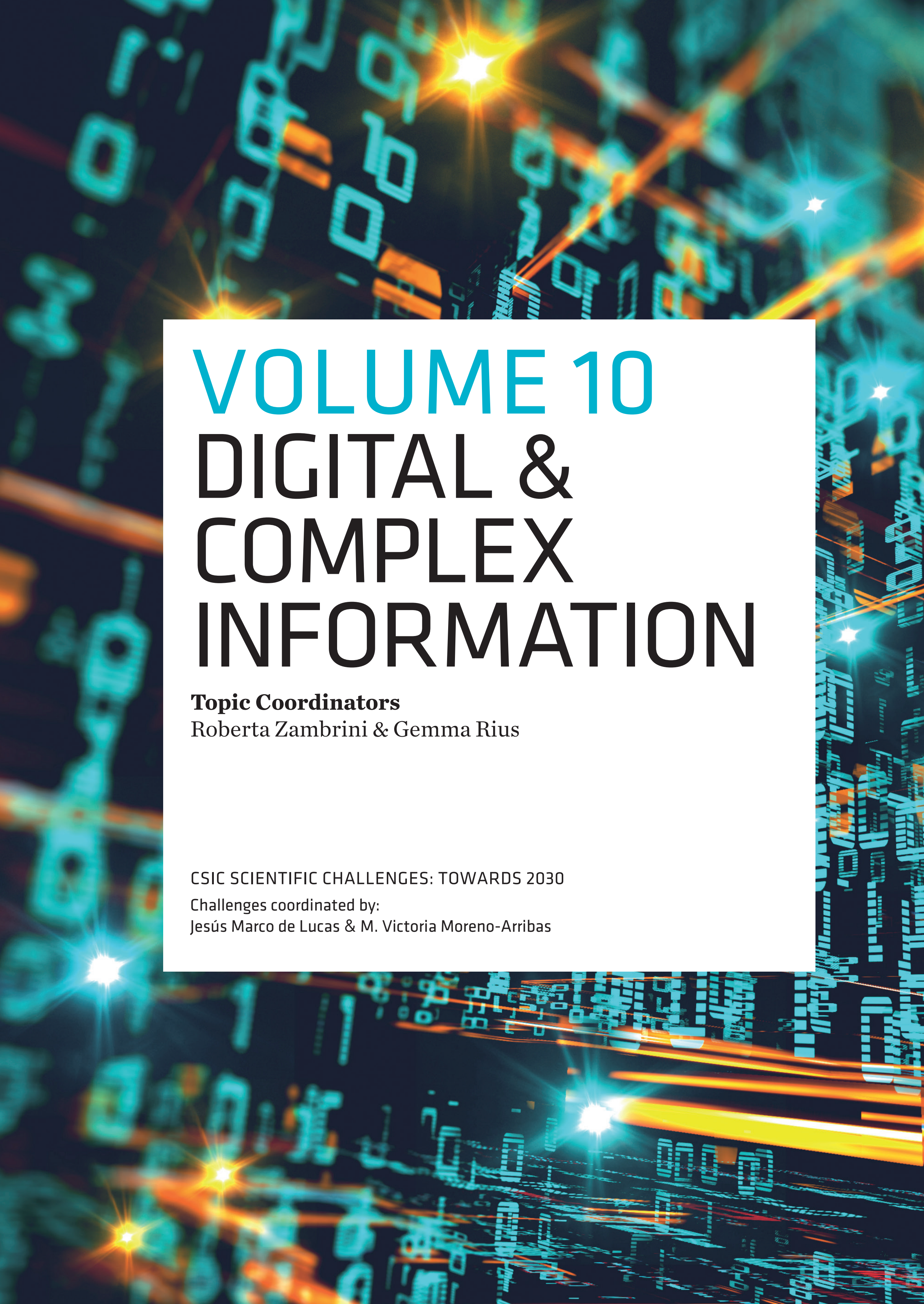

VOLUME 10

DIGITAL & COMPLEX INFORMATION

Topic Coordinators
Roberta Zambrini & Gemma Rius

CSIC SCIENTIFIC CHALLENGES: TOWARDS 2030

Challenges coordinated by:
Jesús Marco de Lucas & M. Victoria Moreno-Arribas

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CSIC SCIENTIFIC CHALLENGES: TOWARDS 2030

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Topic Coordinators
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CSIC SCIENTIFIC CHALLENGES: TOWARDS 2030

What are the major scientific challenges of the first half of the 21st century? Can we establish the priorities for the future? How should the scientific community tackle them?

