Emerging trends in industrial electronics: A cross disciplinary view

***Abstract* —** Industrial Electronics (IE) discipline includes a wide variety of technical areas devoted to the application of electronics and electrical sciences for the enhancement of industrial and manufacturing processes. It inherently acts as a key enabling technology for a diverse number of applications and includes latest developments in intelligent and computer control systems, robotics, factory communications and automation, flexible manufacturing, data acquisition and signal processing, vision systems, and power electronics, among others, as well as educational and human factors involved. This makes IE inherently multidisciplinary, and with many interdisciplinary synergies, playing a key role as an enabling technology in multiple domestic, biomedical, transportation, and industrial applications.

The motivation of this work is to present the main research areas involved in the cross-disciplinary cluster of the Industrial Electronics Society, summarizing the state-of-the-art status, and highlighting future challenges in these cross-disciplinary areas. These include electronic systems on chip, standards, resilience and security matters, human factors, and educational aspects. This paper is aimed to sever as a guidance and motivation for future research in enabling technologies for the industrial electronics discipline.

Index Terms — Industrial electronics, standards, electronic systems on chip, human factors, resilience and security, education, e-learning, life-long learning, open innovation.

NOMENCLATURE

5G NR	5G New Radio
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
AR	Augmented Reality
CC	Cloud Computing
DSP	Digital Signal Processor
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyography
ESOC	Electronic System on Chip
FPGA	Field Programmable Gate Array
FPSOC	SoC FPGA
HLS	High Level Synthesis
ICT	Intelligent Communication Technologies
IE	Industrial Electronics
IEA	International Ergonomics Association
IES	Industrial Electronics Society
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISO	International Organization for Standardization
MEC	Mobile Edge Computing
PBL	Problem/Project-based learning

PWM	Pulse Width Modulator
RTL	Register Transfer Level
SOC	System on Chip
URLLC	Ultra Reliable Low Latency Communications
V2X	Vehicle to everything (connectivity)
VR	Virtual Reality

I. Introduction

Incredible technological innovations in industrial electronics over the last decade provide at the same time huge development possibilities and increasing challenges. New technologies, such as 5G, 3D printing, artificial intelligence (AI), Internet of things (IoT)/Industrial IoT (IIoT), virtual reality (VR) and augmented reality (AR), etc., inspire us to realize our dreams. Smart houses and self-driving are at arm's length. Cloud manufacturing and supply-chain-optimized e-commerce are just around the corner.

Low power electronics and design greatly contribute to a sustainable society that people around the world have been working toward. How to combine new technologies in modern industry to design basic circuits and systems and develop human-friendly design aids to minimize power consumption is an urgent task. Networks are widely used as a common tool for communication, cooperation, and technology implementation. Rapidly expanded network environment not only provides us evolution and innovation but also makes resilience and security challenging. Since new technologies are designed and used by human beings, they need to take human factors, which deal with human abilities and limits, into consideration to ensure not only safety and high performance but also smartness and comfortableness. A key to developing human-centric new technologies is to explore personal training methods. Environment- and learner-adapted training systems are built by integrating advanced learning theory, information technology, and Internet environment. They offer us a wide range of the means to solve sophisticated and complicated problems. Industrial activities are supported by various kinds of standards. Standardization of new technologies guarantees the quality of products, ensures safety and reliability, reduces production cost, protects environment, and deepens mutual understanding. Thus, it has a particular meaning along with the expanse of information technology.

To present an overall picture of the future trends cross-cutting fields, we gather all the knowledge from the main industrial electronics trans-disciplinary enabling technologies including human and educational factors, standards, resilience and security, and system on chip. The interested reader will be able to understand the current state-of-the-art of such areas and envision future developments and trends fostering innovation within the IE community.

To achieve the aims of this paper, each section covers the state-of-the-art of each discipline, and their most relevant future challenges are discussed. These sections include Human Factors, Education, Standards, Resilience and Security, and Electronics Systems on Chip. Finally, some remarks are made about the importance of cross-disciplinary areas as enabling technologies for the industrial electronics development.

