Systems and Control

Recommendations for a European Research Agenda towards Horizon 2020

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Executive summary

The aim of this report, supported by major industrials and academia, is to demonstrate that CONTROL is at the heart of the Information and Communication Technologies of complex systems and as a consequence should be supported as a priority in the coming Work Programmes both at the level of enabling technologies and at application level, including PPP "Public Private Partnership" on *Energy-efficient buildings, Factories of Future and European Green cars Initiatives*. After recalling what control science is, ten crucial needs of society where control will make a strong impact in the next decade are sketched. The next section summarizes some of the main challenges behind these applications without describing methodologies and tools. This is followed by a list of new sectors where control will have also very probably a major role to play. Finally some operational recommendations are listed in order to provide the means to develop this extremely important scientific and technological discipline whose critical role in ICT is essential to meet European Policies in the future.

Table of content

Section 1 – What is systems and control science? ***7***

Section 2 - 10 crucial needs of society where systems and control science will make a strong impact in the next decade ***10***

Section 3 - Focal research themes and challenges ***17***

3.1 - System-wide coordination control of large-scale systems **17**

3.2 - Distributed networked control systems **18**

3.3 – Autonomy, cognition and control **20**

3.4 - Model-based systems engineering **21**

3.5 - Human-machine interaction **22**

Section 4 – Systems and control for new domains ***23***

4.1 – Control and health **23**

4.2 – Control and social and economic phenomena and markets **24**

4.3 - Control and quantum engineering **24**

Section 5 - Recommendations ***25***

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Section 1 – What is systems and control science?

Systems and control science provides the scientific foundations and technology to **analyse** and **design complex, dynamically evolving systems,** in particular systems in which **feedback** plays an important role. Feedback means that the effect of actions is monitored and future actions are planned taking this information into account. Feedback is ubiquitous in technical systems where it enables automation and autonomy, and in social, socio-technical, economic and biological systems.

Systems and control science is both a scientific core discipline and a crucial part of application areas such as automotive, aeronautics and aerospace, manufacturing, generation and distribution of electric energy, heating, ventilation and air conditioning, production of chemicals, paper, food and metals, robotics, supply chains and logistics, to name a few.

Systems and control science **provides tools for modelling of dynamic physical, chemical, biological, economic and social systems and develops concepts and tools for their analysis and design.** It integrates contributions from mathematics, signal processing, computer science and from the application domains. Systems and control science is indispensable to analyse, design, simulate, optimize, validate, and verify the technological and socio-technical systems that will be characterized **by massive interconnection, the processing of huge amounts of data, new forms of synergy between humans and technical systems, and challenging requirements for substantially improved performance, reliability, and energy efficiency.**

The basic roles of systems and control science are then the following:

- **Model physical phenomena and artifacts** to understand and predict their dynamic behaviour and the interactions among their components,
- **Develop control strategies and algorithms** to optimize the behaviour of systems so that they accomplish certain intended functions, satisfy constraints, and minimize negative effects, e.g. consumption of resources,
- **Implement the control strategies** by selecting sensing devices, computing elements and actuators and integrating them into a system with maximum performance under cost constraints,
- **Validate and verify** that the implementation of the control strategies acting on the physical systems satisfies constraints and performance requirements.

Abstracting an application problem to solve it by sound mathematical approaches is a fundamental characteristic of control. If the abstraction captures an essential feature of a class of problems, then the results obtained in one application domain can be transferred to other domains that *prima facie* look completely different. Furthermore this abstraction and systematization process enables a common problematic which links different engineering areas, a very much desirable feature when developing new technologies that involve complex multi-domain systems.

Systems and control science, among other disciplines, has played an important enabling role in virtually all major technological evolutions until today, from the steam engine to rockets, high-performance aircrafts, space ships, high-speed trains, "green" cars, digital cameras, smart phones, modern production technology, medical equipments, and many others. It provides a large body of theory that enables the analysis of dynamic systems of all kinds in order to better understand their behaviours, to improve their design, and to augment them by advanced information processing, leading to qualitative leaps in performance (see [1] on page 22).

Embedded systems interact with physical devices and systems, large and small, ranging from mobile phones to automotive engines, robots, up to entire industrial installations. More than 90% of all CPUs are currently deployed in embedded systems. During the last decade, such systems have seen a tremendous improvement of their performance most notably in cars, where the increase of safety (ABS, ESP, etc.) and the reduction of fuel consumption (EFI, EPS, etc.) are largely due to mechatronic design. That is, the combination of mechanical engineering, electronic engineering, computer engineering, and control system engineering, in order to design and manufacture useful products. Recently *cyber-physical systems* have become synonymous with networked embedded systems and control, conceptualizing the strong interaction between the transmission and processing of information in real time (the cyber system) with the physical device or process [2].

Over the last fifty years the field of systems and control has seen huge advances, leveraging technology improvements in sensing and computation with breakthroughs in the underlying principles and mathematics. Motivated by this record of success, control technologists are addressing contemporary challenges as well, examples of which include the following:

- ✓ The automotive industry is focusing on active safety technologies, which may ultimately lead to partially autonomous driving, where humans will become passengers of automated vehicles governed by automatic control algorithms for substantial parts of their trips, leading to improved safety, better fuel economy, and better utilization of the available infrastructure.

- ✓ Automatic control will help improve surgery. Robots are already used today to support surgeons to minimize intrusive procedures and increase accuracy of operations. It is conceivable that semi-autonomous robots remotely supervised by surgeons will be capable of carrying out unprecedentedly complex operations.

- ✓ Automatic control will play a fundamental role in the energy landscape of the future, both in the efficient use of energy from various sources in industry and in buildings, and in the management of the generation, distribution and consumption of electrical energy with increased use of renewable and decentralized generation. The management of important schedulable loads (e.g., the recharging of electric cars) and of distributed sources (e.g., at the homes of the customers) calls for completely new large-scale control structures.