This book presents the reflections of the Spanish National Research Council (CSIC) on 14 strategic themes established on the basis of their scientific impact and social importance.

Fundamental questions are addressed, including the origin of life, the exploration of the universe, artificial intelligence, the development of clean, safe and efficient energy or the understanding of brain function. The document identifies complex challenges in areas such as health and social sciences and the selected strategic themes cover both basic issues and potential applications of knowledge. Nearly 1,100 researchers from more than 100 CSIC centres and other institutions (public research organisations, universities, etc.) have participated in this analysis. All agree on the need for a multidisciplinary approach and the promotion of collaborative research to enable the implementation of ambitious projects focused on specific topics.

These 14 "White Papers", designed to serve as a frame of reference for the development of the institution's scientific strategy, will provide an insight into the research currently being accomplished at the CSIC, and at the same time, build a global vision of what will be the key scientific challenges over the next decade.

VOLUMES THAT MAKE UP THE WORK

1 *New Foundations for a Sustainable Global Society*
2 *Origins, (Co)Evolution, Diversity and Synthesis of Life*
3 *Genome & Epigenetics*
4 *Challenges in Biomedicine and Health*
5 *Brain, Mind & Behaviour*
6 *Sustainable Primary Production*
7 *Global Change Impacts*
8 *Clean, Safe and Efficient Energy*
9 *Understanding the Basic Components of the Universe, its Structure and Evolution*
10 *Digital and Complex Information*
11 *Artificial Intelligence, Robotics and Data Science*
12 *Our Future? Space, Colonization and Exploration*
13 *Ocean Science Challenges for 2030*
14 *Dynamic Earth: Probing the Past, Preparing for the Future*

CSIC scientific challenges: towards 2030
Challenges coordinated by:
Jesús Marco de Lucas & M. Victoria Moreno-Arribas

Volume 10
Digital & Complex Information

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ABSTRACT

Information, gathered, stored, processed and transmitted, is the cornerstone of the present era and shapes every aspect our daily life, thus permeating cultural and social deep changes. A multi and cross-disciplinary approach is needed to cover all present challenges of the Information Age, ranging from both the more technological aspects to the social ones. This duality is reflected in the title of this volume, Digital and Complex Information. The current Digital Transformation is enabled by developments in physics and engineering and entails several fields including electronics, optics, material science, and quantum technologies. Nowadays challenges include sustainable and energy efficient electronics, integrated photonics with new functionalities, quantum computing and machine learning, and operation within the Internet of Things. Nonetheless the Digital world generates an ever-increasing amount of data in which security and trust play a critical role. The advances in digital technologies call for a new scientific research approach: an Open Science, reproducible, interoperable and accessible. New avenues are open in how we deal with Humanities and with individual/social security and rights, within digital citizenship. This is the broad spectrum of challenges that drives research across about the 40 CSIC institutes in line with the latest developments in digitalization worldwide.

CHALLENGE 4

ABSTRACT

Cyber-Physical Systems (CPS) and Internet of Things (IoT) are complementary paradigms in digitalization. Sensors and actuators, hardware designs and development platforms, architectures and computational frameworks, modeling, control and optimization, and potential applications are analyzed and presented from impact and main challenges up to strategic plan.

KEYWORDS

IoT sensors and actuators

IoT hardware designs and CPS platforms

architectures | computational frameworks

modeling | control and optimization

CHALLENGE 4

CYBER-PHYSICAL SYSTEMS AND INTERNET OF THINGS

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1. EXECUTIVE SUMMARY

Cyber-Physical Systems (CPS) and Internet of Things (IoT) are complementary paradigms of the digital transformation impacting all economy sectors/domain and society levels. Last decade, CPS and IoT have been growing, in parallel, in foundations and developments by sharing Internet, embedded systems and common targets such as tailored sensors and actuators, platforms and frameworks but also emerging methods and computational architectures. The next ten years require a big effort to produce new research-driven knowledge and breakthrough technologies to produce a qualitative change toward Society and Industry 5.0, the new paradigm led by Japan and included in the Horizon Europe framework program. The four areas of key challenging points identified are related with sensors and actuators, hardware designs and platforms, architectures and computational frameworks, and modeling, control and optimization. The impact on science and potential applications in sustainable agriculture, smart buildings and critical infrastructure, smart mobility, logistics, smart manufacturing, and health and well-being have been also identified. Furthermore, key challenging points including scientific as well as technological and engineering issues are properly defined in new materials and novel sensors, specific hardware designs, computational architectures, signal processing and estimation, and modeling, control and optimization.