II. Human Factors

A. *Current perspective*

Human factors/ergonomics is an indispensable and practical technical discipline devoted to implement easy-to-work or comfortable life environment, and to design safe and efficient tools or systems. Its history originates from Europe in the 1850s, the modern research on human factors have been evolved from the background of applied psychology, starting from human error researches in the United States since World War II. Currently, human factors/ergonomics is defined by IEA (International Ergonomics Association) as "*the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance*" [1]. The International Organization for Standardization (ISO) also standardizes ergonomic design of control centers as ISO 11064-1. These descriptions show that human factors/ergonomics is the technical discipline optimizing the interactions among works/tasks, tools/equipment, design/development, environment, organizations/management, and culture/custom/laws.

It is required to understand human characteristics and to use it for designing an assistive system. These requirements exactly form the core of human factors. The understanding of human characteristics is especially important and should be considered along with the requirements of system design. Human characteristics are divided mainly into two categories: (i) physical characteristics such as body motion and biological index and (ii) psychological characteristics including preference, intention, etc. Physical characteristics can be measured by sensing technologies, for example, EMG signals for muscle activities [2, 3], ECG for heart activities [4], heart rate for exercise intensity [5, 6], and motion capture system for human body movements [7, 8]. On the other hand, psychological characteristics are not a measurable value. It can only be estimated using measurable physical characteristics or interviews [9]. Okasaka et al. proposed an estimation method for the state of human activity using fNIRS (functional near-infrared spectroscopy) [10]. A body motion interface was designed to collect pressure on the backrest of an electric wheelchair, and the intention of wheelchair control was estimated using a self-organizing map for the pressure [11]. Mitsukura et al. proposed an evaluation method for human preference based on an EEG analysis [12].

Even when the obtained human characteristics are applied to system design, it is also necessary to integrate knowledge and skills in many different domains. As an example, Chugo et al. [13-15] proposed a robotic walker for the elderly, which assists standing and seating while effectively utilizing their remaining muscle strength. This development include characterizing forces and movements [Fig. 1(a)], musculoskeletal simulation [Fig. 1(b)], prototype evaluation [Fig. 1(c)], and the product conception [Fig. 1(d)]. Of particular importance at every design phase in the above are the understanding and application of human characteristics by measuring and estimating psychological and physical states, which are the basis of human factors.

B. Future challenges

Human Factors should cover varieties of outcomes considering individual cognitive or psychic characteristics [16] with social relationship such as healthcare [17], improvement the quality of communications [18] and removal of physical or cognitive handicaps [19]. In particular, the optimization of the interface among human, society and system become one of the most important subjects of current human factors, such as human-human and human-system communication and preference or thought about health which people have. However, human perception-recognition-action process is quite complicate and is not uniform. Moreover, there are many varieties of cognitive and communicative individual characteristics. Hence, it is required to apply novel knowledge and different discipline to human factors domain.

The mission of human factors is to contribute to the improvement of quality life of human. It is indispensable to introduce a fusion of multiple disciplines for this contribution. For example, biometric authentication technologies [20], such as face authentication, fingerprint authentication [21], iris authentication [22], and gait authentication [23], to solve the tradeoff problems among convenience, security and privacy cannot be realized without electronic-systems-on-chip (ESoC) technology for making wearable sensors. In an information-oriented society where the sophistication and multi-functionality are rapidly increasing, it is necessary to formulate guidelines and standards for eliminating digital divide, such as accessibility guidelines for the elderly and the disabled. In addition, Resilience and security (ReSia) are also important subjects for human life. Moreover, the development of technologies for e-learning or education systems [24] is required to solve various problems of the skill education [25, 26] caused by declining population. Human factors, therefore, will continue to challenge the problems that emerge with the times and society by applying and integrating the knowledge of other technological disciplines.

III. Educational Perspective

A. Current perspective

Industrial electronics has become one of the most important disciplines in engineering studies. The growth in the application of new technologies as well as the emerging areas in industrial electronics (IE) make this subject very important under an educational perspective [27]. Since the beginning of the 20th century, electronics has progressively become part of everyday life (TV, vehicles, radio, electricity, etc.), changing most human routines [28]. Accordingly, the recent IE education can be characterized in the following three keywords (Fig. 2): 1. Adaptability to new technologies, 2. Multi-discipline, and 3. Multi-culture.

