNs) provide a new technology which will play a prominent role in the next years. This technology is based on the cooperation of a large numbers of relatively cheap units for reaching a common goal. However cooperation is impossible if the units composing WSNs do not share a common notion of time between the units. This is obtained if the units possess clocks and if those clocks are synchronized.





Context: One of the key problems in wireless sensor networks (WSNs) is time synchronization. Indeed, in many of the applications of WSMs it is essential that the nodes act in a coordinated and synchronized fashion requiring global clock synchronization, that is, all the nodes of the network need to refer to a common notion of time. For instance, consider the problem of tracking a moving target using proximity sensors, where some nodes are deployed in the environment and their proximity sensors detect when the moving object passes in their vicinity. Other interesting and important applications, which need a time-synchronization service, are habitat monitoring, power scheduling and TDMA communication schemes, and rapid synchronized coordination of power lines nodes in electric power distribution networks for catastrophic power-outage prevention. A wide variety of algorithms and protocols have been proposed to address the problem of time synchronization in WSNs, as surveyed in [1]. Depending upon the architectures adopted, these protocols can be divided into three categories: tree-structure-based, cluster-structure-based, and fully distributed. Consensus based clock synchronization algorithms fall in the last cathegory. However, the existing techniques do not work well when the clocks have significantly different slopes.

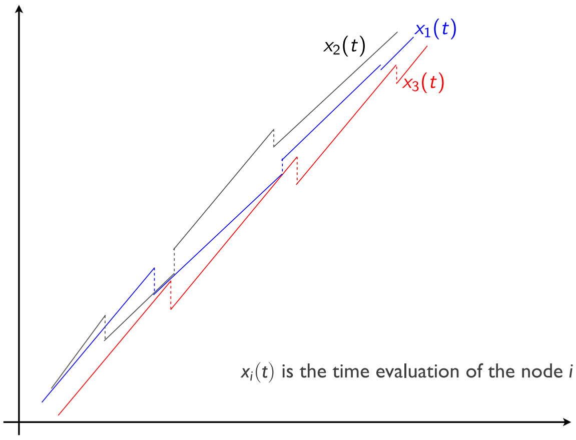




In wireless sensor networks the nodes are most of the time inactive. They are activated when they need to communicate. Therefore the transmitting node need to send its information within the time window in which the receiving node is active. For doing this a common time reference is needed. In hierarchical architectures a leader clock is elected and the other clocks synchronize refering with it directly or though intermediate clocks. In distributed architectures the synchronization occurs without a leader between peer clocks.

Consensus for double integrators and clock synchronization

Description of the algorithm: We propose a clock synchronization algorithm which is based on the consensus algoithm for double integrator dynamics. We proved that it works also for clocks with significantly different slopes.



If $x_i(t)$ denotes the time estimate of the node i at time t, then these functions need to be ramp shaped and close each other, within some admissible error.

Key points of the advance: A clock can be seen as a ramp shaped number generator, namely a generator of numbers which grow as time passes. Different clocks generate ramps which may differ both the offset (due to different clock initialization) and by the slope (due to different clock speeds). The goal of any clock synchronization algorithm is drive all those ramps to the same one. It is clear that it is a consensus that must be reached. In fact, standard consensus algorithms have been proposed as a tool for synchronizing networks of clocks which is based on fully distributed architecture. However the resulting methods suffered of problems, because they compensate only the clock offsets but not the clock drifts and so they don't work in case of clock with sensibly different slopes. Indeed, as pointed out by a work developed within Feednetback [2] in order to synchronize clocks with different drifts, we need to apply consensus algorithms able to synchronize systems with a high order dynamics. As pointed out by the same work, the existing methods for consensus of high order systems are not applicable to the solution of time synchronization due the fact that clocks have to be modeled as heterogeneous systems. For this reason there was a need to develop a new synchronization method, which, being based on simple linear consensus, showed to be very robust to drift variations, to nodes or links failures and to communication delays. This analysis has been performed through extensive set of simulation experiments. From a theoretical point of view, the study of this algorithm was essentially directed towards two goals. One was to develop a general theory of consensus algorithms for high order heterogeneous systems in case of time invariant communication topology. This line of research resulted in a collaboration between KTH and UNIPD with the production of [3,4]. The second goal was to extend this algorithm from the synchronous ideal implementation to an asynchronous more realistic implementation. Some results have been obtained so far within Feednetback [5,6]. However, the general case proved to be much harder to be studied. Actually, this problem has been the inspiration of a research stream having as objective the development of a general theory of consensus algorithms for high order heterogeneous systems in case of time-varying communication topology. Indeed, the present literature on consensus is still far from providing tools for the study of this class of problems.

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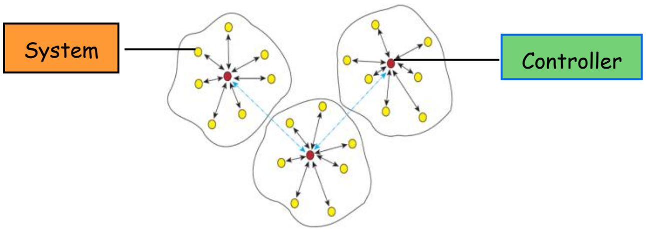
Control & Energy co-design

A New Mathematical Modeling and Optimization of Wireless Sensor Networks Protocols for Control Applications



The state of a system is remotely controlled over an energy efficient wireless sensor network. The nodes of the network are organized into clusters according to the IEEE 802.15.4 standard. The yellow nodes have reduced functionalities and are connected to the system. The red nodes are cluster coordinators. The mathematical modeling of the network behavior is one of the important contributions we developed within WP5 of FeedNetback.

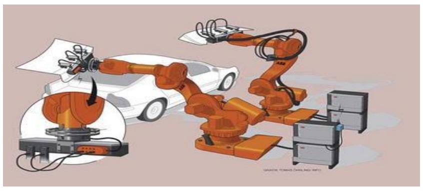
Wireless sensor and actuator networks (WSNs) have a tremendous potential to improve the efficiency of many distributed systems, as in building automation and process control. Unfortunately, the current technology does not offer guaranteed energy efficiency and stability for closed-loop systems due to the packet losses and varying delays of the network. These systems must support the right decision at the right moment by parallel and distributed algorithms despite traffic conditions, unexpected congestion, network failures, or external manipulations of the environment. The development of efficient and reliable systems based on WSNs relies heavily on how well communication protocols can be adapted and optimized to meet quality constraints under limited energy resources.

Modeling and optimization of the performance metrics (reliability, delay, power consumption) for control over IEEE 802.15.4 WSNs. The IEEE 802.15.4 standard is the de-facto reference standard as a low data rate and low power protocol for WSNs applications in control, industry, home automation, health care, and smart grids. The new results are especially important for many control and industrial applications.

Key contributions

- a new approach to the modeling of the protocol behavior based on Markov chain theory.
- a new method based on optimization theory to the co-design of energy efficient control and networking.
- new networking and control protocols to tradeoff the energy consumption of the network with the application requirements in terms of reliability and delay.

Example: robots controlled over a WSN



***Example of application**: control of robots without using cables. Small sensor devices on the robots transmit the measurement of the state IEEE 802.15.4 WSN to a remote controller. Direct communication is not possible or convenient because moving metals and electromagnetic impairments cause high message losses and delays.*

Distributed Networking Algorithm to Support Energy Efficient Control Applications

Investigation of the protocol dynamics

The IEEE 802.15.4 medium access control protocol for WSNs can support energy efficient, reliable, and timely packet transmission by a parallel and distributed tuning of the medium access control parameters.

Markov chain modelling

A generalized Markov chain models the protocol behaviour by rigorous approximate expressions without giving up the accuracy.

Distributed adaptive algorithm

A distributed adaptive algorithm minimizes the energy consumption while guaranteeing a given successful packet reception probability and delay constraints in the packet transmission.

Experimental results

The algorithm has been experimentally implemented and evaluated on a test-bed with off-the-shelf wireless sensor devices. Experimental results show that the new analysis is accurate, that the proposed algorithm satisfies reliability and delay constraints as requested by the controller, and that the approach reduces the energy consumption of the network under both stationary and transient conditions.

The proposed method relies on the solution of optimization problems to co-design energy efficient network and control. The challenges are the modelling of the protocol dynamics, network interactions with the controllers, and the solution to the optimization problems by parallel algorithms of reduced complexity.

$$\begin{aligned} \min_{\mathbf{x}} \quad & E(\mathbf{x}) && \text{Energy Consumption} \\ \text{s.t.} \quad & P_i(\mathbf{x}) \geq \Omega_i, \quad i = 1, \ldots, n\,, && \text{Reliability} \\ & \Pr[D_i(\mathbf{x}) \leq \tau_i] \geq \Delta_i \quad i = 1, \ldots, n && \text{Delay} \end{aligned}$$

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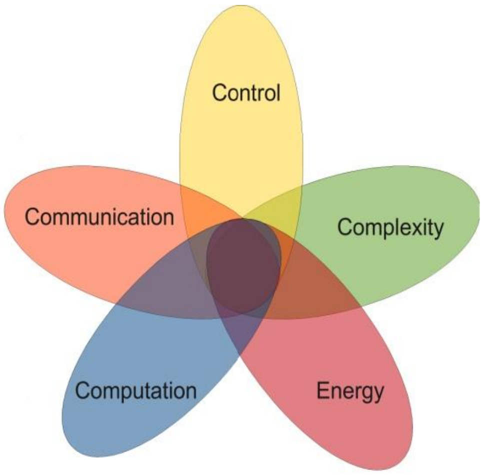
Co-Design Methodology for Networked Control Systems



Elements considered in the C4E framework

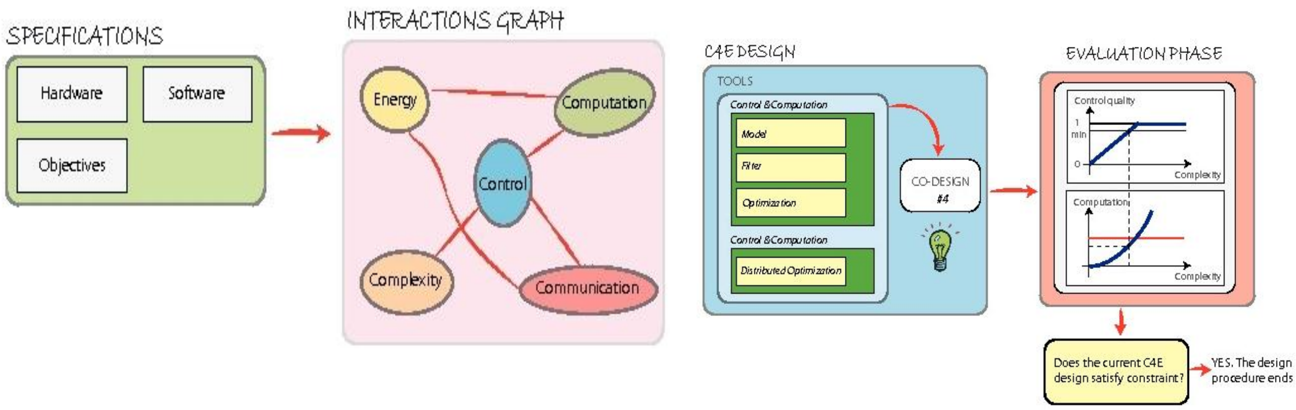
Networked Control Systems (NCS) are becoming ubiquitous, with applications in automotive industry, telerobotics, and deep space exploration, to name a few. Inherent to the design of these systems are the aspects of Control, Communication, Computation, Complexity, and Energy (C4E).

While several techniques have been proposed to deal with specific problems related to one or at best two of the C4E design aspects in NCS, it is fair to say that there is yet no coherent methodological framework to address NCS design problems. As such, the main goal of the FeedNetback project was to devise a novel C4E co-design method, with the aim of improving the overall system performance and quantifying trade-offs between the different designs elements [4]. Still, due to the complexity of the overall design problem, most of the available design methods deal with one or at most two of the C4E elements at a time, which is also adopted by the approach. We show how multiple design considerations can be integrated, typically in a second design stage following an initial pairwise design.

In the C4E design, elements cannot be decoupled in general, since one or more of these elements interact and mutually affect each other. As such, any design methodology that tries to decouple these elements is bound to lead to very conservative overall performance of the system and does not fully exploit the potential of NCS.