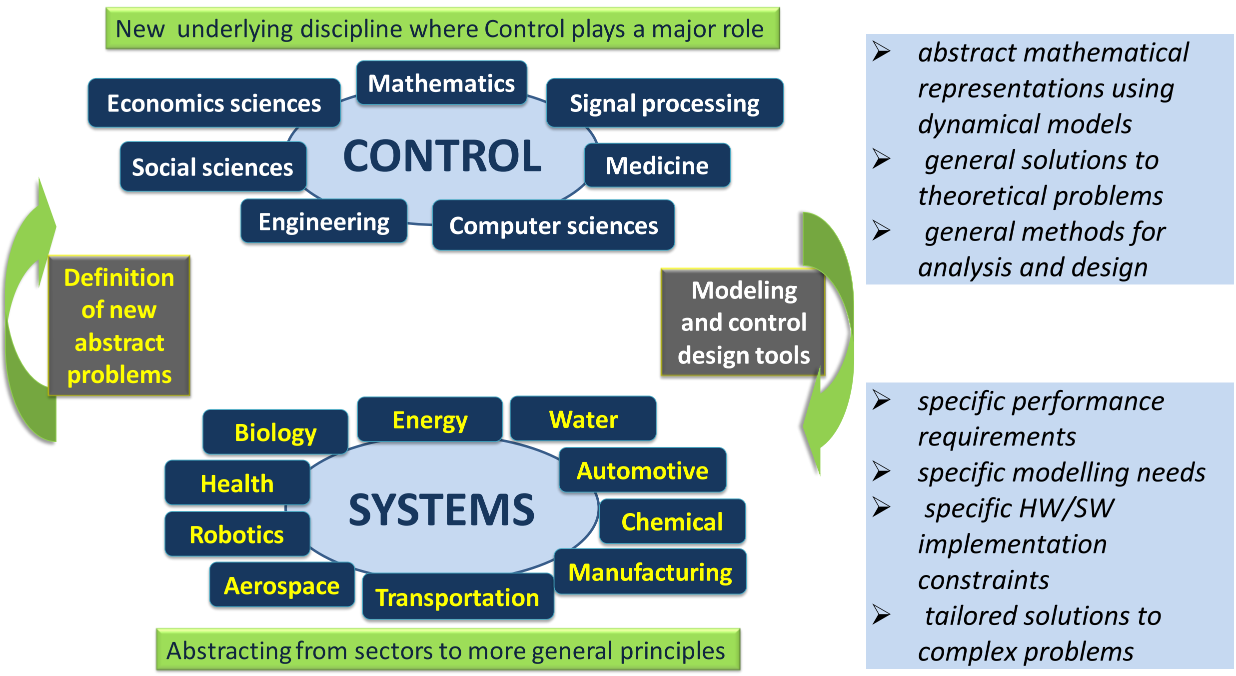
- ✓ Systems and control science is important in all kinds of maintenance tasks for large infrastructures. Robotic sensor and actuator networks will be employed for autonomous surveillance and maintenance in large buildings, distribution networks, etc.

- ✓ Control is ubiquitous in the biological mechanisms that govern life. An improved understanding of the dynamic behaviour of these complex biological systems will provide new opportunities for biotechnology and medicine and support the design of such systems (‘synthetic biology’).

- ✓ In the defence and security domains, besides the interest in improved performance of equipment of all kinds, there is an increasing demand for highly autonomous devices and, in particular in coordinated sets of devices and vehicles that cooperate to carry out a particular task, asking for distributed multi-agent control .

Devices and systems with sensing and control functionality are increasingly integrated into larger cyber-physical systems (CPS), the so-called "**systems of systems** (SoS)". Networks of automated systems arise in many domains. A modern car may include more than 50 electronic control units of subsystems that all contribute to its overall behaviour; in an airplane, the number of cooperating systems may even be one order of magnitude higher. The interconnection between the controllers arises from both the physical interaction via, e.g., the mechanical structure of a car or an airplane or the electric coupling in the grid and the communication network. The complexity of the dynamic interaction involved in such systems is beyond what can currently be handled with available methods. There is a strong need for new methodological and engineering approaches that ensure efficient, predictable, safe and secure behaviour of large interconnected systems. The field of systems and control here has to address novel questions and issues that lie at the interface of control, computing and communication and transcend the traditional problem formulations in these areas.

The strength of the field of systems and control is the close bi-directional interaction between methodological developments and advances in applications as illustrated in the diagram below:



By SYSTEMS it is understood: Complex Systems, Cyper Physical Systems (CPS), Systems of Systems (SoS), Networked Control Systems (NCS)

[1] *"The Impact of Control Technology: Overview, Success Stories, and Research Challenges"* report edited by T. Samad and A. Annaswamy, 2011 www.ieeecss.org/main/IoCT-report
[2] White Paper based on the results of the CCC Workshop on New Forms of Industry – Academy Partnership in CPS Research; George Mason University, VA, May 19, 2009; Edited by Janos Sztipanovits, John A. Stankovic and David E. Corman.

Section 2 - 10 crucial needs of society where systems and control science will make a strong impact in the next decade

"Real-time measurement, modelling & control platforms will drive a smarter planet through the broad Implementation of feedback control", *Darío Gil, Program Director, Energy Technology and Strategy IBM T.J. Watson Research Center.*

1	**Ground and air smart traffic management**	Traffic congestions at rush hours are common in most European agglomerations. The most obvious impacts of traffic congestion for citizens are increase travel times, fuel consumption, emissions, and noise. These effects are amplified if the infrastructures are not operated at their maximum capacity during congestion, implying that fewer vehicles than possible can proceed. The situation is worsening due to the continuous increase of transportation demand while space is lacking to build new infrastructures. By new technologies in sensor networks, information about the traffic can be measured at many points of the roads. This information can be used to develop innovative adaptive traffic management policies. This includes traffic responsive ramp metering and varying speed limits. Future on-line traffic management systems will use integration of and cooperation between intelligent vehicles and the roadside infrastructure via in-car navigation, telecommunication, and information systems in order to provide a balanced utilization of the transportation system that takes into account various objectives and constraints such as travel times, reliability, delays, emissions, CO_2 reduction and fuel consumption. Air traffic demand is predicted to double in the next 10 to 15 years and to triple in 20 years' time. This growth cannot be sustained without a complete overhaul of the air traffic control infrastructure to optimize air routes and mitigate congestion. In addition to air traffic management, aeronautics research investment priorities in Europe are to develop safer, greener, and smarter transport systems. Air travel is the fastest-growing source of greenhouse gas emissions in the world, and the energy demands for the air transportation are expected to more than double in the next three decades. Everything else being equal, airborne emissions are estimated to have a two to four times greater impact than terrestrial emissions. Better air traffic management, improved in flight control of individual aircraft, and improved engine control systems are vital for the reduction of CO_2 emissions and improved fuel efficiency.

2	**Green electricity and Smart Grid**	Electric power networks are among the largest and most complex man-made systems. They connect hundreds of millions of producers and consumers, cover continents and exhibit very complicated behaviours. As a result, there are still many poorly understood phenomena that are caused by the interaction of such a large number of devices and the large spatial dimensions. Currently major changes of the grid structure are being implemented, in particular to support the large-scale introduction of renewable energy sources such as wind farms and solar plants to reduce CO2 emissions. Two crucial features of these sources of electric power have to be coped with: most renewable sources are dispersed over a wide geographical area, and most of them are fluctuating over time. Integration of these highly intermittent, randomly variable, and spatially distributed resources calls for new approaches to power system operation and control. In addition, new types of loads such as plug-in electric vehicles and their associated vehicle-to-grid potential will offer challenges but also opportunities, thanks to the possibility to exploit their energy storage capabilities. Establishing a cyber infrastructure that provides ubiquitous sensing and actuation will be vital to achieving the responsiveness needed for future grid operations. Sensing and actuation will be pointless, though, without appropriate control laws that enable operators on the energy market to optimally manage power flows, maximizing profits (in particular through the use of renewables) under power balancing constraints.
3	**Improved energy efficiency in production systems**	Generally speaking, manufacturing, i.e., production of goods that have a weight, shape, and other physical properties to fulfil their functions, contributes about 22% to the European Gross Domestic Product. 70% of all jobs are directly or indirectly dependent on manufacturing activities. Manufacturing can be divided into two types of activities, *discrete manufacturing*, which produces investment goods and consumer products and their parts and components, and the *process industries*, as e.g., in the chemical, steel, glass, ceramic, and metal industries. Despite increasing pressure and tight regulations, the manufacturing industry has remained competitive in most areas in Europe, thanks to continuous innovation and a high level of automation. Industry as a whole contributes 20-25% to the final energy use in Europe, with the larger part consumed by the process industries. Energy and raw material use reduction is of prime concern in the process industries and represents a major contribution to a greener and sustainable society in Europe. In addition to improvements in the construction and configuration of the production equipment (e.g., better insulation, heat recovery), control plays a major role in energy saving. As an example, crude oil is separated into fractions for final use (gasoline, diesel fuel, kerosene, naphta, etc.) mainly by distillation. In distillation columns, a large amount of thermal energy is used to boil up the liquid: the higher the purity required of the products, the higher the consumption of energy. If these columns are operated automatically under continuous feedback control, the variability