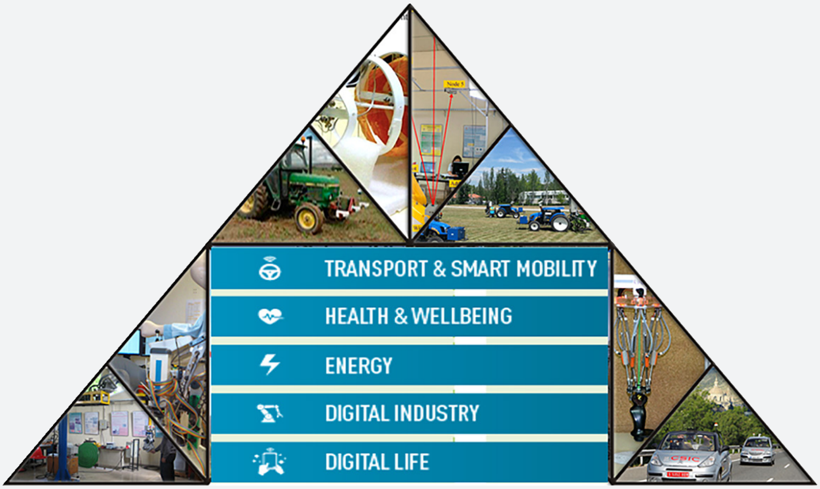
2. INTRODUCTION AND GENERAL DESCRIPTION

Cyber-Physical Systems (CPS) and Internet of Things (IoT) are complementary paradigms because both aim at integrating digital capabilities, including connectivity with physical devices and systems. Moreover, CPS and IoT include interacting logical, physical, and human components by integrating logic and physics. However, there are some differences [Greer et al., 2019]. IoT makes more emphasis on connecting "things" towards connecting "everything" whereas CPS put more attention on integrating computation, networking and physical systems. CPS and IoT are cross-cutting human-in-the-loop technologies covering a variety of all domains, Both paradigms have been driven in parallel by two independent scientific communities in Europe and USA, although CPS and IoT are closely related [Castaño et al., 2019]. Moreover, the core technologies for both IoT and CPS is the Internet as large-scale network and embedded systems. Therefore, nowadays both are considered complementary fields, and Industry 4.0 and the upcoming Industry 5.0 paradigm are special fields of application of CPS and IoT. Most initial IoT concepts were focused on traceable objects, with origins in the Radio-Frequency-IDentification (RFID) context [Greer et al., 2019]: low-power limited-capability "items" that are uniquely identified and can interact to provide location or simple information on state. The original IoT concept expanded over time to include "things" with sensors, offering new, more complex data streams that could be used for measurement and analytical purposes and to create value-added features and services [Griffor et al., 2017].

CPS are recognized as a top-priority in research and development. Although approaches in software engineering (SE) and control engineering (CE) exist that individually meet these demands, their synergy to address the challenges of smart CPS in a holistic manner remains an open challenge towards a System of Systems new paradigm [van Lier, 2018].

Worldwide research agencies such as National Science Foundation (NSF) in USA and the European Commission through the H2020 and the upcoming Horizon Europe framework program have identified CPS and IoT as a top

FIGURE 4.1–Relevant sectors of IoT and CPS in 2025 [ECSEL JTI, 2020].



priority for the next decade and allocated substantial funding to address the development of new paradigms, concepts, and platforms laying the foundation for future generations of System of Systems. CPS and IoT are becoming large-scale pervasive systems, which combine various data sources to control real-world ecosystems such as intelligent traffic control, smart production systems, smart buildings, urban water management, precision agriculture, among others. IoT and CPS have to control emergent behavior, be scalable and fault tolerant. In this book, the impact on the basic science panorama, potential applications and key challenging areas are analyzed.

3. IMPACT IN BASIC SCIENCE PANORAMA AND POTENTIAL APPLICATIONS

3.1. IoT sensors and actuators

At sensor level, techniques such as photon-counting are enabling radical departures from classical vision algorithms. New circuit structures improve the accuracy of depth measurements and are notably reducing the form factor of typically bulky systems. The race for solid-state LiDAR might be very well played in the field of CMOS image sensors.