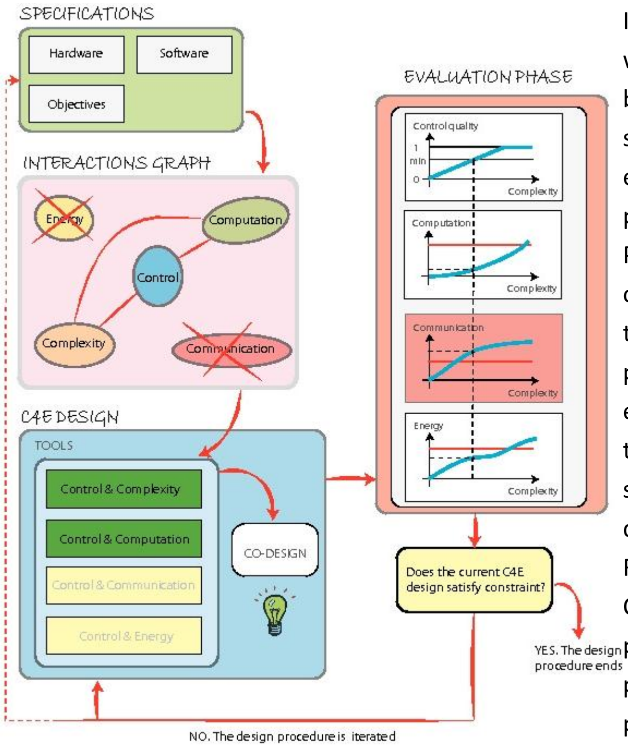
Inspired by [1, 2], we propose an application-based C4E co-design methodology that goes beyond the partial co-design involving 2 Cs of the C4E framework.

Rather than just focusing on one or two elements of the C4E framework, we propose to view the 5 elements in a single framework and apply an iterative co-design scheme. This scheme takes into account the specifications of the problem: limitations of the available hardware/software, computational power, energy limitations, required performance/objectives, etc. Then, through an interaction graph, we highlight which of the C4E elements are of interest and how they interact. An iterative co-design procedure follows this stage.



C4E co-design methodology is structured in three phases. Phase I and Phase II are depicted on the left, where in the first phase the design specifications are provided and in phase II the interactions graph is constructed. Phase III, which is shown in the right figure, is subdivided into the design and evaluation process, where an initial design is considered and evaluated on the base of constraints and objectives. The design, i.e., phase III is then re-iterated until satisfactory results are achieved.

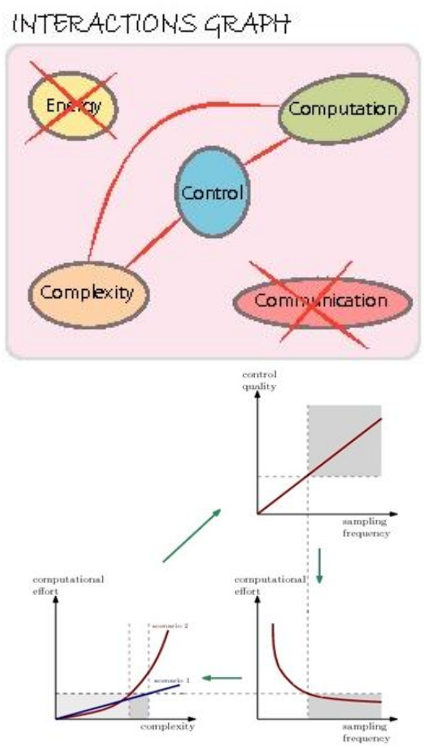
Novel C4E co-design methodology



Scheme for complete co-design methodology of C4E framework indicating the iterative design flow

In almost every NCS, the designer is given certain specications which comprise hardware (e.g., processor, communication bandwidth, etc.) and software specications (i.e. operating system, communication protocol etc.), and requirements (i.e. efficiency, performance, etc.). These factors are the starting point of our C4E design methodology and effect the following Phase II, and III. In principle, the systems performance is optimized while the given specications act as constraints. Given the design specications in Phase I and the nature of the NCS problem, the designer constructs a graph with the 5 C4E element-nodes and edges representing interconnection amont them if they are involved in the NCS. Given the design specications of Phase I and the intteraction graph of Phase II, the designer selects, among the available tools from other FeedNetback workpackages WP2-5 (e.g., WP3 Control & Communication) the relevant ones. The tuning of selected tools parameters constitutes part of the co-design. Given the proposed C4E design, an evaluation phase quantifies the performanceh and the trade-offs among the design elements. The design is completed if all requirements are met. Otherwise, the evaluation phase provides feedback to the C4E design specifying, which design components have to be modied. This inlcudes hardware and software specifications as well.

Example of co-design for smart networks of cameras for surveillance applications



We successfully applied the new iterative co-design approach to address the design issues within the case study of multi-camera surveillance systems. The specifications of the test-bed including hardware and software interactions, revealed that in the smart networks of cameras for surveillance applications, there are interactions between control, computation, complexity, under the assumption of wired communications and power supply (see upper left). Starting form an initial design and evalution-criteria (depicted left) the iterations over the design of used filters and optimization algorithms led to a promising method to give good tracking performance and scalability [3]

References

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[4] Alireza Farhadi; Carlos Canudas De Wit. An Integration Framework For Control/Communication/Computation (3C) Co-design With Application In Fleet Control Of AUVs, 50th IEEE Conference on Decision and Control and European Control Conference (IEEE CDC-ECC 2011), Dec 2011, Orlando, Floride, US

4.1 Final publishable summary report

4.1.4 Impact, dissemination activities and exploitation results

Impact

The impact of the FeedNetback project derives from the combination of fundamental advances in science with application-specific considerations. Feedback control systems that use data networks as medium for the feedback path will particularly benefit in terms of the following aspects:

More efficient, flexible, easier to maintain and more productive large infrastructures, manufacturing and process plants.

The co-design framework for large-scale distributed control systems that FeedNetback proposes will enable the application developers and programmers to use the potential of networked control in a wide set of industrial domains. This is achieved by integrating architectural constraints and performance trade-offs from control, communication, computation, complexity and energy management. As a result more efficient, robust and affordable networked control technologies will be developed that scale and adapt with growing and changing application demands. Systems designed in this manner allow for easy modification of the control strategy by re-routing signals, having redundant systems that can be activated automatically when component failure occurs and in general they allow a high-level control over the entire plant.

Europe with its 25% market share in application and 32% in production of automation equipment is well placed to take advantage of the advances in this area. FeedNetback complements communications infrastructure and embedded systems design. Apart from the leading European companies in the area of automation solutions, there are small and medium enterprises producing important automation equipment that have been interfacing with the project and can benefit from the knowledge generated.

Control more complex systems, increase plant availability, reduce maintenance time and cost

The characteristic of scalability in networked control systems expresses the ability to deploy network applications with low initial capacity, functionality and entry–level costs plus the ability to add capacity and functionality over time to high levels by adding components incrementally, while maintaining system availability. The need of scalability is more intense in the field of wireless networked controlled systems and especially in those networks whose communication nodes have the ability to be mobile. In FeedNetback the co-design methodology result in controlling more complex systems, while increasing availability and reliability. Architectural issues investigated in the project, such as the relative merits of cooperation of numerous, cheap and low quality units versus few, expensive and high quality units inform the relevant system design processes.

FeedNetback developed performance metrics that take into account the interaction between the continuous plant dynamics and the discrete and sometimes random nature of the network. Such stability performance metrics account for the uncertainty in the communication system and information metrics that account for the value of information from a control theoretic perspective.

FeedNetback's co-design methodology offers a new engineering approach to ensure efficient, robust, safe and secure operation of process plants, in particular plants dependant on wireless networking technologies.

Since the FeedNetback co-design framework is generic, it is possible to underpin applications in diverse control application domains such as Process industries; Renewable energy and smart grids; Robotics and Automotive/Aerospace.

The two industrial case studies investigated aimed at the development of new services and applications that are tailored to specific needs. In particular, the case study on smart camera networks aims specifically at more efficient, flexible, secure, easier to maintain and more productive large infrastructures, while the case study on underwater inspection systems aims at enabling low-cost monitoring of the environment and natural resources.

New services and applications that are tailored to specific needs, seizing new market opportunities

As a result FeedNetback contributes in increased safety and security in camera-equipped facilities such transportation hubs such as airports and train stations. Further, the project has an impact towards the monitoring of maritime pollution. Despite AUVs being the smallest of the three autonomous vehicles markets, it has the least number of competitors and is expected to see the highest rate of growth. Although AUV technology received major support within the military arena during its early years of development, civil and commercial markets are not niches any more. AUVs have been successful in supporting offshore oilfield and pipeline route surveys and a proliferation of AUVs is expected due to the focus of the academic community on developing smaller low-cost vehicles. Small AUVs are more marketable because they address practical needs and are easier to handle.

Thanks to FeedNetback progress has been made in video surveillance surveillance and operating a fleet of AUVs in unison. Both areas still represent a small percentage of the overall surveillance and ocean exploration market, respectively. Yet these market segments are growing significantly faster than the overall market. Contributing relevant technology roadmaps, the project informed the respective communities so as to reduce over-hyped or under-performance compared to expectations.

Various domains are expected to benefit from the developed technologies in FeedNetback, other than its two use cases. According to the consortium’s research these are: intelligent building management; networked control of smart power distribution networks; road traffic monitoring and management; co-operative automotive systems; disaster prevention at nuclear power plants; and surveillance with networked aerial and underwater autonomous vehicles.

Enable low-cost monitoring of the environment and natural resources

FeedNetback adds value to sensor networks and therefore will have an indirect impact on enabling low-cost monitoring of environmental and natural resources.

Distributed smart cameras represent key components for future embedded computer vision systems and FeedNetback enables deployments both for security and entertainment domains.

Advances in algorithms facilitate the automated co-operation of CCTV networks, greatly expanding system coverage. FeedNetback has demonstrated how to ensure adequate coverage of an area by integrating PTZ cameras with overlapping fields of vision . The many methods of accessing and analysing images have different implications as regards the type and speed of monitoring

that can be carried out. Extensions towards specialised uses, such as facial and gait recognition, will generate yet more potential applications of this flexible technology.
With regards to the entertainment domain, FeedNetback has contributed in the development of motion capture systems used in production of movies and computer games.
Underwater vehicles represent a rapidly growing technology with numerous scientific, commercial and defence industry applications. Scientific investigations in physical, chemical, geological and biological processes of the marine environment often require the use of such systems to perform exploration, survey, monitoring and data collection tasks.
Significant global trends are driving the marine industry - climate change, energy demand, food production, and sustainability. The FeedNetback project investigated a framework to provide mechanisms for vehicle control in presence of widely varying goals, behaviours and environments. The theoretical results of the project, validated through a series of simulated multi-vehicle mission scenarios, contribute to development of control and communication solutions for the simultaneous operation of unmanned marine vehicles. This finds a direct application in fleets of AUVs, but may also be extended to other existing operational vehicles such as tethered (ROV) and autonomous surface crafts.
Without the technologies FeedNetback underpins, marine exploration would have to rely longer on surface ships or complex submarines since autonomous surface and underwater vehicles would be unable to deliver their full potential.
In summary the impact of FeedNetback arises from outcomes:

- Solutions that cross the traditional boundaries between control and complexity, communication, computation, and energy savings, at a time of unprecedented interest in networked sensor technologies and the need to support diverse applications
- Vital knowledge gained about the C4E concept, not just in developing new technologies, but in applying these technologies to areas of society where they protect the environment and improve people's safety, security and ultimately quality of life
- Commitment to a dissemination strategy that extend throughout and beyond the lifetime of the project.