		of product purity is reduced and operation can be closer to the specifications, leading to significant energy savings. Advanced configurations as, e.g., divided-wall columns and the integration of chemical reaction and separation offer further large potentials for energy savings but pose challenging operation and control problems. The extension of the system view and model-based decision making methodology will lead to a new generation of functionalities in the MES (Manufacturing Execution System) layer. Up to now, most of the applications at this level are related to production management and process supervision, but new areas such as plant-wide energy management, production flow adaptation to changing conditions, for instance by on-line re-scheduling and explicit consideration of the plant-wide dynamics, will significantly improve the performance and efficiency of today's production plants and factories.
4	**Security in decentralized automation**	The problem of how to preserve the integrity of coordination and cooperation of the components of distributed control systems against failures and malicious interferences has become very important in control and automation systems. The relevance of such problems became clear after several attacks, most prominently the global-scale "Stuxnet" worm attack in 2010. Security issues have been addressed in Industrial Automation Protocols both at the LAN/WAN level and the Field Bus and Device Level. Control and automation systems are often implemented on embedded devices. The functionalities of embedded devices are mostly implemented in software. The drive to provide richer functionalities, increased customizability and flexible adaptability requires the ability to dynamically download software on the devices. Without adequate countermeasures, this ability may open up vulnerabilities that are conducive to severe security breaches. The magnitude of this problem will worsen with the rapid increase in the software content of networked control systems. Much work has to be done both in the direction of defining and building a unified reference security architecture that can encompass the full range of embedded systems in a networked control system. The main theory and tools developed in modern industrial automation security systems are strongly based on the existence of one or more centralized supervisors. Each local fault-detection unit is only able to detect its own faults and send a detection alert to the supervisor. While centralized supervision has advantages, it is clearly prone to focused attacks, and does not adapt well to increasingly distributed, reconfigurable control systems. Decentralized detection of malicious intruders represents a new direction of research capable of providing higher robustness and resilience, but also posing some difficult research questions on the convergence of all nodes to a consensus on trust to be assigned to individuals and to the detection of byzantine behaviours on the basis of locally incomplete information.

5	**Mechatronics and control co-design and automation**	In an economic context characterized by fierce competition and concerns about future energy supply, improving the performance and functionalities of processes and products is a key element in order to achieve a better position. New functionalities supported by better control systems allow companies to maintain productivity, markets and product quality. The way these functionalities can be incorporated into products is by mean of embedded systems where the operational and control strategies are wired in a chip connected to the physical device. These systems are ubiquitous in high-tech devices from washing machines, digital cameras, to cars, airplanes and machinery. In Europe, many traditional mechanical industries have moved quickly towards intelligent machines and appliances, with the aeronautical and automotive industries being the spearhead of this revolution. The added value of new products comes for an important part from more intelligent sensing and control. The traditional approach of sequentially and separately developing the mechanical design and control of components, pieces of equipment and machines is no longer sustainable, in view of the growing complexity and need for the optimal use of resources. A similar situation exists in chemical engineering where the design of the plant and its control structure must be integrated to enable flexible, efficient and safe operations. The modern approach in co-design requires interdisciplinary competence and to merge the traditional strength of mechanical, industrial and chemical engineering education in rigorous modelling. Mechatronic research projects in Europe have so far only partially addressed the need for integrated system design. Only individual components and low-level integration used to be considered, lacking a wide system view. Research initiatives in the direction of integrated mechanical and control co-design as well as process and control co-design will to boost the integration of competences and have a strong impact on the future of Europe industrial competitiveness.
6	**Analysis, control and adaptation of large infrastructures**	The quality of life in Europe, as in all densely populated parts of the world, depends critically on infrastructures that provide water, electricity, gas, transportation of passengers and goods, wastewater treatment, garbage collection, health care, etc. Extending and modifying these infrastructures to adapt to new challenges and to cope with the increased demand (especially in mobility and transportation) has become very expensive and is often difficult to implement because of local opposition. Systems and control science can provide tools and methods to increase the performance of the infrastructure by intelligent flow management and resource allocation, e.g., in road and air traffic, to improve the services and to reduce the necessary investments to meet the demands. Beyond this, the analysis of structure formation in dynamic systems can provide guidelines for long term planning of adaptive networks. Large-scale dynamic simulations of infrastructure systems will help to allocate the resources for extensions in the most economic fashion.

7	**Autonomous systems**	In consumer products as, e.g., cameras and cars and in industrial environments, there is an increasing trend towards higher degrees of autonomy of complex technical systems such that they can perform complex tasks ("missions") and react autonomously to influences of the environment rather than being guided by humans. Not incidentally, the term "mission" comes from the military sector, where research has recently focused on unmanned (semi-) autonomous systems. Future autonomous systems like for instance robots in search and rescue operations, mining, deep sea exploration, etc. will need cognitive capabilities such as perception, reasoning, learning and others. Cognitive control systems in automobiles, aircraft, houses and engineering applications will enhance safety and performance. An example is an energy management system in a hybrid electric vehicle: by continuously perceiving the driving style of the pilot and learning a model of this behaviour, it may exploit this knowledge to optimize fuel consumption. Cognitive control can also be used in social and group environments where a cooperative execution of complex tasks is required of agents that can be humans or machines (or both). Much can be expected from the development of technologies for increased autonomy from military and niche applications to broader markets, e.g., driver assistance, personal assistance, monitoring of elderly people, rehabilitation, intelligent heating, etc. The basis of autonomy is the processing of data from the environment and thus feedback – a classical feedback loop is the simplest implementation of the principle of autonomy of a technical system. Autonomous systems pose enormous challenges to design and testing methodologies in order to assert a safe and functionally correct behaviour of such very complex real-time data processing systems in all conceivable situations.
8	**Neurosciences**	Brain related sciences (from neurophysiology to psychophysics) aim at building models of perception, action, coordination, conscience, context awareness, adaptation, and decision making. An enormous amount of facts and findings concerning neural behaviours has already being collected, yet there is a widely felt lack in a systematic approach to modelling and interpretation of the phenomena of interest. Notions of "state awareness", "state-dependent decision making", "identification by anticipation", which appear in the relevant literature, show a striking similarity to system theoretic concepts of state reconstruction, feedback, identification, adaptive control, etc. This similarity is much more than a simple resemblance of language - these problems are actually the same, although the level of complexity of systems is huge in brain sciences. Yet, very little of well-established methodologies and techniques from systems and control theory have been made available to scientists in brain research to provide them with the tools suited to attack complexity. The system approach to the modelling and analysis of brain functioning