Benefits on environment monitoring and wildlife conservation are also remarkable. New and advanced wildlife monitoring technologies are shifting the paradigm of wildlife conservation and management for more precision and efficiency. The monitoring of wildlife includes tracking animal movements and habits, studying population distribution, and identification of species and possible threats. A major requirement for wider adoption of these units is ultra-low-power low-cost realizations. On the other hand, air-coupled ultrasonic efficient technologies in IoT devices include new possibilities to analyze and measure water content of plants for better water control in agriculture. Another field with new possibilities is in the medical field with generation of elastography images of cornea in vivo, or the work and to provide a feedback about the tissue being cut when using laser scalpels. Another example is in the food industry, where this technology can provide completely non-destructive and non-invasive mean to inspect different food products integrated in the production line.

3.2. IoT and CPS hardware designs and development platforms

Nowadays, big companies such as Microsoft, Cisco, Intel among others have consolidated the development of hardware and development platforms, including different processors performances, RAM availability and additional characteristics such as Wi-Fi/Ethernet modules, Input/Output ports, etc.

Overall, nowadays, Raspberry Pi, Beaglbone and Arduino, have fulfilled the demand in simple low-cost platforms, which could provide some basic functionality and widely used in many research and development projects and prototypes. Therefore, the impact on the current IoT and CPS hardware designs and development platforms is tremendous and cross-sectoral, for example in three cross-correlated fields of application such as smart mobility, smart buildings and energy efficiency.

3.3. Architectures and computational frameworks for IoT and CPS

The research on CPS and IoT architectures and computational framework has already produced significant impact, which may be analyzed taking into account different IoT layers: 1) application layer; 2) network layer; and 3) perception layer. The network layer is the most important layer in IoT architecture, because various devices (e.g., hub, switching, gateway, cloud computing perform, etc.), and various communication technologies are integrated in this layer.

Special attention has been given to cloud and fog computing. Nowadays, the integration between cloud computing and the IoT and CPS allows resource-constrained IoT devices to offload data and complex computation onto the cloud, taking advantage of its computational and storage capacity. However, the centralized nature of a cloud can lead to a considerable topological distance between cloud computing resources/services and the vast majority of end (user) devices, limiting the deployment of some cloud-based solutions. On the contrary, Fog computing is an evolution of early proposals with the objective of better addressing needs of the IoT and CPS, therefore cloud and fog computing will be essential for IoT and CPS in the upcoming years.

In order to adopt Cyber-Physical System of Systems (CPSoS) paradigm, new approaches on the integration in several digital functionalities in a cloud-based platform have been yielded. New research results will enable real time multiple devices interaction, data analytic and global reconfiguration to increase the management and optimization capabilities for increasing the quality of facility services, safety, energy efficiency and productivity.

3.4. Modeling, control and optimization for IoT and CPS

The first important area in this key challenging point is signal processing and estimation for IoT and CPS, which has several implications. For example, in the transition from the theoretical research on signal processing and conditioning into the real world applications. It implies facing the limitations of low cost sensors and limited processing power. The results achieved up-to-date have received a great international attention of the research community, as well as on the business sector, especially those companies offering services and solutions based on ultra-wide band technology, since it allows to become aware of the strengths and limitations of ultra-wide band components, and the challenges that still exist at the research level to develop more precise and robust solutions.

The second aspect and one of the cornerstones of CPS and IoT is the modeling, control and optimization, with an important impact in medium and long terms. Nowadays, the research is focused on system modeling and control. The design and implementation of networked control in CPS have posed several problems in time driven and event-driven computation, time-varying delays, transmission failures, and reconfiguration of the system. With the advent of CPS, co-design issues are reconsidered in various aspects. For example, since CPS are typically networked control systems, the effect of the network delay on system stability has recently been studied in terms of the trade-off between stability and real-time schedulability. The interaction among the sensors, actuators, physical systems, and the computing elements should be carefully incorporated into the design of IoT and CPS sensor-actuator networks. Certainly, verification and validation of CPS and IoT have received a lot of attention. In this context, hardware and software components, operating systems, and middleware are required to go beyond complete compositional verification and testing of CPS and IoT.