Dissemination

In relation to academic dissemination, the FeedNetback consortium produced over 250 peer reviewed publications (e.g. European Signal Processing Conference; IEEE International Conference on Distributed Computing in Sensor Systems; Symposium on New Directions of Automatic Control; IEEE Conference on Decision and Control; European Wireless Conference; Acoustics, Speech and Signal Processing) during the life of the project. Several invited sessions (e.g. IEEE Conference on Decision and Control, American Control Conferences, and IFAC Word Congress) and lectures (e.g. UCLA, Berkeley, MIT, Stuttgart, Kyoto) were delivered.
FeedNetback organised a series of annual workshops (Venice 2009, Annecy 2010 and Schio 2012) as well as a Workshop for Ph.D. students and postdocs in conjunction with NecSys'10.
The project made significant contributions to educational activities mainly through new postgraduate courses (e.g. at KTH on Principles of Wireless Sensor Networks) as well as several dedicated summer schools (4th HYCON2 PhD School on Control of Networked and Large-Scale Systems; 31th International Summer

School in Automatic Control; 5th Summer School on Applications of Smart and Connected Devices; Sidra PhD School on Distributed Optimization and Game Theory).
A set of roadmaps was developed to explore usage and applications areas covered by the test cases (autonomous underwater vehicles and distributed smart camera surveillance systems). This public report provides a high level analysis of the current state of the art in the context of C4E and plots the future development of their technical issues setting more competitive and realistic targets for the development work and the commercial exploitation.
Videos illustrating some of the concepts investigated were produced and are publically available (on the project's website http://feednetback.eu/public-deliverables or youtube).
The project operated an interest group members of which received selected e-alerts about relevant activities and results.

Exploitation of results

The foundations for exploitation by the project participants were laid early in the project by developing a series of confidential reports including an IP Landscape Report; a report on Emerging Applications and the Exploitation Plan. These reports informed the project participants on the IP rights claimed by competitors in the fields of the projects, promising applications beyond those investigated as part of the two selected case studies namely intelligent building management; networked control of smart power distribution networks; road traffic monitoring and management; co-operative automotive systems; disaster prevention at nuclear power plants; and surveillance with networked aerial and underwater autonomous vehicles. The exploitation plan summarised the exploitation options considered by the FeedNetback participants. The exploitation of project results is to be realised at three levels:
Level 1: academic participants to incorporate the new knowledge acquired in courses that aim to train new engineers capable of designing and operating the new generation of networked control systems that industry requires.
Level 2: academic and industrial participants to utilize the experiences from feasibility studies and keep operating the facilities developed in the context of the project (testbeds, demonstrators) to enhance their algorithms and tools. The results will be used primarily for demonstration purposes to encourage other researchers and system designers to use the FeedNetback framework in follow on projects.
Level 3: industrial participants to prepare for market launch products based on components designed and developed during the project. In terms of a timeline, first products are expected in video surveillance, followed by motion capture and AUVs.

4.1 Final publishable summary report

4.1.5 Address of the project public website, and contact details

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http://feednetback.eu

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4.1 Use and dissemination of foreground

Section A (public)

NO.	Title	Main author	Title of the periodical or the series	Publisher	Place of publication	Year of publication	Relevant pages	Open Access provided?
1	A Bayesian approach to sparse dynamic network identification	A. Chiuso	Automatica			2011		N
2	A Distributed Information Fusion Method for Localization Based on Pareto Optimization	A. De Angelis	Proc. of IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS '11)		Barcelona, Spain	June 2011		N
3	A distributed Kalman smoother	B. Bell	1st IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'09)		Venice Italy	40057		N
14	A Framework for Robust Synchronization in Heterogeneous Multi--Agent Networks	E. Lovisari	Conference on Decision and Control CDC 2011			2011		N
15	A functional-based approach for robust stability analysis of linear impulsive systems - Beyond monotonically decreasing Lyapunov functions	C. Briat	Systems and Control Letters					N
6	A generalized Markov model for an effective analysis of slotted IEEE 802.15.4	P. Park	IEEE International Conference on Mobile Ad-hoc and Sensor Systems		Macau SAR, P.R.C.	2009		N
7	A Generalized Utility Maximization Problem with Outage Constraints in CDMA Networks	C. Fischione	Proc. of IFAC Workshop on Distributed Estimation and Control in Networked Systems (IFAC NecSys)		Annecy, France	40422		N
8	A gossip-like distributed optimization algorithm for reactive power flow control	S. Bolognani	Proceedings of IFAC WC 2011			2011		N
9	A integration framework for control/communication/computation (3C) co-design with application in fleet control of	A. Farhadi	Conference on Decision and Control and European Control Conference		Orlando, CO, USA	Dec. 2011		N

	AUVs							
10	A Lie Bracket Approximation for Extremum Seeking Vehicles	H-B Durr	Proc. 18th IFAC World Congress		Milan, Italy	Aug-11		N
11	A linear dynamic model for microgrid voltages in presence of distributed generation	S. Bolognani	First International Workshop on Smart Grid Modeling and Simulation (at SmartGridComm 2011)			2011		N
12	A majorization inequality and its application to distributed Kalman filtering	S. Del Favero	Automatica			2011	2438-2443	N
13	A method for testing AQM controllers with probability guaranteed properties	J.M. Maestre	World Congress on Engineering 2010		London, UK	Jun-Jul 2010		N
14	A new kernel-based approach for linear system identification	G. Pillonetto	Automatica				46(1):81–93	N
15	A new kernel-based approach for nonlinear system identification	G. Pillonetto,	IEEE Transactions on Automatic Control			2011		N
16	A nonlinear model predictive control scheme with multirate integral sliding mode	M. Rubagotti	8th IFAC Symposium on Nonlinear Control Systems (NOLCOS 2010)		Bologna, Italy	Sep-10		N
17	A novel stability analysis of linear systems under asynchronous samplings	Alexandre Seuret	Automatica			2010		N
18	A Nyquist criterion for synchronization in networks of heterogeneous linear systems	Enrico Lovisari	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France	Sept. 2010		N
19	A PI consensus controller with gossip communication for clock synchronization in wireless sensors networks	S. Bolognani	Proceedings of the IFAC Workshop on Estimation and Control of Networked Systems (NecSys09)					N
20	A resistance-based approach to consensus algorithm performance analysis	E. Lovisari	MTNS 2010					N
21	A resistance-based approach to performance analysis of the consensus algorithm	E. Lovisari	Conference on Decision and Control CDC 2010			2010		N
22	A robust explicit nonlinear MPC controller with input-to-state stability guarantees	D. M. Raimondo	18th IFAC World Congress		Milano, Italy	2011		N
23	A Robust Filter and Controller Design for NCS with Uncertainties and Data Dropouts	I. Jurado	9th IEEE International Conference on Control & Automation (IEEE ICCA'11)		Santiago, Chile	Dec-11		N
24	A Scalable Robust Stability Criterion for Systems with Heterogeneous LTI Components	Ulf T. Jönsson	IEEE Transactions on Automatic Control					N
25	A Sensor Fusion Algorithm for Cooperative Localization	A. De Angelis	Proc. of IFAC World Congress		Milan, Italy	Aug 2011		N
26	A set theoretic method for verifying feasibility of a fast explicit nonlinear Model Predictive Controller	D. M. Raimondo	Springer book documenting the LCCC Theme Semester			2011		N
27	A stochastic reachability framework for autonomous surveillance with pan-tilt-zoom cameras	N. Kariotoglou	50^{th} IEEE Conference on Decision and Control		Orlanda, USA	Dec 2011		N

28	A tracking algorithm for PTZ cameras	D.M. Raimondo	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France			N
29	A two-tier control architecture for nonlinear process systems with continuous/asynchronous feedback	J. Liu	International Journal of Control			2010	83(2):257–272	N
30	Adaptación del Simulador Opnet para Aplicaciones de Control Industrial con Tecnología 802.11.	J. Jimenez	IX Jornadas de Ingeniería Telemática 2010 (JITEL 2010)		Valladolid, Spain	2010	345-352	N
31	Adaptive Delta Modulation in Networked Controlled Systems With bounded Disturbances	F. Gómez-Estern	IEEE Transactions on Automatic Control			Jan-11	129-134	N
32	Adaptive IEEE 802.15.4 Communication Protocol for Control and Monitoring Applications	P. Park	Wireless Based Network Control, Springer, Chapter 9			April 2011.	203-237	N
33	Adaptive IEEE 802.15.4 Protocol for energy efficient, reliable, and timely communications	P. Park	International Conference on Information Processing in Sensor Networks		Stockholm, Sweden	2010		N
34	Adaptive observer design under low data rate transmission with applications to oil well drill-string	Rafael Barreto-Jijon	Proceeding of the IEEE American Control Conference 2010		Baltimore, Maryland, USA	2010		N
35	Adaptive selftriggered control over IEEE 802.15.4 networks	U Tiberi	IEEE Conference on Decision and Control		Atalnta, Giorgia, USA	2010		N
36	Affine dwell-times characterization for uncertain linear impulsive systems	C. Briat	IEEE Transactions on Automatic Control					N
37	An adaptive IEEE 802.15.4 protocol for reliable and timely communications	P. Park	IEEE Transactions on Networking			2009		N
38	An Adaptive IEEE 802.15.4 Protocol for Reliable and Timely Communications	P. Park	IEEE Transactions on Parallel and Distributed Systems,			2011		N
39	An iterative decentralized MPC algorithm for large-scale nonlinear systems	Davide M. Raimondo	1st IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'09)		Venice Italy			N
40	An LFR approach to varying sampling control design for LPV systems with application to AUVs	Émilie Roche	ACC 2012					N
41	An optimal control L2-gain disturbance rejection design for networked control systems	P. Millán	Proceedings of the American Control Conference		Baltimore, Maryland, USA			N
42	Analog Distributed Source–Channel Coding Using Sinusoids	Johannes Karlsson	6th International Symposium on Wireless Communication Systems (ISWCS)		Siena-Tuscany, Italy			N
43	Analysis and Development of Consensus based Estimation Schemes	S. Del Favero	PhD thesis, Università di Padova		Italy			N
44	Analysis of a distributed algorithm for 3D reconstruction in large camera networks	A. Masiero	ACC2012 - American Control Conference			2012		N

45	Analytical Modeling of Multi-hop IEEE 802.15.4 Networks	P. Di Marco	IEEE Transactions on Vehicular Technology.			2011		N
46	Analytical modelling of IEEE 802.15.4 for multi-hop networks with heterogeneous traffic and hidden terminal	P. Di Marco	IEEE Global Telecommunication Conference		Miami, Florida, USA	2010		N
47	Analytical Modelling of IEEE 802.15.4 for Multi-hop Networks with Heterogeneous Traffic and Hidden Terminal	P. Di Marco	Proc. of IEEE Global Telecommunications Conference 2010, (IEEE Globecom 10)		Miami, Florida, USA	December 2010		N
48	Anytime reliable transmission of continuous information through digital noisy channels	G. Como	Siam Journal on Control and Optimization			2010	48(6):3903–3924	N
49	Anytime Source Transmission using UEP-LT Channel Coding	Shirazinia, A	17th European Wireless Conference 2011		Vienna, Austria	April 27-29, 2011	257-262	N
50	Application of Network-based Robust Control to a Personal Pendulum Vehicle	J. Arriaga	10th EUCA European Control Conference (ECC09)		Budapest, Hungary	40026		N
51	Asynchronous Control of Unstable Linear Systems via L2-gain-based Transformations	M. Lopez-Martinez	14th IEEE International Conference on Emerging Technologies and Factory Automation			40057		N
52	Asynchronous networked control of linear systems via l2-gain-based transformations: Analysis and synthesis	J. M. Cano	IET Control Theory and Applications			2010		N
53	Automatic generation of discrete handlers of real-time continuous control tasks	Soufyane Aboubekr	IFAC World Congress 2011		Milano, Italy	Sept-11		N
54	Auto-tuning procedures for distributed nonparametric regression algorithms	D. Varagnolo	American Control Conference (ACC12)			2012		N
55	Average consensus on digital noisy networks	R. Carli	Proceedings of 1st IFAC Workshop on Estimation and Control of Networked Systems (NecSys09)			2009	36–41	N
56	Average TimeSynch: a consensus-based protocol for time synchronization in wireless sensor networks	L. Schenato	1st IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'09)		Venice Italy			N
57	Average timesynch: a consensus-based protocol for time synchronization in wireless sensor networks	L. Schenato	Automatica			2011	1878-1886	N
58	Bayesian learning of probability density functions: a Markov chain Monte Carlo approach	S. Del Favero	American Control Conference (ACC12)			2012		N
59	Bayesian on-line multi-task learning of Gaussian processes	G. Pillonetto	IEEE Transactions on Pattern Analysis and Machine Intelligence			2010	193-205	N
60	Breath: a self-adapting protocol for timely and reliable data transmission in wireless sensor networks.	P. Park	IEEE Transactions on Mobile Computing, Vol. 6. N. 6,			June 2011	821-838	N