		becomes an accepted tool in these communities, which are open to absorb other ideas and approaches from systems and control sciences. It is a central issue - and one where Europe could gain an edge over other global players - to make these communities talk and work together towards a deeper understanding of brain, and applications of such understanding to the development of new artefacts.
9	**Health care: from open medication to closed loop control**	The term "Electrical stimulation" encompasses a broad array of electrical treatments targeting a therapeutic alteration of the function of the nervous system by means of implanted devices. Two functionally different approaches can be distinguished: *functional electrical stimulation* and *neuromodulation*. Functional electrical stimulation is directed towards the restoration of motor function and is used to activate muscles in patients with paralysis from neurological disorders. In neuromodulation, the stimulation is used to modify the activity in specific circuits of the central nervous system and it is successful in the management of persistent pain disorders, certain symptoms related to Parkinson's disease, etc. However, deep understanding of the mechanisms involved in electrical stimulation is still missing and currently used stimulation patterns are under open-loop control. Adequate models of neuronal activity and of the propagation of electrical stimuli produced by electrodes and corresponding simulation tools must be developed. Based on these models new (closed-loop) stimulation techniques can be developed, making stimulation methods more adapted to human physiology and more individualized. In an ageing society, the cost of medication for chronic diseases which require long-term, expensive treatment is continuously increasing. For example, in Germany the treatment of chronic diseases is responsible for more than half of the cost of the health care system. High blood pressure and diabetes mellitus are the most widespread of these diseases. Currently, even the most advanced instruments for their treatment administer medications following a preset daily program with some corrections based upon (more or less frequent depending on the illness) isolated measurements. If the administration of medication could be changed to a feedback configuration where the real situation of the patient is monitored and the medication regime is adapted to the measurements automatically, the quality of the control as well as the comfort of the patient could be increased considerably. Some results in this direction have been already obtained in the case of diabetes.
10	**Cellular and bio-molecular research**	Biological research has been collecting a tremendous amount of information about the biochemical processes that go on in living organisms and enable life, growth and reproduction. The complexity of the interactions even in the simplest of these organisms, single-cell organisms like *Escheria coli* or *Saccaromyces cerevisiae* (baker's yeast) is

		awesome, and most of the available information is still semi-quantitative (describing only the existence and the relative strength of interactions) and static. For a deeper understanding and for a systematic design of drugs or of microorganisms for the production of pharmaceutically or technically relevant substances, an increased interaction with systems and control research is strongly needed. Only the creation of mathematical models that can be simulated and (at least partially) analysed enables one to understand the dependencies of the different mechanisms fully and to distinguish between dominant and subordinate, fast and slow interactions. Systems and control theory offers tools to analyse nonlinear, dynamic and discontinuous behaviour in complex systems, and in turn will benefit from the new theoretical challenges posed by the biological community. Building mathematical models also provides a common reference for the integration of results of work in the laboratory and the determination of crucial open questions. Of course, sufficient trust in “in silico” experiments has to be built as a first step. Recently, biological research is moving from the analysis of natural organisms to the deliberate re-design of biological systems, termed synthetic biology, by removing existing components and adding new ones to the living cell. Systems and control theory provides a useful framework to study this re-design. Control functions are crucial to the viability of such artificial biochemical systems and the field of systems and control theory is in an excellent position to contribute to this area based upon a long record of synthesis of control functions of all kinds.

Section 3 - Focal research themes and challenges

There exist a large variety of control schemes in use today; in the following some of them will be sketched. It is very important to remark that these control schemes address different sorts of systems, in many situations physical systems, but also biological and economical ones. Today control is at the heart of the technological and scientific uprising of complex systems, networked systems, Systems of Systems and Cyber Physical Systems.

3.1 - System-wide coordination control of large-scale systems

For system-wide control and real-time optimization of large-scale and spatially distributed processes, (e.g. electric power networks, large chemical or metallurgical plants, traffic systems, water distribution systems) the main question is how to operate a wide-area physical system to maximize overall performance measures under operational constraints, drawing from a broad range of information sources, and to ensure a robust and stable operation even in case of subsystem failures. The performance measure typically describes economical and environmental criteria, while the constraints are related to dynamical restrictions of the process, limitations of equipment and resources, and the legislation (e.g. safety codes and emission limits). The information sources include measurements from a large number of sensors with different accuracies, reliabilities and availabilities, models of processes, sensors and communication channels, and external factors such as market analyses and weather forecasts.

How to systematically design and verify mechanisms for dynamic reconfiguration of the overall system due to the disconnection or shut-down and re-integration of subsystems?

Control systems for large-scale systems can be structured hierarchically in layers or can be organized so that independent "agents" control the subsystems and exchange information with each other or with a central coordination mechanism. A multi-level control structure must be designed based upon suitable abstraction techniques, e.g., hybrid continuous-discrete models, so that the safe and near-optimal operation of the overall system can be assured. An important area of research is how one can cope with the inevitable imperfections of the models used on all layers as well as with the lack of knowledge on disturbances and on external influences as, e.g., future prices, demands and capacities.

In distributed control systems, the local controllers have only limited information about the evolution of other subsystems and the actions of their controllers. The value of information for the stability and performance of the overall system needs to be analysed as well as the robustness of distributed systems to failures of components or of the communication system. Methods for the systematic design and verification of mechanisms for dynamic reconfiguration of the overall system due to the disconnection or shut-down and re-integration of subsystems are required.

A promising approach to distributed optimization and control is the use of price-based or market-like coordination mechanisms. The underlying idea is to coordinate the use of scarce resources by a bidding procedure where the "agents" offer and buy resources at certain prices that then enter into the local cost functions. Such schemes must be analysed more deeply from the points of view of stability and of performance.

A challenging issue in the coordination and control of large-scale systems is the control of populations of subsystems that exhibit different individual behaviours and interact with each other, as, e.g., living cells in a culture or a fermenter, large crowds, or cars in a traffic system. From a system-theoretic perspective, the goal is to control a population of non-identical nonlinear systems. Classic control theory that is tailored to single, monolithic models is inadequate for this purpose. Important research topics are the development of a hierarchical modelling framework for populations of systems accounting for uncertainty and stochastic sources of variability; procedures for the identification of microscopic and macroscopic parameter distributions from microscopic experimental data; algorithms for the online estimation of population states from measurements on individuals; and feedback controllers to steer dynamic populations in a desired manner.

3.2 - Distributed networked control systems

Given the importance of distributed sensing and control for a wealth of application domains, the effects of the practical limitations of the interconnections must be characterized and understood. In the traditional view of control, communication among controlling and controlled entities occurs instantaneously and with signal degradation only by stochastic noise. In reality, delays and signal degradation are common especially when the distance between elements of a communication system is considerable. There are two new approaches to the design of distributed control systems: one is to derive constraints on the characteristics of the interconnection and of the communication protocols so that delays and signal degradation (including packet drops) impact the desired characteristics of the control algorithm in a tolerable manner; the other is to consider the effects of the interconnection and of the protocols when the control algorithm is designed so that these effects have little impact. The two approaches may be combined by co-designing the network and the control algorithm so that a better solution can be found, at the price of an increase in the dimension of the design space.