3.5. Potential applications

Long and medium term impact on society is analyzed, considering relevant economic and social sectors and potential applications, as follows.

Sustainable Agriculture: CPS and IoT sensors and computational framework will be essential in sustainable agriculture (IAS, CAR). The development of new sensors for monitoring crop physiological parameters in applications such as irrigation scheduling, early plant disease detection or plant phenotyping will have strong impact in short terms. This includes monitoring the soil-plat-atmosphere continuum using a suite of sensors technologies (e.g., thermal, hyperspectral, LiDAR, micrometeorological) at different scales (airborne imaging sensors, ground sensors and sensor networks).

Smart buildings and critical infrastructure: The challenge of the next decade is not only the development of IoT for smart buildings but also the application of this technology and its concept of intercommunicated networks to different problems that until now had been solved in a closed and autonomous way. The key is, therefore, how to migrate these applications to the technology and the concept of IoT. The drawbacks of this type of data-based environments have also to be assessed and solved, powered by devices connected to a network; the main one is the security aspect, both physical and cybernetic. Structural health monitoring enables to obtain information about the behavior and degradation state of construction structures. For critical infrastructures such as nuclear power plants, transportation networks, electrical, water, oil and natural gas systems, different techniques are rising. ITEFI is working to deepen in basic science and development technologies in which incorporates the knowledge acquired for structural health monitoring. The characterization of construction materials conjugates different degradation processes with the use of non-destructive techniques. Some of the structural health monitoring techniques are based on wireless sensor networks but it is still necessary the migration of some wired systems. Therefore, it is necessary the conjugation of basic science and technology. IRI develops model-driven and data-driven techniques for state estimation and real-time monitoring of critical infrastructure, predictive control techniques for optimal management and fault-tolerance methodologies for CPS efficiency, reliability, resilience and sustainability.

Smart mobility: During the last decade a large number of IoT and CPS technologies for smart mobility (CAR, IRI, IMB) have been developed by the research community.

Automated cars use today a huge amount of information that is gathered, processed and analyzed by the vehicles themselves. With the emergence of the IoT and CPS, autonomous driving services will be able to use information from a huge variety of devices both from the vehicle surrounding and from the cloud. In this connection, some limited functions traditionally located on the vehicles in the past, might now be processed, using multiple data sources, in the surrounding IoT-infrastructure or in the IoT-backend, resulting in more dependable functions. In addition, the recent emergence of high-performance edge computing will allow to embed intelligence that enables for consistency checks with the cloud data, and therefore lead to a safer and more secure mobility experience.

IoT and CPS are also relevant in artificial vision, ranging from the image plane to the interpretation of the scene. One focus is on intelligent transportation, where the impact can be especially significant at various levels: automation, traffic management, safety, security, etc. This is also directly connected with the lines on sensor networks and remote driving. Finally, the aforementioned paradigm of the Internet-of-Things is another massive technological (and market) framework where future advances in terms of power efficiency, 2D/3D embedded integration, energy harvesting, visual processing acceleration, etc., will find direct applicability.

Smart logistics and transportation: In particular, CAR is involved in very specific sectors including the development of technical aids for firefighters, making use of inertial sensors, virtual reality, use of maps and cooperative location, to improve safety and speed in interventions of burning or collapsed buildings.

In the logistics sector, the analysis of movement patterns in many not yet automated warehouses, where the operator has to travel dozens of kilometers per day for the preparation of on-line orders is very promising for IoT and

CPS. Tracking worker movements and applying data analysis will allow improving the efficiency in the plant. Another area of interest is the analysis of large flows of people, in common places such as shopping centers and airports. The objective is not advertising, but the creation of informative tools for both the common user and the operators of the spaces.

Smart manufacturing and emerging cyber-production systems: Industry 4.0 is evolving towards more automated data exchange beyond manufacturing technologies by unifying technologies of the third industrial revolution (automation processes and new production technologies) with technologies of the information age such as storage, processing and massive data transmission. Solving this challenge will have implications of great impact in robotics, computer science, mathematics and engineering, also in health and social sciences, as they will change the way we relate to the factory of the future. One strategic theme (CENIM,CAR) is to focus on Modeling and Control 5.0 to be able to understand and guarantee the manufacture on demand of custom metal prototypes and parts in short run productions, since this is one of the fastest growing areas in the industry thanks to advances in additive manufacturing.