61	Chapter: Distributed estimation and control applications using linear consensus algorithms	F. Garin	Lecture notes on control and information sciences, Springer			2011		N
62	Closed-Loop Stabilization Over Gaussian Interference Channel	A. A. Zaidi	IFAC World Congress 2011		Milano, Italy	Sept, 2011	14429-14434	N
63	Coding of streaming sources for the bidirectional broadcast channel	Tobias J. Oechtering	5th International ICST Conference on Communications and Networking					N
64	Collaborative Estimation of Gradient Direction by a Formation of AUVs	Lara Briñon Arranz	5th International ICST Conference on Performance Evaluation Methodologies and Tools 2011		Cachan, France	May 2011		N
65	Collaborative Estimation of Gradient Direction by a Formation of AUVs under Communication Constraints	Lara Briñon Arranz	50th IEEE Conference on Decision and Control, held jointly with the European Control Conference		Orlando, USA	Dec 2011		N
66	Commande Linéaire à ParamètresVariants discrète à échantillonnage variable : application à un sous-marin autonome	Émilie Roche	PhD dissertation		Grenoble University, France	Sept-11		N
67	Consensus based estimation of anonymous networks size using Bernoulli trials	D. Varagnolo	American Control Conference (ACC12)			2012		N
68	Consensus of double integrator multi-agents under communication delay	Alexandre Seuret	8th IFAC Workshop on Time Delay Systems		Sinaia, Romania			N
69	Consensus under communication delays	Alexandre Seuret	47th IEEE Conference on Decision and Control		Cancun, Mexico			N
70	Consensus–based distributed sensor calibration and least–square parameter identification in WSNs	Saverio Bolognani	International Journal of Robust and Nonlinear Control					N
71	Continuous-time double integrator consensus algorithms improved by an appropriate sampling	Gabriel Rodrigues de Campos	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France			N
72	Contraction control of a fleet circular formation of AUVs under finite communication range	Lara Briñon Arranz	Proceedings of the American Control Conference		Baltimore, Maryland, USA	June-July 2010		N
73	Control Óptimo-L2 Basado en Red Mediante Funcionales de Lyapunov-Krasovskii	P. Millán	Revista Iberoamericana de Informática y Automática Industrial					N
74	Control over a hybrid MAC wireless network	J. Araujo	IEEE SmartGridComm			2010		N
75	Contrôle distribué de la symétrie d'une formation multi-agent: une approche alternative	G. Rodrigues de Campos	IEEE Conférence Internationale Francophone en Automatique (CIFA)		Grenoble, France			N
76	Convex vs nonconvex approaches for sparse estimation: Lasso, Multiple Kernel Learning and Hyperparameter Lasso	A. Aravkin	Conference on Decision and Control CDC 2011					N
77	Decentralized task assignment in camera networks	A. Cenedese	Conference on Decision and Control CDC10		Atlanta, Georgia, USA	Dec. 2010		N

78	Delay-dependent robust stability analysis for systems with interval delays	L. Orihuela	Proceedings of the American Control Conference		Baltimore, Maryland, USA			N
79	Delta-Modulation Coding Redesign for Feedback Controlled Systems	C. Canudas-de-Wit	IEEE Trans. on Industrial Electronics					N
80	Design and application of suboptimal mixed H2/H∞ controllers for networked control systems	P. Millán	IEEE Transactions on Control System Technology					N
81	Design of UEP-based MSE-minimizing rateless codes for source-channel coding	Shirazinia, A	Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on		Prague, Czech Republic	May 22-27, 2011	3144-3147	N
82	Design Principles of Wireless Sensor Networks Protocols for Control Applications	C. Fischione	Springer, Chapter 11				271-299	N
83	Distortion Bounds on Anytime Source Transmission Using UEP Channel Coding	Shirazinia, A	19th European Signal Processing Conference (EUSIPCO 2011)		Barcelona, Spain	Aug 29-Sep 2, 2011	2089-2093	N
84	Distributed averaging on digital erasure networks	R. Carli	Automatica			Jan. 2011	vol. 47, no.1, pp. 115-121	N
85	Distributed averaging on digital noisy networks	R. Carli	6th ITA Workshop (invited paper)		San Diego, CA, USA	Feb. 2011		N
86	Distributed change detection based on a consensus algorithm	S. S. Stankovic	Proc. 2nd IFAC Workshop on Distr. Estim. Contr. Networked Systems (NecSys)		Annecy France			N
87	Distributed Change Detection Based on a Consensus Algorithm	S. S. Stankovic	IEEE Trans. On Signal processing			2011		N
88	Distributed collision avoidance for interacting vehicles: a command governor approach	F. Tedesco	2st IFAC Workshop on Distributed Estimation and Control in Networked Systems (Nec- Sys'10)		Annecy, France	Sept. 2010		N
89	Distributed consensus-based Bayesian estimation: sufficient conditions for performance characterization	D. Varagnolo	2010 American Control Conference		Baltimore, MD, USA			N
90	Distributed control for optimal reactive power compensation in smart microgrids	S. Bolognani	Conference on Decision and Control CDC 2011					N
91	Distributed estimation over unknown fading channels	Alain Kibangou	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France			N
92	Distributed Estimation through Randomized Gossip Kalman Filter	Simone Del Favero	48th IEEE Conference on Decision and Control 2009		Shanghai, China			N
93	Distributed event-based observers for LTI networked systems	P. Millán	Proceedings of the American Control Conference		Montreal, Canada	2012		N
94	Distributed Function and Time Delay Estimation using Nonparametric Techniques	Damiano Varagnolo	48th IEEE Conference on Decision and Control		Shanghai, China			N

95	Distributed hierarchical MPC for conflict resolution in air traffic	Georgios Chaloulos	American Control Conference		Baltimore, Maryland, USA			N
96	Distributed Khatri-Rao space-time coding and decoding for cooperative networks	A.Y. Kibangou	Proc. EUSIPCO 2011		Barcelona, Spain	Aug.-Sept 2010	809-813	N
97	Distributed Model Predictive Control for Hierarchical Systems in Air Traffic Control	Georgios Chaloulos	American Control Conference		Baltimore, Maryland, USA	Jun-Jul, 2010		N
98	Distributed Model Predictive Control of Nonlinear Process Systems	Jinfeng Liu	American Institute of Chemical Engineers Journal				vol. 55, pp. 1171-1184	N
99	Distributed model predictive control of nonlinear systems subject to asynchronous and delayed measurements	J. Liu	Automatica			2009	46(1):52–61	N
100	Distributed model predictive control of nonlinear systems subject to delayed measurements	J. Liu	Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference		Shanghai, P.R. China	2009	7105–7112	N
101	Distributed parametric and nonparametric regression with on-line performance bounds computation	D. Varagnolo	Automatica			2011		N
102	Distributed Parametric-Nonparametric Estimation in Networked Control Systems	D. Varagnolo	PhD thesis, Università di Padova			2011		N
103	Distributed Partitioning Strategies for Perimeter patrolling	R. Carli	American Control Conference (ACC11)					N
104	Distributed perimeter patrolling and tracking for camera networks	M. Baseggio	Conference on Decision and Control CDC10		Atlanta, USA	2010		N
105	Distributed Positioning of Autonomous Mobile Sensors with Application to Coverage Control	H-B Durr	Proc. American Control Conference		San Francisco, CA, USA	Jun-11	4822-4827	N
106	Distributed quasi-Newton method and its application to the optimal reactive power flow problem	S. Bolognani	Proceedings of NECSYS 2010		Annecy, France			N
107	Distributed seeking of {N}ash equilibria in mobile sensor networks	M. S. Stankovic	Proc. IEEE Conf. Decision and Control		Atlanta, Georgia, US	Dec-10	5598-5603	N
108	Distributed seeking of {N}ash equilibria with applications to mobile sensor networks	M. S. Stankovic	IEEE Trans. On Automatic Control			2011		N
109	Distributed size estimation in anonymous networks	D. Varagnolo	IEEE Transactions on Automatic Control			2011		N
110	Distributed statistical estimation of the number of nodes in sensor networks	D. Varagnolo	Conference on Decision and Control CDC10		Atlanta, Georgia, USA			N
111	Distributed synchronization of noisy non-	R. Carli	IEEE Transactions on Automatic Control			2011		N

	identical double integrators							
112	Doppler estimation and data detection for underwater acoustic ZF-OFDM receiver	A.Y. Kibangou	Proc. of IEEE Int. Symposium on Wireless Communication Systems (ISWCS) 2010		York, UK			N
113	Duty-cycle Analytical Modelling and Optimization in Unslotted IEEE 802.15.4 Wireless Sensor Networks	C. Fischione	IEEE Transactions on Networking					N
114	Dwell-time adaptive delta modulation signal coding for networked controlled systems	J. Jaglin	IEEE Transactions on Automatic Control					N
115	Elastic Formation Control Based on Affine Transformations	Lara Briñon Arranz	Proceedings American Control Conference 2011		San Francisco, CA, USA	June 2011		N
116	Electricity market strategies for wind energy producers with co-located storage	E. Bitar	Conference on Decision and Control CDC10		Atlanta, Georgia, USA			N
117	Encoder-controller design for control over the binary input Gaussian	L. Bao	2010 International Symposium on Information Theory and its Application & 2010 International Symposium on spread Workshop on Factory Communication Systems		Taichung, Taiwan		23-28	N
118	Energy-aware consensus algorithms in networked sampled systems	M. Lopez-Martinez	2nd IFAC Workshop on Distributed Estimation and Control in Networked Systems		Annecy, France			N
119	Energy-Aware Consensus For Networked Sampled MIMO Systems	M. Lopez-Martinez	18th IFAC World Congress		Milan, Italy	2011		N
120	Energy-aware wireless networked control using radio-mode management	Nicolas Cardoso de Castro	2012 American Control Conference		Montréal, Canada	June 2012		N
121	Event-based sampling algorithms based on a Lyapunov function	A. Seuret	Conference on Decision and Control and European Control Conference		Orlando, CO, USA			N
122	Experimental validation of a localization system based on a heterogeneous sensor network	J. Araujo	7th Asian Control Conference 2009		Hong Kong			N
123	Exponential stability and stabilization of sampled-data systems with time-varying period	Alexandre Seuret	9th IFAC Workshop on Time Delay Systems		Prague, Czech Republic	2010		N
124	Fast computation of smoothing splines subject to equality constraints	G. Pillonetto	Automatica			2009	45:2842 –2849	N
125	Fast explicit nonlinear model predictive control via multiresolution function approximation with guaranteed stability	S. Summers	8th IFAC Symposium on Nonlinear Control Systems (NOLCOS 2010)		Bologna, Italy	Sept. 2010		N
126	Fast-Lipschitz Optimization with Wireless Sensor Networks Applications	C. Fischione	Proc. of ACM/IEEE International Conference on Information Processing in Sensor Networks 2011, (ACM/IEEE IPSN 11)		Chicago, IL, USA	April 2011.		N