With the years, industrial electronics became more complex and the programs required for the university educational levels were redesigned to adapt them to this spectacular development [29-31]. In the 21st century, education on IE has penetrated every educational level. In some countries, since kindergarten children are introduced to fields as robotics, while in primary school they deep in areas as configurable devices (Arduino, field-programmable gate arrays (FPGA), PC, microcontrollers [32], etc.). In concordance, the equipment in all educational levels has been adapted to the new technologies to be taught in the industrial electronic area, emerging virtual laboratories, remote laboratories [33] and classrooms, tactile screens and blackboards, holograms and open courses, gamming. On the other hand, the educational methodologies in undergraduate/graduate levels have lived a parallel development, from traditional master classes to new methods based on flip teaching, webinars, individual learning, project-based learning (PBL) [34], as well as a boosted interaction within the industrial context [35]. They enhance the autonomous learning, as well as the interest and motivation toward the urgent topics in the area [36].

In order to motivate and make IE courses more attractive, a more recent trend followed by many universities relies on proposing multidisciplinary courses that combine the contents of different IE areas, typically in problem/project-based learning (PBL) approaches. PBL requires that the students define objectives and project requirements, face-to-face discussions among all participants, sharing ideas and knowledge, analyzing data, etc. In PBL, students are continuously evaluated by examinations, reports and interviews in which they must demonstrate the acquired knowledge and skills [37]. During recent decades, PBL has had a great impact not only on the IE students but also on instructors in this area. As some authors have reported, this methodology has contributed to increasing the interest and motivation of the students toward the IE courses, as well as to improving their results in the courses that have put into practice this educational methodology [38].

Another relevant trend in the current technological and industrial context are learning factories [39], providing a promising environment for education, training and research. Industry-academia synergies [35] have proved to have significant positive impact in education, providing wider problem-solving vision, additional technical resources and improved education for both staff and students. In this context, several learning factories in the area of manufacturing education are discussed in [40, 41], showing benefits in terms of improved learning process thanks to constructivist, positioned and PBL learning methodologies.

B. Future challenges

The adaptation of education on IE to new educational frameworks has implied the use of new learning methods and techniques. Flipped teaching is one of the methods that has emerged as a preferred option in many universities and IE courses. This method consists of online video tutorials and classroom time, which is assigned to problem-solving and discussions [42, 43]. The flip learning is known also as inverse learning, whose benefits are self-learning [44], cooperation between students and professors, problem-based learning [45], and versatile of the materials [46]. Sigh et al. [47] describe the results of blended learning based on flip teaching and online assessments. The proposed method improved students' interest in the course as well as increased learning flexibility, interaction between students and professors.

The conventional laboratory sessions can be combined with a simulation laboratory. Modeling and simulation experience provide students with a better understanding of the modeling/design and analysis process of the problem because students learn how to plan, define the concepts and develop the project. To pass the barriers of not having access to the real equipment, several universities introduced in some courses with portable learning technologies as Arduino Nano [48], the Texas Instruments LaunchPad [49], and Raspberry Pi [50]. The conventional laboratory sessions are complemented also with the virtual or remote laboratories, which allow students to perform their laboratory experiments from distance [51, 52]. Remote laboratories in IE allow monitoring, control and interaction with real equipment and offer a high level of experimentation. This practice helps students and professors to overcome limited resources as students are scheduled to use the equipment at a specific hour, etc.

Along with the fast evolution of technology in the 21 century, the educational process in IE also is evolving. It is crucial that students and professors as well as professionals, should every year involved in learning to stay current with the new methods and developments in their professional areas. For being actualized with the new developments, professionals should be involved in the domestic and international conferences, courses and awards. The future challenge for the IE education is to adapt the educational programs to continuous learning in IE. Introduction of continuous learning in IE may require more economic and intellectual resources, implying redefinition of the learning and professional needs. The support or involvement of IE professionals from industries will also give a great impact on continuous learning due to the share of knowledge from factory/company to undergraduate/graduate students.

IV. STANDARDS VIEW

A. Current perspective

Standards are an integral part of society and industry. Technology adoption and economic growth are possible because of standards, and in the global community they promote international trade [53]. Standards utilized in the world today provides ease of use for public and industry consumption and drives down the cost of development [54].

Global advancements on the quality of life and standards of living can be traced to the impact of standards implicitly or explicitly. Industry trends and standards initiated and propagated by IEEE Industrial Electronics Society (IES) are in emerging areas of *Industrial Sensors and Systems, Industrial Communications, Industrial Agents, and Industrial Power and Energy Systems (Smart Grids),* and *Industrial Wireless Technologies* [55, 56].

From the industrial electronics perspective, the technological trends with strong standards potential, based on the clustered fields of interest of IES, are shown in Fig. 3 [55].