Smart human motion, well-being and health monitoring: Monitoring the health of the elderly, to promote their independent life at home, is a classic line, but in which it is mandatory to introduce new non-intrusive monitoring techniques (e.g., RFID and UWB tomography), as well as ambient intelligence, supported by special sensors in the home which will not only allow to monitor the location and mobility of the persons in their home, but also to monitor their type of activity, their vitality or fragility, and the early detection of diseases predicted by changes in the behavior of the elderly.

4. KEY CHALLENGING POINTS

4.1. IoT Sensors and Actuators

New functional materials for IoT sensors and actuators are needed to enable low cost, energy efficient mm-wave devices of the new IoT paradigm. For example, a promising candidate is the aim at developing a new family of ferrites based on *s*- Fe_2O_3. A key concept zero field magnetic resonances in the mm-wavelength and THz bands, based on their large magnetic anisotropy, where the larger the magnetic anisotropy the higher is the magnetic resonance frequency.

The new materials and alloys, and processing to be considered in the next 5-10 years for IoT devices are:

a. New family of ferrites for efficient non-reciprocal devices for wireless communications in the mm-waves and THz frequencies.
b. Epitaxial quartz films on Si for new devices for IT and sensing applications.
c. Patterning those films and fabricating on-chip quartz-based MEMS for ultra sensitive mass sensors, high frequency oscillators and optomechanical devices.
d. Doped PMN-PT single crystal materials with gigant piezoelectric to produce a new generation of air-coupled transducers.
e. Novel fabrication technologies to produce thick film materials, stacks of thick film materials such as reinforced syntactic foams.

Another challenge in IoT sensors is the sensory plane as, for instance it is concerned with efficiency in extracting the relevant information contained in the visual stimulus. Any alternative representations of the scene that constitute an effective reduction of the visual data flow in favor of distinctive features can be the key to practical implementation of embedded vision systems, from compressive sampling to event-driven image sensors.

In a higher hierarchy level, the second challenge is the processing of visual information, which is very expensive in computational terms. Visual information processing has traditionally been a major issue for the practical realization of embedded vision systems. Consequently, the scientific community is focused on developing non-traditional strategies that efficiently cope with the computational load while keeping the advantages they have brought about. These strategies cover from the design of the sensor itself, to mixed-signal processing schemes, hardware acceleration, or dataflow organization.

These challenges will effectively leverage the various components for particular requirements of vision-based applications. Even when the data flow is suitable for a properly designed underlying processing architecture, only optimal selection of the different components will provide needed specifications and expected performance.

A comprehensive analysis of the operations to be carried out in terms of scheduling and parallelization, together with a deep understanding of the impact on different hardware platforms, is crucial to boost the application performance.

Another aspect to be considered is the power management, which is rather important in future applications related with smart mobility and smart buildings. A certain level of autonomy can prevent, for instance, the influence of noisy power lines inside a vehicle. It can also leverage the need of developing always-on traffic monitoring infrastructures. In these scenarios, energy harvesting permits vision nodes to operate exclusively on batteries. Extracting energy from the ambient is also pursued in application fields of IoT. Prototypes of image sensors simultaneously capturing images and harvesting energy, even embedding processing and memory have been recently reported.

Special attention will also receive the combination of electrochemical or optical transducers at the microscale in relation with microfluidic applications, fully automated with compact analysis systems, which can perform autonomous measurements of (bio)chemical parameters. Most analytical procedures require sample preparation/conditioning, frequent calibration, and the use of reagents in order to obtain the concentration of a chemical species.

For complete IoT systems, the following developments are to be delivered:

a. LiDAR and CMOS-SPAD image sensors for 2D/3D vision. Single-photon avalanche diodes (SPADs).
b. Low-power, highly-integrated and low memory requirements of sensors.
c. Autonomous operation in the measurement of chemical parameters with low power and compact systems suitable for IoT.
d. Doped PMN-PT single crystal materials with gigant piezoelectric to produce a new generation of air-coupled transducers.
e. Integration of all elements for a new generation of air-coupled transducers.
f. Technology standardization.

4.2. IoT and CPS hardware designs and development platform

New hardware design and development platforms with new embedded functionalities and computational processing capabilities are urgently needed for IoT and CPS. These platforms should meet new requirements of specific projects and research should be conducted on new knowledge about platforms, embedded operating systems and the corresponding sensors. For example, emerging and promising technology is being nowadays limited by conventional non-destructive systems to guarantee quality of components. This has a direct impact on the productivity and positioning of Spanish and European strategic sectors like carbon fiber reinforced parts for aerospace industry, where non-destructive tests are becoming the production bottleneck in the next years.