127	Finite-time average consensus based protocol for distributed estimation over AWGN channels	A.Y. Kibangou	Proc. IEEE International Conference on Decision and Control (CDC) 2011		Orlando, Florida, USA	Dec. 2011		N
128	F-Lipschitz optimization with wireless sensor networks applications	C. Fischione	IEEE Transactions on Automatic Control			2010		N
129	Formation Control via Distributed Optimization of Alignment Error	Brandon J. Moore	48th IEEE Conference on Decision and Control 2009		Shanghai, China			N
130	General framework using affine transformations to formation control design	Lara Briñon Arranz	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France			N
131	Gossip algorithms for distributed ranking	A. Chiuso	American Control Conference (ACC11)					N
132	Gossip algorithms for simultaneous distributed estimation and classification in sensor networks	A. Chiuso	IEEE Journal of Selected Topics in Signal Processing			2011		N
133	Gossip consensus algorithms via quantized communication	R. Carli	Automatica 2010			2010	46:70–80	N
134	Hankel-Norm-Based Lumping of Interconnected Linear Systems	H. Sandberg	In Proceedings of MATHMOD 2009		Vienna, Austria			N
135	How to Select the OOK Modulation Detection Threshold in Wireless Ad Hoc and Sensor Networks	M. D'Angelo	Proc. of IEEE 67th Vehicular Technology Conference - Spring 2009 (IEEE VTC Spring 09)		Barcelona, Spain			N
136	HYBRID GREEDY PURSUIT	Saikat Chatterjee	19th European Signal Processing Conference (EUSIPCO 2011)		Barcelona, Spain	Aug 29-Sep 2, 2011	343-347	N
137	Improved Consensus Algorithms using Memory Effects	G. Rodrigues de Campos	Conference on Decision and Control and European Control Conference		Orlando, CO, USA			N
138	Improved delay-dependent stability for uncertain networked control systems with induced time-varying delays	P. Millan	1st IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'09)		Venice Italy			N
139	Improved delay-dependent stability for uncertain networked control systems with induced time-varying delays	P. Millán	1st IFAC Workshop on Estimation and Control of Networked Systems		Venice, Italy			N
140	Improved stability analysis of networked control systems under asynchronous sampling and input delay	Wenjuan Jiang	2nd IFAC Workshop on Estimation and Control of Networked Systems (NecSys'10)		Annecy, France			N
141	Improving TCP Performance during the LTE Handover	D. Pacifico	IEEE Global Telecommunications Conference 2009, (IEEE Globecom 09)		Honolulu, Hawaii, USA			N
142	Information fusion strategies and performance bounds in packet-drop networks	A. Chiuso	Automatica 2010			2011		N
143	Iterative encoder–controller design based on approximate dynamic programming	L. Bao	2010 IEEE International Workshop on Signal Processing Advances for Wireless		Marrakech, Morocco			N

			Communications					
144	Iterative encoder–controller design for feedback control over noisy channels	L. Bao	IEEE Transactions on Automatic Control Volume : 56 , Issue:2			40575	265 - 278	N
145	Iterative source-channel coding approach to Witsenhausen's counterexample	Karlsson Johannes	ACC 2011		San Francisco, CA, USA	June 29-July 1 2011	5348-5353	N
146	Iterative source-channel coding approach to Witsenhausen's counterexample	Karlsson, Johannes	Automatica					N
147	Joint channel and doppler estimation for multicarrier underwater communications	A.Y. Kibangou	Proc. of IEEE Int. Conf. on Acoustics, Speech, and Signal Processing (ICASSP) 2010		Dallas, Tx, USA		5630–5633	N
148	Learning sparse dynamic linear systems using stable spline kernels and exponential hyperpriors	A. Chiuso	NIPS, 2010			2010		N
149	LFT/Hinf varying sampling control for autonomous underwater vehicles	Emilie Roche	4th IFAC Symposium on System, Structure and Control		Italie Ancona	2010		N
150	Localization of an underwater source flow by a fleet of AUVs supervised by an ASV	A. Farhadi	American Control Conference, Montreal, June 2012		Montréal, Canada	June 2012		N
151	Look ahead orthogonal matching pursuit	Chatterjee, Saikat	Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on		Prague, Czech Republic	May 22-27, 2011	4024-4027	N
152	Low density wireless sensors networks for localization and tracking in critical environments	A. Cenedese	IEEE Transactions on Vehicular Technology			2010		N
153	LPV/Hinf based Varying Sampling Control of an AUV	Émilie Roche	IFAC World Congress 2011		Milano, Italy	Sept-11		N
154	LQG and Medium Access Control	Chithrupa Ramesh	1st IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'09)		Venice, Italy			N
155	Lyapunov-Krasovskii functionals parameterized with polynomials	Alexandre Seuret	IFAC ROCOND 2009		Haifa, Israel			N
156	MAC Protocol Engine for Sensor Networks	S. Coleri-Ergen	IEEE Global Telecommunications Conference 2009, (IEEE Globecom 09)		Honolulu, Hawaii, USA			N
157	Mean square performance of consensus-based distributed estimation over regular geometric graphs	F. Garin	Siam Journal on Control and Optimization					N
158	Mean-square boundedness of stochastic networked control systems with bounded control inputs	D. Chatterjee	IEEE Conference on Decision and Control		Atlanta, USA			N
159	Medium Access Control Analytical Modeling and Optimization in Unslotted IEEE 802.15.4 Wireless Sensor Networks	C. Fischione	Proc. of Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks		Rome, Italy			N

			(IEEE SECON 09)					
160	Methods and applications in networked control Feedback control design for quantum system	S. Bolognani	PhD thesis, Università di Padova			2011		N
161	MIMO Bidirectional Broadcast Channels with Common Message	Wyrembelski, R.F.	GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference		Miami, FL	6-10 Dec. 2010	1-5	N
162	Mixed H2/H∞ control for discrete-time delayed systems: application to networked systems	L. Orihuela	Optimal Control Applications and Methods					N
163	Mixed H2/H∞ robust control approach for NCS with uncertainties and data dropouts	I. Jurado	18th IFAC World Congress		Milano, Italy			N
164	Mobile Node Localization with Orientation, Speed, and Ranging Information	A. De Angelis	IEEE Transactions on Signal Processing,			2011		N
165	Modeling Cross-Layer Interactions of IEEE 802.15.4 Wireless Networks in Cyber Physical Systems	P. Di Marco	IEEE Transactions on Parallel and Distributed Systems,			2011		N
166	Monitoring and handling of actuator faults in a distributed model predictive control system	D. Chilin	Proceedings of the American Control Conference		Baltimore, Maryland, USA			N
167	Monitoring and handling of actuator faults in two-tier control systems for nonlinear processes	J. Liu	Chemical Engineering Science			2010	65(10):3179–3190	N
168	Multidimensional Newton-Raphson consensus for distributed convex optimization	F. Zanella	American Control Conference (ACC12)			2012		N
169	Multiple Access with attention-based tournaments for monitoring over wireless networks	Chithrupa Ramesh	European Control Conference (ECC'09)		Budapest, Hungary			N
170	Network Estimation and Packet Delivery Prediction for Control over Wireless Mesh Networks	Phoebus Chen	Proc. 18th IFAC World Congress		Milan, Italy	Aug 2011		N
171	Networked control under time-synchronization errors	Alexandre Seuret	8th IFAC Workshop on Time Delay systems		Sinaia, Romania			N
172	Networked control: taking into account sample period variations and actuators saturation	A.Seuret	IFAC World Congress		Milano, Italy			N
173	Networked monitoring and fault-tolerant control of nonlinear process systems	B. J. Ohran	Joint 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference		Shanghai, P.R. China	2009	4117–4124	N
174	Newton-Raphson consensus for distributed convex optimization	F. Zanella	Conference on Decision and Control CDC 2011					N

175	Nonlinear Distributed Sensing for Closed-Loop Control Over Gaussian Channels	Mattias Andersson	IEEE Swedish Communication Technologies Workshop		Stockholm, Sweden	19-21 October 2011		N
176	Nonparametric sparse estimators for identification of large scale linear systems	A. Chiuso	Proc. of 2010 IEEE CDC			2010		N
177	Observers in Model-Based Networked Control System under Parametric Uncertainties	L. Orihuela	Conference on Control Applications (CCA-09), 3rd IEEE Multi-conference on Systems and Control (MSC 2009),		Saint Petersburg, Russia			N
178	On the Dual Effect in State-based Scheduling of Networked Control Systems	Chithrupa Ramesh	Proc. American Control Conference		San Francisco, CA, USA	June, 2011		N
179	On energy-aware communication and control co-design in wireless network controlled systems	Nicolas Cardoso de Castro	2nd IFAC Workshop on Estimation and Control of Networked Systems, NecSys'10		Annecy France	2010		N
180	On Optimal Policies for Control and Estimation Over a Gaussian Relay Channel	A. A. Zaidi	IEEE CDC 2011		Orlando, FL	Dec, 2011		N
181	On Optimal Policies for Control and Estimation Over a Gaussian Relay Channel	A. A. Zaidi	Automatica			October 2011		N
182	On stochastic model predictive control with bounded control inputs	P. Hokayem	Proceedings of the combined 48th IEEE Conference on Decision & Control and 28th Chinese Control Conference			2009	6359–6364	N
183	On Stochastic Receding Horizon Control with Bounded Control Inputs	Peter Hokayem	IEEE Conference on Decision and Control		Shanghai, China	2009		N
184	On the capacity of a channel with action-dependent state and reversible input	Kittichokechai, K.;	IEEE International Symposium on Information Theory (ISIT) 2011		St. Petersburg, Russia	July 31 - Aug. 5 2011	331 – 335	N
185	On the discardability of data in Support Vector Classification problems	S. Del Favero	Conference on Decision and Control CDC 2011					N
186	On the graph building problem in camera networks	A. Cenedese,	IFAC Workshop on Distributed Estimation and Control in Networked Systems (Necsys'10)			2010		N
187	On the sample complexity of probabilistic analysis and design methods	T. Alamo	Lecture Notes in Control and Information Sciences, Preliminary entry 399. Springer.					N
188	On the Sample Complexity of Randomized Approaches to the Analysis and Design Under Uncertainty	T. Alamo	Proceedings of the 2010 American Control Conference. Baltimore. USA. 2010. Pag. 4671-4677					N
189	On triangulation algorithms in large scale camera network systems	A. Masiero	ACC2012 - American Control Conference			2012		N
190	Optimal networked control of a 2 degree-of-freedom direct drive robot manipulator	L. Orihuela	International Conference on Emerging Techonologies and Factory Automation		Bilbao, Spain	40422		N
191	Optimal Sampling Time for Consensus in Time-Delayed Networked Systems	M. Lopez-Martinez	IET Control Theory and Applications			2011		N
192	Optimal strategies in the average consensus	R. Carli	Systems & Control Letters			2009	58:759–	N

	problem						765	
193	Optimal Synchronization for Networks of Noisy Double Integrators	R. Carli	IEEE Transactions on Automatic Control					N
194	Optimized analog network coding strategies for the white Gaussian multiple-access relay channel	Ali A. Zaidi	IEEE Information Theory Workshop					N
195	Optimized Rate Allocation for State Estimation over Noisy Channels	Lei Bao	Proceedings IEEE International Symposium on Information Theory					N
196	Peer-to-Peer Estimation over Wireless Sensor Networks via Lipschitz Optimization	C. Fischione	Proc. of ACM/IEEE International Conference on Information Processing in Sensor Networks 2009, (ACM/IEEE IPSN 09)		San Francisco, CA, USA			N
197	Performance Analysis of a Peer-to-Peer Estimator over Wireless Sensor Networks via Lipschitz Optimization	C. Fischione	IEEE Transactions on Signal Processing					N
198	Performance analysis of different routing protocols in wireless sensor networks for real-time estimation	Damiano Varagnolo	47th IEEE Conference on Decision and Control		Cancun, Mexico			N
199	Performance Analysis of GTS Allocation in Beacon Enabled IEEE 802.15.4	P. Park	Sixth Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (IEEE SECON 09)		Rome, Italy			N
200	Performance Analysis of the IEEE 802.15.4 Hybrid Medium Access Control Protocol	P. G. Park	ACM Transactions on Sensor Networks.			2011		N
201	Performance bounds for information fusion strategies in packet-drop networks	A. Chiuso	10th EUCA European Control Conference (ECC09)		Budapest, Hungary			N
202	Performance metrics in the average consensus problem: a tutorial	E. Lovisari	Annual reviews on Control			2011		N
203	Performance metrics in the consensus problem: a survey	E. Lovisari	4th IFAC Symposium on System, Structure and Control					N
204	Performance of consensus algorithms in large-scale distributed estimation	F. Garin	European Control Conference			2009		N
205	Prediction error identification of linear systems: a nonparametric Gaussian regression approach	G. Pillonetto	Automatica			2011		N
206	Primal and dual criteria for robust stability and their application to systems interconnected over a bipartite graph	Ulf T. Jönsson	2010 American Control Conference		Baltimore, MD, USA	40330		N
207	Probabilistic certification of pan-tilt-zoom camera surveillance systems	D. M. Raimondo	50th IEEE Conference on Decision and Control		Orlanda, USA	Dec 2011		N