Networked control is an interesting example of a domain where interactions between research communities can bring large benefits. Wireless as well as mixed communication where wireless connectivity is combined with wired communication pose significant challenges such as the mitigation of the effects of the unreliability and stochastic time varying characteristics of wireless connections on control performance. In this context, it is important to take into consideration issues such as channel characterization, to make sure that channel communication quality meets the demands of the control algorithm and of power consumption, to maximize the life of wireless nodes. These issues are in general considered with heuristics and ad hoc methods so far.

How to design control for networked systems with structures that change over time and with communication links established in a limited period of time?

Much of the current research on networked control systems is focused on fixed structures for communication and interaction. But networks of mobile vehicles or smart energy grids with time-varying sets of producers and consumers give rise to system structures which change over time. Control methods for networked systems must be able to cope with the fact that communication links may be only established for a limited period of time. Ensuring stability or performance for systems in which communication or coupling between subsystems is restricted in this way goes much beyond the present investigations of time-delays or (single) packet-losses in communication.

Among the advantages introduced by distributed control systems, one of the most notable is the resilience to faults that is made possible by the redundancy of agents and connections. Together with this positive characteristic, though, comes a number of very challenging problems that need to be better analyzed and understood in order to enable reliable application of distributed control systems in highly critical systems. While a failure in a single node of a networked system can typically be better tolerated than in a centralized system, distributed systems are potentially vulnerable to domino effects. One important aspect is the analysis of robustness with respect to misbehaviours of agents, due to either accidental faults or malignant intrusion of potential adversaries. In distributed systems, simple nodes are more easily attacked by potential malignant adversaries, and clever policies might be devised that propagate false information or even dangerous control commands throughout the network. It is therefore crucial that a distributed system is endowed with the capability of monitoring the correct functioning of its nodes, detecting possible misbehaviours and isolating faults and tampered-with nodes. Another important aspect is that the distributed system be able to continue smooth operations even when a few nodes are removed, or added, which can be achieved only if algorithms are devised with the ability to self-reconfigure. These topics, which are known and well studied in (static) distributed computing environments emerge in a much more complex fashion in distributed control systems, because of the dynamic phenomena that characterize all physical systems, and feedback-controlled systems in particular.

How to ensure safe control architectures for large-scale networked industrial automation?

Monitoring, reconfiguration, security and reliability are aspects of paramount importance in developing efficient, predictable, and safe control architectures for large-scale networked industrial automation. There is a need for new algorithms, protocols and procedures for next-generation distributed control systems, to drastically reduce configuration, commissioning and maintenance costs.

In many domains as service networks, virtual enterprises, civil security, telecommunications, etc... the organization to be controlled results from the interconnection, sometimes for a short period of time, of pre-existing and heterogeneous systems supposed to interoperate efficiently and economically. Today, Interoperability is the emerging paradigm that extends the paradigm of integration to distributed systems. As shown by the FP6 IDEAS-TN continued by the FP7 INTEROP-NoE then by the INTEROP-VLab initiative (http://interop-vlab.eu) the engineering of interoperable organizations must ensure the alignment of IT (standards, platforms) with business requirements (process engineering). Model-oriented engineering methods and model transformation automated procedures are needed to bridge the various layers of system definition from business requirements to architectures & platforms specification, see e.g. the Model Driven Interoperability (MDI) architecture developed in INTEROP-NoE and disseminated by INTEROP-VLab. The development of a critical mass, the defragmentation of the research resources at the European level, the maturation of a multidisciplinary research community merging System Control, ITC, Ontologies of organizations, Enterprise Modeling able to impact the standards are the way to address scientifically the design and engineering of distributed and user-friend networks

3.3 – Autonomy, cognition and control

Autonomous and cognitive systems:

- ✓ exhibit goal-oriented behaviour in sensing, thought and action and flexibly changes its goals and behaviour depending on context and experience;
- ✓ act in unstructured environments without human intervention and robustly responds to dynamic changes;
- ✓ interact with humans and other cognitive systems to jointly solve a task.

How to control autonomous systems with cognitive capabilities so to harmonize the interaction with humans?

Today's autonomous systems operate well in a static, predictable environments, but so far cannot cope with uncertainty and dynamic changes induced by the interaction with complex and intelligent systems, such as humans. Designing a control system for this type of tasks requires acquiring knowledge and understanding of the interacting players via perception, reasoning, and learning. Autonomous systems, e.g., parking assistants, home robots for the elderly and (almost) unmanned production systems, consist of a hierarchy of feedback control loops in which large streams of data, often from image sensing, are processed. Today, collecting and storing large amounts of data is no longer a challenge, but extracting meaningful information from these data requires the adequate combination of methods that are based on explicit mathematical models and hence can be analysed rigorously. Advances in computing power and algorithms currently enables systems with a high degree of autonomy to be conceived, but the route from lab implementation to safe and certified operation in the real world is very long. For the deployment of autonomous systems, their behaviour must be validated under all conceivable conditions.

Systems and control theory provides well understood methods to establish stability, i.e., guaranteed convergence to a desired state, of complex systems. But this is not enough due to the hybrid nature of such autonomous systems where continuous dynamics interact with algorithms that take discrete decisions. Testing of such systems can only cover a very small part of the possible situations. Current trends is ex-post verification which is out of reach for systems of significant size since it can only occur for a very small part of the possible situations. Therefore a major challenge for the next decade is to design such systems with in-built verifiable monitoring and control mechanisms. To address such a challenge, interdisciplinary research is required on the edge of systems and control theory, information science, computer science and statistics, which will enable the verification and validation of highly autonomous systems.

How to ensure safe and certified operation for highly autonomous systems?

The rapid development of technology for sensing and actuating devices, data storage and communication creates new opportunities for data-based control. In particular, the data sets and models are becoming increasingly complex and there is a strong need for methods that can handle the data in a scalable and robust way. Applications include energy grids, transportation networks as well as health care systems. System identification is the term for data driven modelling used in the control community. The dominant approach, based on statistical analysis of parametric models, has been very successful as a basis for feedback control. However, the need to handle large data sets in high dimensions is currently inspiring new methods using non-parametric models closely related to Machine Learning. More research is needed to analyze how these models can be used efficiently in real-time applications.

3.4 - Model-based systems engineering

Since the early days, the design of control systems has always relied on mathematical models of the system under control and of the controller, and a large number of computer tools have been developed to support the design possibly multivariable and coupled control loops by numerical calculations, graphical representations and dynamic simulation. In practice, modelling the physical system under consideration is often the most time- and resource-intensive part of the development process of control systems. Systematic approaches such as object-oriented modelling, which enable the user to combine sub-models from different domains, aim at reducing the effort in model building. In the future, physical elements of complex systems in many cases will be provided by the vendors with their mathematical models that can be combined to build global system models as a basis for system-wide simulation and validation of controlled systems.

While simple controllers can be adapted to differences between the expected and actual behaviour of the controlled systems by manual tuning, complex high-performing control systems must be developed and maintained in a fully model-based fashion in order to operate safely and correctly, taking into account all elements of the implementation, the computer hardware, the software system, the communication system and the control algorithm itself. The fully model-based development of complex multi-layered control systems is not yet possible in an integrated fashion, but is necessary for increased levels of dependability and performance.