Key challenges in IoT and CPS hardware design and development platforms for specific cases are:

a. IoT/CPS design and platforms for cognitive and resilient production systems.
b. IoT/CPS design and platforms for adaptive ultrasound imaging in industrial applications.
c. Fast the imaging frame-rate up to 20.000 images per second required for ultrafast scanning applications
d. IoT/CPS hardware design and platforms for 3D ultrafast ultrasound imaging systems.

4.3. Architectures and computational frameworks for IoT and CPS

Research and development challenges of digital transformation in the next decades require new paradigms combining control engineering, information software and telecommunication engineering. Nowadays the **top-10 topics targeted worldwide** are: signal processing and estimation, computational models, architectures and design approaches, interfacing the computational and physical world, dependability, synergy between monitoring and adaptation techniques, distributed algorithms, monitoring and control, handling emergent behavior and uncertainty, modeling and simulation, scalability and evolvability.

Software platforms with well-defined and appropriate levels of abstractions and architecture are essential for the development of reliable, scalable, and evolvable CPS in various application domains. Methods and theories for high-level decision making based on information collected from different sources at different spatial and temporal scales are necessary for system-wide reliability, efficiency, security, robustness, and autonomy of CPS.

In this regard, reliable architectures and computational frameworks should be addressed in the next decade for the following aspects and specific applications:

a. Monitoring, supervision and control 5.0.
b. Holistic methods based on a multi-level approach.
c. Dependable and cost-efficient high-definition maps for novel mobility paradigms.
d. 5G-based collaborative perception and navigation for safe and efficient autonomous driving.

e. Seamless use of heterogeneous sources of information in intelligent vehicles.
f. Robust and resilient multi-sensor connected networks.
g. Smart irrigation based on remote and proximal sensing.

4.4. Modeling, control and optimization for IoT and CPS

A framework consisting in an integrated vision of IoT and CPS is needed. New theoretical foundations will allow to better understand and predict complex dynamical behaviors caused by tight interactions between cyber and physical domains. Furthermore, it is required to develop unified theories which enable us to capture and analyze the dynamics of the communications, computation, control, and applications at once in a unified theoretical framework. Moreover, complexity issues in the design and development of CPS should also be investigated. Further advances are also required to support automated transformation between models in different semantic domains, model-level execution and debugging capabilities, composition of models to build an application, and incorporation of verification and validation capabilities.

The specific aspects and elements to be addressed in the next decades are:

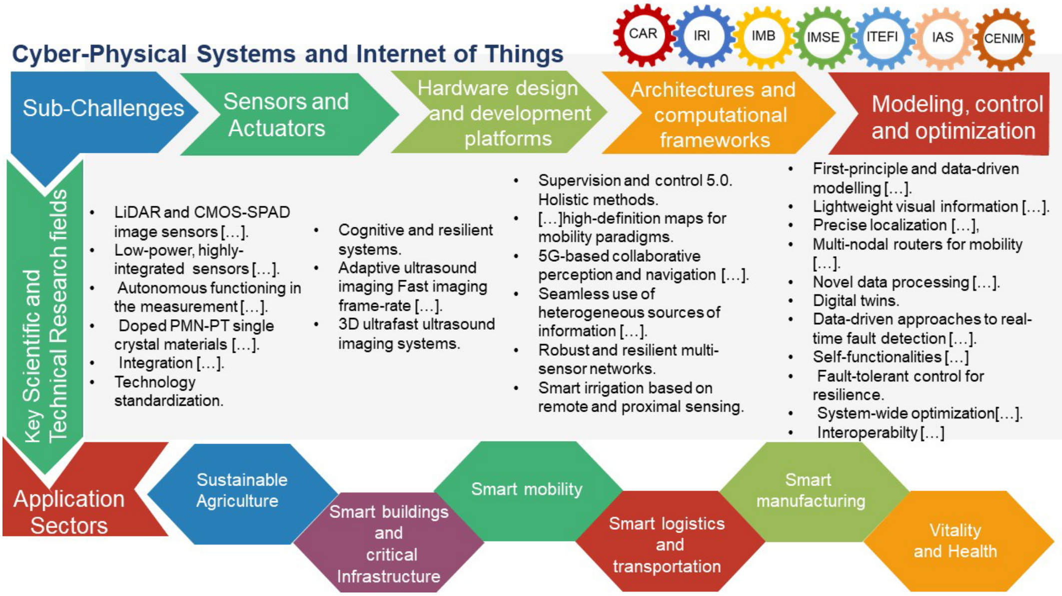
a. Lightweight representation of visual information.
b. Fast and computational efficient signal processing method.
c. Extended Kalman filters.
d. Precise localization in cities supported on Galileo system and multi-band GNSS systems.
e. Multi-nodal routers for mobility as a service.
f. Novel data processing algorithms for the Internet of Crops.