208	Quadratic indices for the analysis of consensus algorithms	R. Carli	Proceedings of Information Theory and Applications Workshop			Feb 2009	96–104	N
209	Randomized strategies for probabilistic solutions of uncertain feasibility and optimization problems	T. Alamo	IEEE Transactions on Automatic Control			2009	Vol. 54 (11).	N
210	Rate allocation for closed-loop control over noisy channels.	L. Bao	IEEE International Symposium on Information Theory		Seoul, S. Korea	2009		N
211	Rate Allocation for Quantized Control over Noisy Channels	Lei Bao	IEEE Workshop on Control over Communication Channels (Concom 2009)		Seoul, South Korea			N
212	Rate allocation for quantized control over noisy channels	L. Bao	IEEE Conference on Decision and Control		Shanghai, China	2009		N
213	Rate allocation for quantized control over noisy channels	L. Bao	IEEE Transactions on Signal Processing			2010		N
214	Rate Allocation for Quantized Control over Noisy Channels	L. Bao	Automatica					N
215	Rate sufficient conditions for closed-loop control over AWGN relay channels	Ali A. Zaidi	Proc. IEEE International Conference on Control & Automation					N
216	Rate sufficient conditions for closed-loop control over half-duplex AWGN relay channels	Ali Abbas Zaidi	Reglermöte 2010					N
217	Rate-maximizing mappings for memoryless relaying	Ali A. Zaidi	2009 IEEE International Symposium on Information Theory		Seoul, Korea	39965		N
218	Real-time applications in 802.11 networks	J. Jimenez	WIRELESS COMMUNICATIONS AND MOBILE COMPUTING					N
219	Reducing Packet Loss Bursts in a Wireless Mesh Network for Stochastic Bounds on Estimation Error	Phoebus Chen	CDC-ECC 2011.		orlando, FL	December 2011		N
220	Regularized estimation of sums of exponentials in spaces generated by stable spline kernels	G. Pillonetto	ACC 2010		Baltimore, Maryland, USA			N
221	Robust control of autonomous underwater vehicles	Sébastien Varrier	Master's thesis, ENSE3 Master in Automatic Control, Systems & Information Technology		Grenoble INP, France			N
222	Robust model predictive control with integral sliding mode in continuous-time sampled-data nonlinear systems	M. Rubagotti	IEEE Transaction on Automatic Control			2010		N
223	Robust stability of nonlinear time-delay systems with interval time-varying delay	L. Orihuela	International Journal of Robust and Nonlinear Control			2010	21(7):709-724	N
224	Scheduled communication in sensor networks for stability and minimum variance	L. Orihuela	IEEE Transactions on Control System Technology					N
225	Self-Triggered Control of Multiple Loops over IEEE 802.15.4 Networks	U. Tiberi	Proc. of IFAC World Congress		Milan, Italy	August 2011		N

226	Self-Triggered Sampling Selection Based on Quadratic Programming	P. Millán	18th IFAC World Congress			2011		N
227	Sequential and iterative architectures for distributed model predictive control of nonlinear process systems. Part I: theory	J. Liu	Proceedings of the American Control Conference		Baltimore, Maryland, USA			N
228	Sequential and iterative architectures for distributed model predictive control of nonlinear process systems. Part II: Application to a catalytic alkylation of benzene process	J. Liu	Proceedings of the American Control Conference		Baltimore, Maryland, USA			N
229	Simultaneous distributed estimation and classification in sensor networks	A. Chiuso	IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys'10)			2010		N
230	SOS for sampled-data systems	A. Seuret	IFAC World Congress		Milano, Italy	40787		N
231	Source coding with common reconstruction and action-dependent side information	Kittipong Kittichokechai	IEEE Information Theory Workshop		Dublin, Ireland	Aug. 30 2010- Sept. 3 2010	1-5	N
232	Stability analysis for sampled-data systems with a time-varying period	Alexandre Seuret	48th IEEE Conference on Decision and Control 2009		Shanghai, China			N
233	Stability analysis of networked control systems with asynchronous sampling and input delay	A. Seuret	Proceedings of the American Control Conference		San Francisco, CA, USA			N
234	Stability analysis of sampled-data systems using Sum of Squares	A. Seuret	IEEE Transactions on Automatic Control					N
235	Stability and Performance of Networked Control Systems with Time-multiplexed Sensors and Oversampled Observer	L. Orihuela	18th IFAC World Congress		Milano, Italy	2011		N
236	Stability Criteria for Asynchronous Sampled-data Systems - A Fragmentation Approach	C.Briat	Proc. 18th IFAC World Congress		Milan, Italy	August 2011	1313-1318	N
237	Stability of Asynchronous Feedback-Interconnected Dissipative Systems	M. Lopez-Martinez	10th EUCA European Control Conference (ECC09)		Budapest, Hungary			N
238	Stabilization of neutral systems with saturating control inputs	J.M. Gomes Da Silva	International journal of Systems Science			2010		N
239	Stable stochastic receding horizon control of linear systems with bounded control inputs	P. Hokayem	International Symposium on Mathematical Theory of Networks and Systems (MTNS)		Budapest, Hungary			N
240	Static anti-windup synthesis for linear systems with time-varying input delays	V.F. Jeferson	IFAC World Congress		Milano, Italy			N
241	Steady State Performance Analysis of Multiple State-based Schedulers with CSMA	Chithrupa Ramesh	CDC-ECC 2011		orlando, FL	December 2011		N

242	Stochastic localization of sources using autonomous underwater vehicles	S. M. Huck	American Control Conference		Montreal, Canada	June 2012		N
243	Stochastic model predictive control with bounded control inputs: a vector space approach	Debasish Chatterjee	IEEE Transactions on Automatic Control (Journal)			2009		N
244	Stochastic MPC with imperfect state information and bounded controls	P. Hokayem	Proceedings of the UKACC International Conference on Control		Coventry, UK	2010		N
245	Stochastic MPC with output feedback and bounded control inputs	Peter Hokayem	American Control Conference		Baltimore, Maryland, USA	Jun-Jul, 2010		N
246	Stochastic MPC with output feedback and bounded control inputs	Peter Hokayem	Automatica (Journal)			2009		N
247	Stochastic receding horizon control with output feedback and bounded control inputs	P. Hokayem	IEEE Conference on Decision and Control		Atlanta, USA	Dec-10		N
248	Stochastic receding horizon control with output feedback and bounded controls	P. Hokayem	Automatica			2011		N
249	Stochastic Receding Horizon Control: Stability Results	Ashish Kumar Cherukuri	IFAC World Congress on Automatic Control		Milano, Italy			N
250	Suboptimal Explicit Hybrid MPC via Branch and Bound	D. Axehill	18^{th} IFAC World Congress		Milano, Italy			N
251	Sufficient conditions for closed-loop control over a general half-duplex white Gaussian relay channel	A. A. Zaidi	ACC 2011		San Francisco, CA, USA	June 29 - July 1 2011	2240-2245	N
252	Sufficient conditions for closed-loop control over multiple-access and broadcast channels	A. A. Zaidi	IEEE CDC 2010		Atlanta, USA	Dec, 2010	4771-4776	N
253	Sufficient Conditions for Stabilization in Feedback Control over Noisy Channels using Anytime Rateless Codes	Shirazinia	ACC 2012		Montreal, Canada	June 27-29, 2011		N
254	Sur la stabilité des systèmes linéaires impulsifs par fonctionnelles de Lyapunov	C. Briat	IEEE Conférence Internationale Francophone en Automatique (CIFA)		Grenoble, France			N
255	Taking into account period variations and actuators saturation in sampled-data systems	A.Seuret	Systems and Control Letters					N
256	To hold or to zero control inputs with lossy links	Luca Schenato	IEEE Transactions on Automatic Control					N
257	To use or not to use feedback channel in fleet control of AUVs supervised by an ASV	A. Farhadi	2012 American Control Conference		Montréal, Canada	June 2012		N
258	To zero or to hold control inputs with lossy links?	L. Schenato	IEEE Transactions on Automatic Control			2009	54:1093 –1099	N
259	Towards perfectly symmetric multi-agent deployment	G. Rodrigues de Campos	IEEE International Conference on Robotics and Automation (ICRA)		Minnesota, USA			N
260	Translation Control of a Fleet Circular Formation of AUVs under Finite	Lara Briñon Arranz	48th IEEE Conference on Decision and Control 2009		Shanghai, China	40148		N

	Communication Range							
261	TREnD: a timely, reliable, energy efficient, and dynamic WSN protocol for control applications	P. Di Marco	IEEE International Conference on Communications		Cape Town, South Africa	2010		N
262	Truetime extendido: un marco de simulación para el estudio de sistemas WNCS	J. Jimenez	X Jornadas de Ingeniería Telemática 2011 (JITEL 2011)		Santander, Spain		317-323	N
263	Unified Approach for the Design of H2/Hinf Controllers for Linear Time Delay Systems	L. Orihuela	IET Control Theory and Applications					N
264	Upper bound to error probability for coding on bidirectional broadcast channels	Tobias J. Oechtering	Proc. Int. Conf. on Telecommunications		Doha,Qatar	Apr-10	355-362	N
265	Utility Maximization via Power and Rate Allocation with Outage Constraints in Nakagami-Lognormal Channels	C. Fischione	IEEE Transactions on Wireless Communications, Vol. 10, N. 4,				1108-1120	N
266	Variable structure observer for discrete-time multi-output systems	L. Orihuela	12th International Workshop on Variable Structure Systems		Bombay, India	2012		N
267	Verification of consensus in networks of heterogeneous LTI agents	Ulf T. Jönsson	SICE 2010 annual conference		Taipei, Taiwan			N
268	Wireless networked control system: 802.11 performance analysis	J. Jiménez	9th Portuguese Conference on Automatic Control		Coimbra, Portugal			N
269	ZF OFDM receiver for underwater communications	Alain Kibangou	Proc. of Int. Symp. on Communications, Control, and Signal Processing (ISCCSP 2010)		Cyprus Lemesos	2010		N

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES							
NO	**Type of activity**	**Main leader**	**Title**	**Date**	**Place**	**Type of Audience**	**Size of Audience**
1	Workshop	UNIPD	Workshop in Lecce, Italy	01 September 2009	Lecce, Italy	Academia	20
2	Workshop	UNIPD	SIDRA Workshop	01 September 2009	Siracusa, Italy	Academia	100
3	Workshop	INRIA	8th IFAC Workshop on Time Delay Systems (TDS'09)	01 September 2009	Sinaia, Romania	Academia	100
4	Workshop	INRIA, ETH, KTH, US, UNIPD	1tst IFAC Workshop on Distributed Estimation and Control in networked systems (Necsys)	01 September 2009	Venice, Italy	Industry and Academia	80
5	Workshop	All	FeedNetback Workshop 2009	27 September 2009	Venice, Italy	Industry and Academia	40
6	Workshop	UNIPD	ERNSI Workshop 2009	30 Sept -2 Oct 2009	Stift Vorau, Austria.	Academia	35

7	Concertation meeting	INRIA	CLaSS Concertation meeting- Control of Large Scale Systems	01 October 2009	Brussels, Belgium	Industry, Academia, Government	50
8	Workshop	INRIA, ETH	International workshop on the impact of control: past, present, and future	01 October 2009	Berchtesgaden, Germany	Industry, Academia, Government	50
9	Workshop	ETH	IfA Open House (Presentations to prospective Ph.D. and master students. Feednetback (with also the cameras testbed) has been presented as part of the ongoing research)	27 November 2009	ETH, Zurich	Academia	50
10	Workshop	Vodera	MBDA Innovation Workshop	30 November 2009	Shrivenham, UK	Industry and Academia	60
11	Conference	UNIPD	48th IEEE Conference on Decision and Control 2009	01 December 2009	Shangai, China	Industry and Academia	2500
12	Conference	INRIA	48th IEEE conference on Decision and control (CDC)	01 December 2009	Shanghai, China	Academia and industry	450
13	Conference	KTH	IEEE 48th Conference on Decision and Control 2009 (IEEE CDC 09)	01 December 2009	Shanghai, China	Industry and Academia	3000
14	Course	UNIPD, KTH	Intensive Course on Distributed Optimization	01 February 2010	Stockholm, Sweden	Academia	50
15	Conference	UNIPD, KTH	Conference "Multi-agent Coordination & Estimation"	01 February 2010	Lund, Sweden	Academia	100
16	Symposium	INRIA	4th International Symposium on Communications, Control an d Signal Processing (ISCCSP)	01 March 2010	Lymassol, Cyprus	Academia	100
17	Conference	INRIA	35th IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)	01 March 2010	Dalla, Tx, USA	Academia and industry	450
18	Workshop	Vodera	National Aerospace Technology Strategy (NATS), Health Management and Prognostics National Technical Committee (HMaP NTC) Wireless Technologies projects workshop	04 March 2010	Bristol, UK	Industry	15
19	Exhibition	Vodera	Oceanology International	09 March 2010	London, UK	Industry and Academia	6500
20	Research visit	UNIPD	Research period at UCLA	24 February - 22 May 2010	UCLA - Los Angeles, CA, USA	Academia	20
21	Research visit	UNIPD	Meeting and seminar on multi-agent systems	3 May 2010	UCB - Berkeley, CA, USA	Academia	10
22	Research visit	UNIPD	Meeting and seminar on multi-agent systems	12 May 2010	UCSB - Santa Barbara, CA, USA	Academia	20