Embedded controllers with numerous CPUs acting in parallel are critical parts of complex systems in which both continuous dynamics and discrete switching are present. The complexity of these systems prohibits the verification of their design by exhaustive testing. Verification requires a combination of tools from systems and control science, such as those used for stability analysis, with tools from computer science, such as static analysis and the tools used for assessing the reachability of timed or hybrid automata. Different aspects of control systems are often modeled by different formalisms that are the basis of the use of specific tools, especially if both continuous and discrete dynamics are present. This calls for the integration of different formalisms into one environment with seamless re-use of models and integration of results obtained by different tools. The Compositional Interchange Format (CIF) that is currently developed in a European Project provides a basis for such an exchange of models on a sound basis. Besides the transformation of models from one formalism into another, abstraction of models with guaranteed preservation of certain properties is crucial, as it is neither feasible nor reasonable to try to consider all details of a system in each stage and on each level of the design process.

How to integrate different formalisms into one environment with seamless re-use of models and integration of results obtained by different tools?

One of the most difficult and important problems to solve in the near future is the integration of mathematically sound control design and analysis methods into industrial environments where heterogeneous software and formalism dominate, and where design data, documentation, and models abound on all design levels. These have to be integrated in such a way that inconsistencies and errors are detected early. Such integration can lead to an enormous increase of the efficiency in the design phase and in later operations. While the lack of such integration today already leads to a large waste of resources and lack of robustness to errors, it can be expected that in future systems design projects which will become more and more complex, the lack of such integration mechanisms may lead to an inability to successfully complete complex projects at all.

3.5 - Human-machine interaction

While many control loops in technical devices of all kinds work autonomously without human intervention (apart from initial tuning), large systems such as airplanes, power plants and urban traffic control systems are controlled by human operators who interact with the automatic control systems. One possible way of such an interaction is that the operators (e.g., pilots) actually control the systems but with their orders "translated" into the actuation (movement of the wing flaps in an airplane, opening of valves in a power plant) by a subordinate control system. In this case, the dynamics of the controlled system must be shaped in such a way that its behaviour is considered as satisfactory by the human operator. Another type of interaction is that the controlled system works autonomously but the human operators supervise its behaviour and intervene in case it is not judged appropriate or safe, by modifying set-points or by switching (partly) to manual control. Early detection of faults or changes in system behaviour then is a crucial task. A control system may also compute proposals for the optimal operation of the system, e.g. an optimal adaptation to a change in power demand in an electrical power plant, and offer these proposals to the operators who can accept or modify them and trigger their execution.

How to optimally conjugate automated systems with the interplay of humans?

Advanced control offers huge benefits for a more economic, safer and ecologically more benign operation of potentially unsafe technical systems, but these benefits are often not fully achieved because human operators do not accept the automatic system and switch off important parts of its functions. The more complex and sophisticated control systems become, the more difficult it is for operators to understand the computed strategies and this may lead to more instead of less manual interventions. There is little understanding of the information needs of the operators and of the way in which they perceive and process the information provided. The interplay of humans with highly automated systems with complex dynamics and complex controllers needs a much deeper analysis, bringing together researchers from cognition, human-machine interaction and systems and control. The goal of such research must be the development of a synergistic approach where the capabilities of complex and theoretically well-founded control systems and of humans are combined in the most effective manner.

The adequate design of controlled systems for the needs of humans and so that humans can effectively interact with them is also a pressing issue in all kinds of assistance systems, especially for elderly and disabled persons. Learning is a process governed by feedback as well, so the design of computer-based teaching systems could also benefit much from a system-theoretic understanding of the dynamics of human learning and how it can be stimulated.

Future applications will to a much higher extent intertwine human operation with technical equipments. For the example of manufacturing systems, today's paradigm of strictly separating the workspace of robots and human operators will be partially replaced by cooperation of humans and robots, in order to increase efficiency for complex production steps. In future traffic systems, autonomously operating vehicles have to interact with human-operated vehicles. Future control systems must therefore reach a new level of robustness with respect to the non-determinism of human behaviour. Control techniques must be able to respond timely to new situations and to unpredicted events arising from human behaviour, i.e. the new controllers must be designed for system dynamics which include various types of probabilistic components and stochastic distributions. Achieving high control performance while guaranteeing safety (e.g., avoiding collision of vehicles) will be a major challenge in this field.

Section 4 – **Systems and control for new domains**

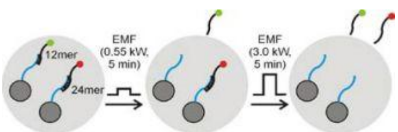
Control science and technology are at the core of the algorithms embedded in the computers and micro-controllers driving most modern systems surrounding us in our everyday life. Ten applications from standard domains and with current and future great impact have been sketched in Section 2. It becomes more and more apparent that in a near future, several other applications relying heavily on control and with significant impact will develop. For the sake of brevity, we introduce below only two of these future applications.

4.1 – **Control and health**

“The challenges to designing instrument control user interfaces and applications”

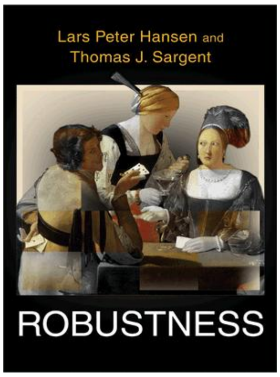
Medical applications can benefit of system and identification theory for models of populations. This is a domain where systems and control methodologies and tools are not yet of standard use but certainly will be in a near future. As an example, in the design of automated methods for anesthesia or control of glucose concentration in diabetic patients (the so-called “artificial pancreas”), regulators must be validated in silico on simulated patients. It is therefore crucial to develop models for a population of patients and then obtain “virtual patients” by sampling in the class. Macroscopic models of patient populations help understand which aspects of inter-individuals variability are responsible for performance degradation of the control action and suggest ways of performing ad-hoc identification experiments on individual patients for reducing critical uncertainty.

“Remote-control nanoparticles deliver drugs directly into tumors”



Progresses on modelling and identification of population dynamics will also impact on pharmacokinetics studies and enable the development of advanced models capturing the role of population variability in drug development or evaluation. For instance in tumor growth inhibition, models capturing the effect of combinations of antitumor drugs are in their infancy and require identifiable dynamic models flexible enough to describe either synergistic or antagonistic drug effects within a population of patients. Such models will open the way to optimal drug delivery in cancer therapy that can be recast into a control problem with conflicting objectives of effective tumor growth inhibition and acceptable toxicity.

4.2 – Control and social and economic phenomena and markets

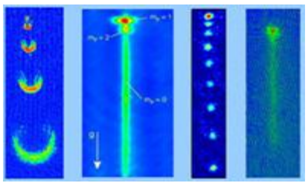


Another nonstandard domain where systems and control science can have a great impact is social and economic phenomena and markets. It is generally accepted that society and economy are complex systems where both deterministic and stochastic descriptions are needed to define main features of their dynamics. This awareness and consequently the requirement of more realistic models have lead to powerful new concepts and tools to deal with apparently random phenomena that at deeper level could be complex and/or chaotic. Recent financial crisis showed that the understanding of socio-economic systems is not enough mature to deal appropriately with these type of events. Such crises are generated by the complex interplay of many actors of the "system". In particular, the concept of "black swan", i.e. a dramatic event, which is understood *a posteriori* to be of low probability but not impossible, starts to be a paradigm in the field. The possibility of intervention on such large systems is limited but not irrelevant and the development of new control techniques is of paramount importance. The central concept is the necessity of controlling very large groups via targeted actions on small subgroups. *See '*Robustness*' by Lars Peter Hansen & Thomas J. Sargent, 2007 (eBook, 2011). Thomas J. Sargent, Winner of the 2011 Nobel Prize in Economics, See also his paper published* in IEEE TAC 40(5) 1995, pp.968-971.