IIoT and Sensors and Industrial Wireless Communications trends will continue from present standards development within IES such as IEEE 1451 family of sensor networks standards (P21451.002, P1451.1.6), and Industrial agents (P2660.1). Potential future trends for sensor networks will be within the IoT/IIoT technologies, and where harmonization of sensor networks standards with other IIoT standards will come to fruition under P1451.99 – standard for Harmonization of IoT Devices and Systems. In particular, a well adopted industrial standard, the Open Platform Communications Unified Architecture (OPC UA) (IEC 62541) are utilized in the fourth industrial revolution – Industry 4.0 – IIoT applications and systems. Further, integrating OPC UA with Web Technologies enhances OPC UA interoperability, a solution especially useful towards resource constrained devices [57].

Another innovative area in industrial electronics sensors are in electronic ‘sense of smell’. The IEEE P2520 Standard in Testing Machine Olfaction Devices and Systems is jointly sponsored by IES with the IEEE Sensors Council.

One of the most prominent global technological trends today is autonomous vehicles and usage of non-fossil energy. Both are driving industrial technological developments within the realm of IES, and *Battery and Energy Storage* and *Transportation and Electrification* for *Autonomous and Connected Vehicles* will be new trends in standardization. From this, *Connected Vehicles* must include *Communications* where the promise of 5G will make these applications realizable.

Riding on the heels of these trends, industrial communications impact to industrial automation and autonomous connected vehicles are technologies such as *multi-access edge computing, 5G and digital transformation*.

Multi-Access Edge Computing or Mobile Edge Computing (MEC) refers to computing at the edge of the network, often in distributed cloud computing with close proximity to the edge of the network to the end-users where time critical requirements are essential, delivering ultra-low latency, reliability and scalability with technologies such as 5G, among others. Standardization and standards become imperative in such a technological scenario.

5G networks may be connected to many more devices for IoT communications. With improvements in speed, latency and capacity of 5G, it will provide better competitiveness for manufacturing controls, robotic and warehouse automation. The 5G network characteristics will accelerate and facilitate the next industrial revolution because 5G allows for data collection and actionable analysis in real time from IoT and other sources for computing on the edge. It opens up new areas of potential cognitive analytics, predictive maintenance and data monetization.

Digital Transformation – According to CDW.com’s White Paper [58], while the terms ‘digital transformation’ and ‘IoT’ are often used interchangeably, IoT is a subset of digital transformation. Applications envisioned for digital transformation include energy management/smart buildings, smart cities, video surveillance and monitoring, real-time location tracking, worker safety, predictive maintenance and predictive analytics (big data) [58]. The challenge here will be generating standards and standardization.

B. Future challenges

Existing standards development will provide industry best practices or standards in the fields of sensor networks, industrial agents for industrial automation. The challenges will be in deployment in the ever-increasing areas of IIoT. The newer trends will present future challenges as the technologies evolve and mature, standards and standardization will be set and used for the future of society and improving standards of living and public convenience and safety, in areas of smart cities, autonomous transportation and smart buildings and homes, coupled with the increasing use of social media.

IES will see the increasing use of augmented reality/virtual reality (AR/VR) technologies in everyday use, where standards are being developed that IES is involved (P2048, Standards for Virtual Reality and Augmented Reality); the use of digital transformation (P2023, Standard for Digital Transformation Architecture and Framework) where the scope addresses scalability, systems and interfaces, security and privacy challenges for digital transformation applications. IES is also sponsoring MEC standards for industrial automation (P2805.1-3).

Currently 5G devices, networks, and service plans are still in the early phases and there are still a number of challenges to make it all functional and achievable. In fact, evolutionary enhancements are being made to the 5G standards and 5G networks. 3GPP Release 16 - expected release June 2020 - will specify 5G system Phase 2, V2X, Industrial IoT, URLLC, higher efficiency and NR based access to the unlicensed spectrum, and Release 17 is expected in September 2021. To support the capability of Releases 16 and 17, new devices and upgraded networks will be required [59-61]. IES has close contact with and access to the progress of the Steering Committee on IEEE Future Networks Initiatives that consider 5G as a network of networks, driving evolutions in various ecosystems resulting in shifting industry structures and adjacent industry boundaries. IEEE 1451 family of sensor networks standards and architecture is also being enhanced to take advantage of 5G network interfaces for critical industrial applications.