23	Workshop	INRIA	9th IFAC Workshop on Time Delay Systems (TDS'10)	01 June 2010	Prague, Czech	Academia	80
24	Concertation meeting	INRIA	CLaSS Concertation meeting on Control of Large-scale systems	01 June 2010	Brussels, Belgium	Industry, Academia, Government	80
25	Seminar	KTH	An Introduction to Wireless Sensor Networks seminar	02 June 2010	ICES center, Stockholm, Sweden	Academia	40
26	Seminar	ETH	Presentation of IfA laboratories to high school students (Educational out reach to high schools in Switzerland)	29 June 2010	ETH, Zurich	High school students	20
27	Conference	INRIA	American Conference on Control (ACC)	01 July 2010	Baltimore, Ma, USA	Academia and industry	300
28	Workshop	INRIA, UNIPD	Workshop "Algorithms and dynamics over networks"	01 July 2010	Torino, Italy	Academia	30
29	Seminar	UNIPD, KTH	An Overview on F-Lipschitz Optimization	21 July 2010	University of Padova, Italy	Academia	30
30	Exhibition	Vodera	Farnborough Airshow	21 July 2010	Farnborough, UK	Industry	1000+
31	Conference	KTH	9th ACM/IEEE International Conference on Information Processing in Sensor Networks	12-16 April, 2010	Stockholm, Sweden	Industry and Academia	180
32	Workshop	UNIPD	Workshop "Inverse problems in data driven modeling"	20 July -23July 2010	Linz, Austria	Academia	25
33	Symposium	ETH	Organized invited session on Nonlinear Model Predictive Control at the upcoming 8th IFAC Symposium on Nonlinear Control Systems (NOLCOS)	1-3 September 2010	Bologna, Italy	Industry and Academia	
34	Conferene	US, KTH, ETH, INRIA, UNIPD	Participated in the 48th IEEE Conference on Decision and Control	16-19 December 2009	Shanghai, China	Industry and Academia	2000
35	Conference	US	Jornadas de Automática 2009	9 Feb 2010 - 9 April 2010	Valladolid, Spain	Academia and Industry	400
36	Conference	KTH	IEEE International Conference on Communications	23-27 May, 2010	Cape Town, South Africa	Industry and Academia	2000
37	Conference	KTH	IEEE Global Communications Conference – GLOBECOM	2-5 December 2009	Honolulu, Hawaii	Industry and Academia	1500
38	Symposium	ETH	Participated in the 19th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2010)	5-9 July 2010	Budapest, Hungary	Industry and Academia	500
39	Symposium	ETH	Organized an invited session on Stochastic Model Predictive Control at the 19th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2010)	5-9 July 2010	Budapest, Hungary	Industry and Academia	30-40

40	Conference	KTH	6th IEEE International Conference on Mobile Ad Hoc and Sensor Systems – MASS	6-12 October 2009	Macao SAR, P.R.C	Industry and Academia	150
41	Conference	ETH	13 International Conference on Hybrid Systems: Computation and Control	April 12-16 2010	Stockholm, Sweden	Academia and industry	
42	Conference	US, KTH, ETH, INRIA, UNIPD	Participated in the American Control Conference ACC2010	June 30 - July 2, 2010	Baltimore, Maryland, USA	Industry and Academia	1500
43	Research visit	UNIPD	Research period at UCSB	Oct/Nov-09	Santa Barbara, California	Academia	10
44	Research visit	UNIPD	Research period at Massachuchetts Institute of Technology (MIT)	Oct-09 - Jan-10	Cambridge, Massachusetts, USA	Academia	15
45	Course	KTH	“Principle of Wireless Sensor Networks”, PhD course at KTH	September-November 2009	Stockholm, Sweden	Academia	15
46	Seminar	ETH	Presentation of Feednetback project to several guests (Professors, PhD applicants) at IfA		ETH, Zurich	Industry and Academia	30
47	Conference	US	Conference on Control Methodologies and Technology for Energy Efficiency		?	Academia and Industry	400
48	Conference	Vodera	Innovate 2010 Conference	12-Oct-10	London, UK	Academia, Industry, Government	1000
49	Seminar	Vodera	Presentation featuring FeedNetback at London Chambers of Commerce	08-Nov-10	London, UK	Industry, Government	60
50	Conference	Vodera	Energy Harvesting Dissemination Conference	07-Feb-11	London, UK	Academia, Industry	120
51	Seminar	ETH	Presentation of the work on Feednetback WP8 to whole IfA lab	31-Mar-11	Zurich	Academia	30
52	Research visit	UNIPD	Resarch period and seminar at Palermo University	01-May-11	Palermo, Italy	Academia	20
53	Workshop	Vodera	Energy Harvesting Workshop on Condition Monitoring	04-May-11	Solihull, UK	Academia, Industry	40
54	Research visit	UNIPD	Resarch period and seminar at Stuttgart University	01-Jun-11	Stuttgart, Germany	Academia	15
55	Workshop	Vodera	Emerging Technologies and Industries Programme workshop on Energy Harvesting	13-Sep-11	London, UK	Academia, Industry, Government	60
56	Symposium	UNIPD	Symposium on New Directions of Automatic Control	01-Oct-11	Seoul, Korea	Academia	250
57	Research visit	UNIPD	Resarch period and seminar at Kyoto University	01-Oct-11	Kyoto, Japan	Academia	10
58	Confeerce	Vodera	Innovate 2011 Conference	11-Oct-11	London, UK	Academia, Industry, Government	1000
59	Seminar	ETH	Presentation of FeedNetback project at an invited talk at the MOSAIC Computer Science Group at ETH	16-Nov-11	Zurich	Academia	15

60	Seminar	ETH	IfA Open House, ETH, Zurich	22-Nov-11	Zurich	Academia	50
61	Seminar	ETH	Presentation of Feednetback project to several guests (Professors, PhD applicants) at IfA, ETH, Zurich	22-Nov-11	Zurich	Academia, Industry	20
62	Meeting	Vodera	Meeting with Danish National Advanced Technology Foundation (DNATF)	27-Nov-11	London, UK	Funding Agency	2
63	Workshop	Vodera	iNet Smart Sensors Innovation Lab	30-Nov-11	Bristol, UK	Academia, Industry	60
64	Conference	KTH, INRIA	IEEE CDC 2011	01-Dec-11	Orlando, FL	Academia, Industry	2000
65	Workshop	Vodera	MEMS/NEMS Energy Harvesting Research Theme Workshop	02-Dec-11	Southampton, UK	Academia, Industry	30
66	Conference	KTH	19th European Signal Processing Conference (EUSIPCO 2011)	29 Aug - 2 Sep 2 2011	Barcelona, Spain	Academia, Industry	250
67	Conference	KTH	ACM/IEEE International Conference on Information Processing in Sensor Networks 2011, (ACM/IEEE IPSN 11)	April 2011.	Chicago, IL, USA	Academia, Industry	?
68	Conference	KTH	IEEE International Conference on Distributed Computing in Sensor Systems (IEEE DCOSS '11)	June 2011	Barcelona, Spain	Academia, Industry	?
69	Research visit	UNIPD	Resarch period and seminar at Linkoping University	May 2011 and Nov 2011	Linkoping	Academia	10
70	Course	UNIPD, INRIA	31th International Summer School in Automatic Control	07/10-09-2010	Grenoble, France	Academia	100
71	Research visit	UNIPD	Research period and seminar at Berkeley University	08/25-04-2011	Berkeley, California, USA	Academia	50
72	Course	UNIPD	Sidra PhD School on Distributed Optimization and Game Theory	11-13 July 2011		Academia	100
73	Conference	ETH, UNIPD, KTH, INRIA	50th IEEE Conference on Decision and Control (CDC10)	12-15 Dec 2011	Orlando, Florida, USA,	Academia, Industry	2000
74	Symposium	ETH	8th IFAC Symposium on Nonlinear Control Systems (NOLCOS)	1-3 Sept 2010	Bologna, Italy	Academia, Industry	500
75	Workshop	ETH, UNIPD, KTH, INRIA	2nd IFAC Workshop on Estimation and Control of Networked Systems	13-14 Sept 2010	Annecy, France	Academia, Industry	200
76	Symposium	UNIPD	4th IFAC Symposium on System, Structure and Control, SSSC'10	15/17-09-2010	Ancona, Italy	Academia	300
77	Conference	UNIPD, INRIA	IEEE 49th Conference on Decision and Control, CDC'10	15/17-12-2010	Atlanta, Georgia, USA	Academia, Industry	2500
78	Conference	ETH	SIAM Conference on Optimization	16-19 May 2011	Darmstadt, Germany	Academia, Industry	300
79	Conference	UNIPD	2nd IEEE International Conference on Smart Grid Communications	17/20-10-2011	Brussels, Belgium	Academia, Industry and Government	400

80	Conference	UNIPD	IEEE Power & Energy Society, PowerTech '11	19/23-06-2011	Trondheim, Norway	Academia, Industry	300
81	Workshop	KTH	IEEE Swedish Communication Technologies Workshop	19-21 October 2011	Stockholm, Sweden	Academia, Industry	120
82	Course	UNIPD, INRIA	4 th HYCON2 PhD School on Control of Networked and Large-Scale Systems	21/24-06-2011	Trento, Italy	Academia	80
83	Workshop	UNIPD	European Research Network on System Identification Workshop, ERNSI '11,	25/28-09-2011	Nice, France	Academia	350
84	Conference	KTH	17th European Wireless Conference 2011	27-29 April 2011	Vienna, Austria	Academia, Industry	300
85	Conference	ETH, UNIPD, KTH, INRIA	18th IFAC World Congress	28 Aug-2 Sept 2011	Milano, Italy	Academia, Industry	1000
86	Conference	UNIPD, KTH, INRIA	American Control Conference 2011 (ACC11)	29 Jun - 01 Jul 2011	San Francisco, California, USA	Academia, Industry	500
87	Workshop	UNIPD, INRIA	European Project HYCON2 Meeting, 29/30-04-2011, Eindhoven, Netherlands	29/30-04-2011	Eindhoven, Netherlands	Academia	40
88	Conference	UNIPD	24th Annual Conference on Neural Information Processing Systems (NIPS'11)	6/9-12-2010	Vancouver, Canada	Academia	300
89	Conference	KTH	GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference	6-10 Dec. 2010	Miami, FL	Academia, Industry	2000
90	Workshop	KTH	Information Theory Workshop (ITW), 2010 IEEE	Aug. 30 2010-Sept. 3 2010	Dublin, Ireland	Academia, Industry	400
91	Symposium	KTH	IEEE International Symposium on Information Theory (ISIT) 2011	July 31 2011-Aug. 5 2011	St. Petersburg, Russia	Academia, Industry	1500
92	Conference	KTH	Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on	May 22-27, 2011	Prague, Czech Republic	Academia, Industry	2000
93	Symposium	KTH	International Symposium on Information Theory and its Applications (ISITA) 2010	October 17-20, 2010	Taichung, Taiwan	Academia, Industry	1000
94	Workshop	All	Junior FeedNetback Workshop	15-Sep-10	Annecy, France	Academia	40
95	Research visit	Vodera	Research Visit to Porto University (Underwater Systems and Technology Laboratory)	15-Dec-10	Porto, Portugal	Academia	2
96	Course	KTH	5th Summer School on Applications of Smart and Connected Devices (SenZations 2010).	30 Aug - 03 Sept 2010	Rijeka, Croatia	Academia, Industry	80
97	Research visit	INRIA	Research period at University of Newcastle	Sept-Dec 2011	Newcastle, Australia	Academia	2
98	Workshop	INRIA	6th Information Theory and Applications Workshop	Feb. 6-11 2011	UCSD, San Diego, USA	Academia, Industry	500
99	Concertation meeting	INRIA	Concertation Meeting on Control and WSNs	09-Jun-11	Brussels, Belgium	Academia, Industry	

Section B (Confidential) Part B1

The project participants do not have to report applications for patents, trademarks, registered designs, etc. in connection to the project. .