Systems and control theory has a lot to offer for the analysis and evaluation of policies for long- and short-range social and economic phenomena, and for operating on markets. Examples include the stabilization of currencies, placing bids on the energy power exchange, and hedge portfolios of assets against risk. Systems and control theory can support this by important insights in the reaction of complex dynamic systems to feedback in order to avoid, e.g., oscillations due to rapidly changing policies or prices.

4.3 - Control and quantum engineering

"Finding ways to seize atoms, molecules, and photons"



Systems and control science can lead to significant improvements in emerging quantum technologies ranging from magnetic resonance imaging (MRI), inertial navigation systems, optical communications to high precision metrology, quantum communications and circuits and prototypes of quantum computers. Extensions of traditional control concepts developed for classical systems, such as optimality, feedback, stability, robustness, filtering and identifications to the quantum systems are becoming key issues. As an example feedback control admits two different quantum counterparts: measurement feedback and coherent feedback; this multiplicity results from a fundamental difficulty that must be overcome by any quantum extension of classical feedback, namely the random back-action on the system caused by sensor measurements. Similarly state estimations (quantum tomography) and system identifications (quantum process tomography) face the same difficulty with the precision limits imposed by the Heisenberg uncertainty principle. Future technological developments exploiting quantum features will have to include some robust stabilizing mechanism to protect their fragile quantum states against decoherence due to environment coupling. These quantum technologies will rely on control concepts redesigned for the quantum world.

Section 5 - **Recommendations**

Stimulate collaborative multi-national and multi-disciplinary research.

Research and development in systems and control are vital for the future of Europe. Systems and control have to be a top priority in the next framework program, with considerable funding provided for the topics listed in section 3.

Support basic research and research focused on application domains

Systems and control science has two facets: research in basic principles, theories, and tools, and research related to specific application domains. The strength of the discipline is the interplay between these two sides: while research related to application domains provides new solutions to pressing problems in these areas, it also generates new approaches, theoretical results and tools that can be transferred to other domains, as well as challenges to fundamental research. This fundamental research provides the sound basis on which technical solutions with guaranteed properties can be developed, independent of specific applications. Funding is necessary both for fundamental and applications-oriented research, and both in sector-specific programs and in ICT as a program that provides enabling technologies for all sectors.

Overcome the barriers between the traditional disciplines.

The application of systems and control science requires the knowledge of the application domains as well as of its theoretical foundations. The full strength of the discipline is made effective in close collaborations with researchers and developers in the application domains. While this has already been achieved in many application areas as, e.g., mechatronics and process control, a qualitative leap is necessary in the application of systems and control science to sectors and phenomena where it has as yet not been adopted, such as health care, biological systems, social systems, development of large infrastructures.

Foster co-funding among several European and national sources.

The dual nature of control research, theoretical and applied, is well suited for co-funding mechanisms. A larger project may have its fundamental research supported by FP8, while its application to close-to-market research may be carried out in close collaboration to companies in the framework of the European Institute of Innovation and Technology (EIT) which main objective is to foster academia and industry cooperation. EIT support would mainly be done through its three Knowledge and Innovation Communities (KICs) – Climate-KIC, EIT ICT Labs and KIC InnoEnergy. National supporting agencies can also join in a co-funding scheme added to European main funds. In the same way, it will be important to continue supporting bilateral cooperation with countries like USA, China, Russia and Brazil for specific topics.

- **Disseminate methods and tools in education, industry and society.**

Powerful methods and tools are being developed in the field of systems and control: they are general enough to be transferred to other domains thus providing a common interface among often separated research communities. New stimulation actions are needed to disseminate these methods by a suitable educational effort. A rigorous education in the fundamentals of control and its applications together with the principles of economics is essential to develop a robust innovation ecosystem. Our present students will be the engineers and researchers of the future and must be formed to cope with the interdisciplinary nature of ICT, by planting in them the seed of innovation. Furthermore, new tools for modelling, analysis and design of advanced control systems are needed to transfer these methods to industry. The tools shall allow an engineer (not necessarily a researcher) to apply the methods developed to problems of industrial relevance thus ensuring a significant socio-economical impact to the outcome of advanced research. Transferring technology is always a difficult but necessary activity to make research relevant to industry. In addition, citizens have a hard time understanding technology and part of a technology transfer agenda must include a dissemination activity aimed at illustrating the relevance of the technology to society at large. Technology transfer must be addressed with a concerted effort and cannot be left to the goodwill of the researchers involved. Specific funding for this purpose should be planned.

- **A focal point is needed on top of applications.**

The interest of systems and control is shared by several industrial sectors and companies, as demonstrated by the variety of industries supporting this report. We need application-oriented control research, but also cross-cutting / generic research in order to ensure we move beyond the state of the art of methods, algorithms, architectures and tools for the future.

- **Recommended topics.**

System-wide coordination control of large-scale systems
Distributed networked control systems
Autonomy, cognition and control
Model-based systems engineering
Human-machine interaction

➢ Recommendations from the HYCON2 Industrial Advisory Board

DENSO AUTOMOTIVE	*"Automotive systems are evolving continuously and they are becoming more complex to control to. Today, via smart-grids, electric and plug-in hybrid vehicles are being integrated into the electric power networks. Thus, the scale of automotive systems is growing larger, relating to infrastructure, energy production and storage, tele-communication, and so on. Therefore DENSO thinks that the control methodologies and tools concerning smart-grids, cyber-physical systems, large-scale distributed systems and other emerging issues as outlined in this report are very important. DENSO appreciates and supports the research in those fields, and itself actively takes part"*
BAYER Technology Services	*"Most of the plants in chemical industry operated completely by automated systems. The operator is not operating anymore, but more monitoring and optimizing the process. More and more process training simulators based on dynamic models of the process are helping to keep the operator trained in the behaviour of the production plant and process and to optimize the control system. The new challenge and very important is to increase the efficiency even more in operating the production under all circumstances as economical as possible. This is only possible by a holistic process control of very complex systems. It means to help the operator to make the right decision in each situation of the process in communication with a highly automated process. Based on process models he needs to get the right information – not less and not more – at the right time under present circumstances, enabling to forecast the behaviour of process. This kind of assistant systems have to use all relevant existing data of the process, derive information out of that and present this to the expert in an totally new type of man-machine interaction. This should be really a team-system-interaction taking under consideration, that the team could be distributed all over the world. This new way of process control would be a big step forward in order to operate our processes and using the resources more efficiently by reducing the environmental impact e.g. by reducing energy consumption and CO2-emission. However is a huge challenge for the research to derive these new methods, which surely requires international co-operation and co-operation between industry and academia."*
BASF SE	*"Automation technology is becoming more and more a key technology for production efficiency and operational excellence in chemical production plants. Examples for this are significant contributions to feedstock efficiency, energy efficiency and plant safety excellence. The development of process automation has to consider the development of methods and the rapid improvement of IT on the one hand and specific requirements for the process industry on the other hand. The rapid technology push is characterized by the penetration of automation technology through information technology. From a market pull aspect, complex online-applications with extensive computing effort, much simpler cross-linking of diverse systems and better human machine interfaces will be required in the future. The usage of modern automation technology brings up new challenges to operations, system integrators and manufacturers of automation systems, which have to be solved to achieve an enduring value proposition for chemical plants also in the future:* - *new automation technologies must be compatible to existing assets* - *the increasing technical complexity of automation solutions has to be encapsulated for operators and demands new concepts in qualification of system integrators and service providers*