While longer term challenges in modeling, control and optimization are:

a. Digital twins. Design and development.
b. First-principle and data-driven modelling in complex systems for real-time monitoring.
c. Data-driven approaches to real-time fault detection and diagnosis
d. Smart nonlinear control. Self-optimization and self-reconfiguration.
e. Fault-tolerant control for CPS resilience.
f. System-wide optimization for CPS efficiency and economic operation.
g. Interoperability of multiple systems for coordinating operation and improving efficiency and sustainability.

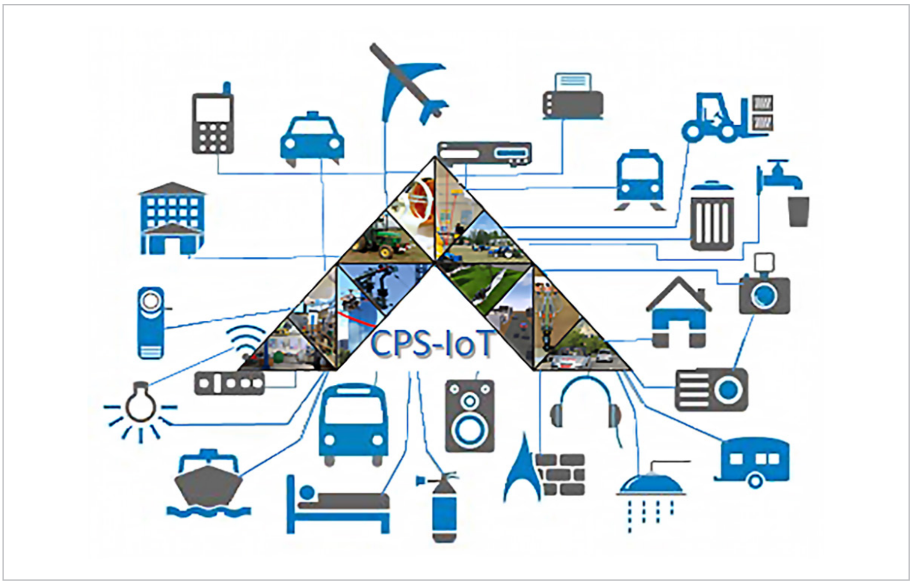
ANNEX: ONE SLIDE SUMMARY FOR EXPERTS

FIGURE 4.2–Internet of Things and Cyber-Physical Systems: Key scientific and technological research areas towards 2030.



ANNEX: ONE SLIDE SUMMARY FOR THE GENERAL PUBLIC

FIGURE 4.3–Internet of Things and Cyber-Physical Systems: towards Cyber-Physical System of Systems



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Information, gathered, stored, processed and transmitted, is the cornerstone of the present era and shapes every aspect our daily life, thus permeating cultural and social deep changes. A multi- and cross-disciplinary approach is needed to cover all present challenges of the Information age, ranging from both the more technological aspects to the social ones. This duality is reflected in the title of this volume, Digital and Complex Information. The current Digital Transformation is enabled by developments in physics and engineering and entails several fields including electronics, optics, material science, and quantum technologies. Nowadays challenges include sustainable and energy efficient electronics, integrated photonics with new functionalities, quantum computing and machine learning, and operation within the Internet of Things. Nonetheless the Digital world generates an ever-increasing amount of data in which security and trust play a critical role. The advances in digital technologies call for a new scientific research approach: an Open Science, reproducible, interoperable and accessible. New avenues are open in how we deal with Humanities and with individual/social security and rights, within digital citizenship. This is the broad spectrum of challenges that drives research across about the 40 CSIC institutes in line with the latest developments in digitalization worldwide.

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