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge,	Generation of multi-task/multi-rate real-time feedback controllers	YES	31/12/2013	Open-source software based on freely available software components (C/C++/Eclipse/Posix)	Research and development in networked control systems and advanced automation			Solely owned by INRIA., open-source licence (Cecill)
General advancement of knowledge, Exploitation of results through social innovation (environmental).	Source seeking via multiple mobile sensor networks	YES	31/12/2017	Algorithms for collaborative control, and simulation software with HMI-interfaces and APIs interfaces with Matlab.	Underwater exploration, supervision, and monitoring. However other sectors like sounds localization for teleconferences is also concerned. More generally, those algorithms can be seen as real-time distributed optimization.			INRIA. Algorithms are public, but simulator is private own by the research center and IFREMER.
General advancement of knowledge, Exploitation of results through social innovation (efficient manufacturing).	Energy efficient radio mode management	YES	31/12/2013	Radio-mode management for reducing the amount of energy, with a tradeoff with the performance of the control application, in a large range of applications involving networked control	Wireless networked control systems with energy constraints			INRIA

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
				systems.				
General advancement of knowledge, Exploitation of results through social innovation (security).	Stochastic reachability framework for tracking and surveillance	YES			Civil Protection, Private security, Entertainment			ETH. Public domain (submitted to conference). Other partners involved are Videotec and Vicon
General advancement of knowledge, Exploitation of results through social innovation (civil protection).	Source seeking algorithm for search and rescue missions	YES			Civil protection			ETH. Public domain (submitted to conference)
General advancement of knowledge, Exploitation of results through social innovation (efficient power distribution).	Methodology for control of plants	YES	31/12/2015		Wide-area plants; Plants with network topology and/or communication constraints.			US. Results published in peer-review journals.
General advancement of knowledge,	Low latency and low loss protocols for wireless networks	YES	31/12/2015	Representative model or prototype system tested in a realistic environment. Represents a major step up in demonstrated the technology's readiness level. The research includes testing a prototype both in a high fidelity laboratory	Industrial factory automation.		Publications, patents, and open source software.	KTH

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
				environment and in a simulated operational environment.				
General advancement of knowledge, Exploitation of results through social innovation (teaching).	New PhD and Master Courses	NO	31/12/2014	Universities, research centers, and industrial organisations.			Open source approach. The course lectures will be available online.	KTH
General advancement of knowledge, Exploitation of results through social innovation (civil protection)..	Patrolling and tracking for video surveillance	YES	31/12/2012	Perimeter patrolling and tracking strategy in a fully distributed asynchronous scenario to provide the smart camera networks with high degree of autonomy for large scale scenarios	Civil protection; private security.			UNIPD
General advancement of knowledge,	Distributed reconstruction of 3D scenes	YES	31/12/2012	Development of a real-time distributed reconstruction framework for marker based motion capture systems	Motion capture applications industry.			UNIPD
General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of results through social innovation (environmental	Simulated multi-vehicle mission scenarios	YES		Application as an enhancement opportunity for IFREMER fleet of AUVs, but may also be extended to other existing operational vehicles such as tethered (ROV) and autonomous surface	Underwater exploration and survey			IFREMER

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
and security).				crafts (ASV).				
General advancement of knowledge,	Provision of consulting services related to networked control systems	NO	1/2/2012	New professional services underpinned by the knowledge acquired in the project	Academic, Regional and National Government Departments and Agencies			VODERA
General advancement of knowledge,	Further development and promotion of project management know-how and tools	NO		Exploit management know-how and tools (Project netboard and Home netboard)	FP7 project management			VITAMIB
General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, Exploitation of results through social innovation (security).	PTZ tracking beyond single camera capabilities	YES	31/12/2013	Simultaneous tracking of several targets moving in a given monitored area using a set of collaborative PTZ units. Commercial product exploitation. Input to standards (protocols of modern CCTV systems). Further R&D.	Video surveillance		Technical details kept trade secret.	VIDEOTEC
General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D	Cooperative patrolling	YES	31/12/2013	Collaborative PTZ units focusing on the more areas in parallel, in order to prevent intrusions. Commercial product exploitation. Input to	Video surveillance		Technical details kept trade secret.	VIDEOTEC

Type of Exploitable Foreground	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
results via standards, Exploitation of results through social innovation (security).				standards (protocols of modern CCTV systems). Further R&D projects.				
General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of results through social innovation (entertainment).	Full performance motion capture	YES	31/12/2013	Simultaneous capture of body and facial data during a single performance using a master system for body capture in parallel with a dedicated facial capture 'follow' subsystem – one per performer.	Visual Effects / Entertainment Production		Technical details kept trade secret	OMG
General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of results through social innovation (entertainment).	Visual effects/animation Motion Capture in large and varied control environments	YES	31/12/2013	Less control of camera positions therefore cameras may need to be placed in non-optional locations/positions. Pan/tilt heads may allow a 'moving' capture volume within a shooting space thereby increasing the usable capture volume and enabling capture in less controlled or dedicated spaces.	Visual Effects / Entertainment Production		Technical details kept trade secret	OMG

Potential/expected impact			
Beneficiary	**Impact to organisation**	**Impact to others**	**Actions planned for exploitation of results**
INRIA	Assessment of theoretic work through working prototypes, contribution to students education, extended collaboration with IFREMER Competitive advantage against existing commercial solutions through a better exploitation of existing radio chip features	Opportunities for new collaborations Contribute to European leadership in advanced control methodologies with potential applications to existing and emerging control problems.	Assessment with selected partners and testcases; then releasing a public version Elaboration of new project on collaborative formation control in other areas than the underwater, i.e. aerial. Integration of the mode management policy into the existing networked control systems solutions. Demonstration of the amount of energy saved with the new mode management policy.
ETH	Develop a new reachability framework dealing with time varying reach avoid sets. Develop sophisticated patrolling strategies for pursuit-evasion problems. Improving the acceptance/practicability of stochastic search strategies/control for applications.	Improvements for security systems and related services. Reduction in health risk for humans, both rescuers or victims (e.g. buried after earthquakes)	Immediate work on improving the scalability of the framework to a larger network of cameras (target: tens of cameras). Development of a testbed with unmanned vehicles with PTZ cameras onboard. Extend collaboration with security companies towards making the framework more robust and suitable for commercial roll out. Immediate work on improvements on algorithm speed. In parallel, adapt the theory for unmanned aerial vehicles and design simulator/testbed. For this ETH already started a specific project for building a testbed and applying this theory. Up to now this involves several student theses and would require more elaborate work if the implementation on real drones is concerned. Cooperation will be sought with producers of autonomous drones or spin-off to offer package solutions (integrated software and hardware)
US	Field for potential future research Potential commercial product. Competitive advantage against existing commercial solutions (Fieldbus).	Contribute to European leadership in advanced control methodologies with potential applications to existing and emerging control problems.	Contact industrial partners to analyse the commercial viability of the approach. Publish quality academic papers.
	Potential commercial product success for factory and building automation. Competitive advantage against alternative offerings in terms of extended sensor network lifetime. Better satisfaction of existing customer need. The courses offer a novel approach to the design of wireless sensor networks. No other course can be	Contribute to European growth in manufacturing and related services Contribution to success and advancement of industries relying on automation, e.g. process and manufacturing industries. Contribute to European growth in education, manufacturing and related services.	Market research surrounding potential market benefits to establish cost/benefits and appropriate pricing models. The research is taken in collaboration with KTH Innovation office. Analyse the viability and profitability of different subsystem configurations by more extensive implementation with industrial partners.

	found world-wide having the same holistic approach.	Contribution to success and advancement of automation related industries – process and manufacturing industries	The courses will give the base to develop further scientific and technical research in the future. It is likely that students with an entrepreneurial attitude will be able to create companies for sensor networks design and service provision
UNIPD	Obtain theoretical results in the field of autonomous agents, particularly in the case of asynchronous and collective behaviour.	Develop further know-how in camera networks that can be used in the context of industrial collaborations and funded R&D projects.	Complete the asynchronous management of the network and provide theoretical convergence proofs for coverage and partitioning; tackle the task assignment problem in such a context; extend to 2D domains. Activity on a wider range of scenario simulations. Cooperation with company (e.g. Vicon) to refine the algorithmic solutions.
IFREMER	Contributed to the ongoing internal development of control and communication solutions for the simultaneous operation of unmanned marine vehicles. This finds a direct application as an enhancement opportunity for IFREMER fleet of AUVs, but may also be extended to other existing operational vehicles such as tethered (ROV) and autonomous surface crafts (ASV).	increase the efficiency of the use of underwater systems as well as oceanographic carrier vessels. The extensive study through simulation represents a key step on the way towards plausibility of multi-vehicle concepts as a tool in practical ocean research. The fields of geophysics, coastal environment management, fish stock evaluation, and deep sea ecosystems are potential areas that will benefit from the above technologies in the near future. The achieved results increase the awareness of the user communities with respect to new fields and ways of usage of autonomous underwater system. This cultural change is a necessary step for the introduction of new technology.	development of acoustic mobile sensor networks based on the company's fleet of underwater vehicles and the development of efficient networked control architectures in presence of severe communication constraints Furthermore, the coordination of the trajectory of an AUV with respect to a 'master' vehicle (ROV or manned submersible) receives a strong interest from the scientific user community.
VODERA	Raised the profile of company, extended network of contacts, improved quality of products/services and income generation. Continue develop innovation management tools.	Support skills development; form new academic/industrial partnerships; and support employment.	Engage with representatives of organisations to establish detailed requirements and offer quality services at competitive prices
VITAMIB	Income from project management service provision.	More effective project management in collaborative projects. Researchers have more time to concentrate on R&D.	Adaptation of Project netboard to FP8 financial rules
VIDEOTEC	Ability to serve customers interested in increased security levels at affordable prices. Market differentiation is expected to drive product success.	Improved security performances in critical installations and public buildings. Improved security and technological standards in the European CCTV market. Connections established between industry and academia are expected to have positive effects on educational and technological activities.	Automatic calibration procedures. Further optimization of the developed algorithms, optimized porting in C code for embedded custom platforms. Integration of the developed algorithms into the existing product platforms. Systematic analysis to demonstrate to the

			customers that the additional setup costs are justified by increased security levels.
OMG	Potential commercial product success. Competitive advantage. Unique satisfaction of existing need.	Contribute to growth in national manufacturing sector. Contribution to success and advancement of market related industries – Film, Game, TV production	Market research surrounding potential market benefits leading to cost/benefit analysis.

4.2 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	223866
Title of Project:	Feedback design for wireless networked systems
Name and Title of Coordinator:	Carlos CANUDAS de WIT - INRIA

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes*** ***0No***
2. Please indicate whether your project involved any of the following issues (tick box) :	***NO***
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	

• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	6
Work package leaders	0	12
Experienced researchers (i.e. PhD holders)	3	22
PhD Students	3	10
Other	6	12

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**15**
Of which, indicate the number of men:	12

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

- ○ Yes
- ⦿ No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
❑	Design and implement an equal opportunity policy	○	○	○	○	○
❑	Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
❑	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- ⦿ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ⦿ Yes- please specify : 8 Post doc; 17 PhD students
- ○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ⦿ Yes- please specify: Website, Theses, Publications, Videos
- ○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ⦿ Main discipline[1]: 1.1
- ○ Associated discipline[1]:
- ○ Associated discipline[1]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

- ○ Yes
- ⦿ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

- ○ No
- ○ Yes- in determining what research should be performed

[1] Insert number from list below (Frascati Manual).

- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**47**
To how many of these is open access[2] provided?	**41**
How many of these are published in open access journals?	
How many of these are published in open repositories?	**41**
To how many of these is open access not provided?	**6**
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ☑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[3]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☑	Increase in employment, or	☑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[2] Open Access is defined as free of charge access for anyone via Internet.
[3] For instance: classification for security project.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* **45**
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

⦿ Yes ○ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ⦿ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☑	Press Release	☑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
☑	Brochures /posters / flyers	☑	Website for the general public / internet
☑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	☑	English
❑	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]