	- *the growing business requirements like shorter project execution times and higher plant availability need new project execution strategies.* *Research studies on these rapidly changing topics will generate high future value. And these research activities will qualify automation engineers which are highly and moreover increasingly needed."*
ECOSIMPRO	*"One of the essential requirements in designing aerospace systems is to guarantee high system reliability; ie, a low failure probability. In the case of space systems, it is enforced by the practical impossibility of repairs in orbit. For its part, in aviation it is enforced by the stringent safety requirements imposed. The control and simulation of these systems constitutes, more and more, an important stage of the design phases. In the preliminary phases the model enables us to evaluate the performances of different alternatives, and in the last phases to predict results, fine-tune the control and design parameters and verify the design in the different operating modes, thus increasing reliability."*
GTD Sistemas de informacion	*"Control of modern aerial vehicles by networks of sensors and actuators along with performance and efficiency requirements represents a new scenario in the domain of control and information in complex and non-linear systems. This scenario becomes still more research-demanding when looking forward to future UAV aerial vehicles. Regarding not only the vehicle itself, air traffic control and management has become a major concern. Although being still human operated in the future, the continuous growth of traffic makes this human based control very difficult. It is important to provide human controllers with tools to model, simulate and predict situations in order to allow better understanding and decision making. Working in the aerospace domain in collaboration with European and French space agencies, GTD founds essential the research and development concerning the future airlaunch vehicles, allowing to provide better launch services and to a larger scope of clients, where control, guidance and navigation play a major role."*
CADLM	*"Manufacturing technologies and in particular automotive related process are gaining exponentially in complexity. This is due to the market demand related to the need for enhanced safety and environmental compatibility of products. The combination of mechanical and non-mechanical technologies (passive/active/on-board/communications, etc.) is at the origin of the increased complexity and needs integrated control strategies which monitor in a predictive way the robustness of the proposed solutions. At CADLM we are concerned with solutions and products in order to improve the management of such complex systems and think that the proposals made in this paper lead to innovative solutions in this respect and therefore support it's initiative."*
EDF	*"The integration of renewable intermittent generation in the power systems presents many challenges (generation hard-to-predict and not easily dispatchable, location rather dispersed on the territories..) and globally generates technical and economic problems for the management and monitoring of the power systems to maintain its safety and reliability. So, the power systems are facing an increasing complexity with larger random aspects for the management of the intermittent renewable generation (solar, wind, ...) and the new applications (i.e. EV/HEV). This complexity includes the technical constraints of the power system (balance supply and demand at global and local levels, network congestions, voltage control, etc.), and also the multiple interactions between ICT and power network particularly with new open questions such as ICT architectures for massive data processing at different time and space scales, decentralized versus centralized control solutions, management of degraded modes, interoperability, secure operation particularly in terms of cyber-security, etc."*

ALSTOM	*"Today, smart grids are about power supply, information and intelligence. Integration of renewable energy, energy storage, electric vehicle and self-healing technologies taking into account environmental impact, quality, security, energy efficiency and Customer feedback together with all economic aspects will add more complications in dealing with modelling and control of such system. Consequently, CONTROL is at the heart of the Information and Communication Technologies of complex systems."*
WEST Aquila	*Design and development of embedded networking technologies for advanced monitoring and control applications requires detailed modelling of interconnected (often distributed) sub-systems and accurate mapping of application performance on network architecture and protocol requirements: while meeting QoS requirements (also in terms of security protection against attackers, mis-behaviours, etc.), the design approach is aimed at minimizing energy expenditures, complexity and costs. Moreover, network-wide minimization of energy consumption is envisaged as a crucial paradigm in modern network (re)-design, since communications networks consume today a significant part of energy worldwide. As a technology start-up operating in the field of wireless networked systems, WEST Aquila is highly committed in designing, developing and prototyping advanced networking platforms and their integration in various application domains (smart agriculture, physical/logical access control, emdedded positioning,....): then we strongly support long-term research plans aimed at fundamental advances in modelling of distributed and networked systems, development of design tools that integrate simulation and validation and close the gap with the implementation phase.*
Ford Motor Company	*"The increased amount of degrees of freedom and information in vehicles (e.g., steering actuators, vehicle connectivity, hybrid powertrains,...) opens several possibilities for reducing emissions and fuel consumption, and for increasing active and passive safety. The coordination of the smart actuators and the selective processing of the available information require the use of novel control strategies, as well as of formal verification methods to ensure system-wide control robustness and software correctness. In addition, while becoming more pervasive, the control strategies are interacting more and more with the driver. Human-machine interaction is extremely important to guarantee the correct operation and the performance of the vehicles. As such there is need to formally study and model this interaction. We consider these research studies of important value and we look forward to interact on many related topics in these rapidly expanding areas."*
INEOS	*"Modern chemical plants are operated by a relatively small crew. The number of controllers, regulatory and advanced, per operator has increased significantly over the last decades. This is especially true in the basic, bulk chemicals business such as refining and petrochemicals. At the same time, plant efficiency, energy efficiency and product quality reproducibility by optimization has become a major focus for modern applications. These conflicting goals can only be reached by employing a modern automation infrastructure, modern advanced control solutions and regular, possibly online optimisation as well as by continuously challenging the employed control structure. The results are highly efficient, nearly fully automated plants. Only the research in process control already performed and the facing of future research challenges will help us maintain the high efficiency and product quality of today and allow us to remain sustainable and profitable in the future. One of the advantages of the modern plant operation are operators that need not simply operate the plant but can be employed in better plant and product management and optimisation using experience that only they have collected, thus using the unique capabilities of the human mind. One of the resulting challenges is to interface with and monitor the automation system in*

	such a way that only relevant information (not data) is passed to the operator. The final result of human interface research should thus be the answer to the question: "What can the human operator do best and what can the machine do best?" *While most of the theory for successful advanced application of automation is readily available, the answer where and how to best employ and monitor it with the correct human interface has yet to be answered. An answer to this question requires interdisciplinary (possibly not just natural science and engineering) approaches and will give plant operation and plant effectiveness a further boost.* *Online, possibly dynamic, nonlinear optimization of complete product plants, maybe even whole sites with highly interacting plants is one candidate to help answer that question, while at the same time finding the last realizable plant operation improvement, especially on multi-product plants. Thus, one major future challenge for tapping the full potential of optimization are re-usable, fast implemented, cost effective dynamic plant models."*