From a cross disciplinary view, standards touch the full range of all of IES fields of interest and its technical committees (TCs), namely industry automation, power and energy, industrial communications and control, as well as with its cross disciplinary partners such as education, resilience and human factors. In subsystems areas, standardization in ESOC is realizable in appropriate circumstances. As shown in Fig. 4, the cross disciplinary technology cluster of technical committees can provide umbrella coverage to all the technology clusters within IES. As an example, a standards development in progress is P2834, a standard for Secure and Trusted Learning Systems. IES is a joint sponsor with the Education Society and the Computer Society. This standard "specifies technical requirements for student data management and privacy protection in Learning online systems and services." IES active participation in this standard include the Education TC and the Standards TC in the lead.

V. A RESILIENCE AND SECURITY PERSPECTIVE

A. Current perspective

The concept of resilience was first introduced by Holling in the field of ecology in 1973. The term resilience is defined as a system property to measure the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables [62]. This concept was soon adopted by many other disciplines including social-ecological systems [63], psychology [64], disaster and risk management [65], energy systems [66], civil/industrial engineering [67], computer networking [68], etc. The use of "resilience" term experienced an exponential growth in publications after 2000s accordingly to Web of Science statistics [69]. In industrial applications, a consensus on the definition of the resilience is yet to be established. There were many attempts to both qualitatively and quantitatively define resilience in different industrial applications, e.g., energy system [70], transportation system [71], communication system [68], manufacturing system [72], civil infrastructures [73], etc. Despite the various technicalities, these different interpretations of "resilience" all share the same core: "the ability of an entity to anticipate, resist, absorb, respond to, adapt to and recover from a disturbance" [74]. In the light of the broad definition, visualization of resilience measurements (resilience level) throughout all system states that are impacted by a cyber-physical event is illustrated in Fig. 5. The resilience and security concepts are often paired together when it comes to the industrial applications, as more and more intelligent communication technologies (ICT) have been applied to many critical industrial applications, such as transportation, energy, manufacturing, etc. The resilience concept describes the dynamic property of the system, instead of static properties such as security. Both cyber and physical resilience and security of these critical infrastructures are critical to the well-being of the society.

From industry perspective, resilience and security became two of the most demanded technologies/features, as many industrial systems are undergoing tremendous changes or evolutions. Driven by policy incentives and industry needs, the resilience and security become a trending research topic in recent years. State-of-the-art transportation system research topics includes but not limited to resilient and secure risk management strategies to protect the transportation system from disasters and terrorist attacks [75], resilient and secure controls to tackle the cyberattacks in the intelligent transportation system [76], resilient transportation system planning and management [77], collective resilience between transportation and energy systems [78], etc. State-of-the-art energy system research topics includes but not limited to post-disasters electrical service restoration [79], resilient networked microgrids [66], system hardening, reconfiguration, and self-healing to achieve resilience [80], resilient energy management system against cyber-attacks [81], resilient and secure smart grid planning [82], etc. State-of-the-art communication system research topics includes but not limited to resilient communication in distributed computer networks [83], resilient and secure communication network against cyberattacks [84], resilient cryptography [85], resilient and secure IoT and sensor networks [86], resilient communication networks against disasters and extreme event [87], resilient and reliable communication network design [88], etc. State-of-the-art manufacturing system research topics includes but not limited to resilient cyber-physical manufacturing system design [89], resilient supply chain [90], resilient task scheduling in manufacturing system [91], resilient and secure manufacturing system against cyberattacks [92], etc.

B. Future challenges

Moving into the future, the resilient and secure industrial applications are facing the following 3 key challenges: (1) need for standardization: Standardization efforts are needed to develop qualitative and quantitative definitions and metrics for resilience and security in different fields. (2) human factor: It is important to model human factors in the cyber-physical-social model of the industrial systems. (3) need for resilience and security framework: To facilitate inter- and cross-disciplinary scientific communications and collaborations, it is important to form working groups in each technical area and establish a holistic resilience and security framework to systematically integrate different types of research works.

Resilience and security in industrial applications is an emerging cross-disciplinary field. In this field, human factor plays an important role and it becomes one of the new growth points where lots of new research are oriented around cyber-physical-social system topic. The designed resilient and secure controls and algorithms from this field will eventually be implemented on electronics systems on chip. Thus, it is very important to secure the ESOC systems as the system resilience depends on its secure computations and executions. Moreover, the education sector also plays an important role in documenting and disseminating the newly accumulated knowledge in this emerging field. In addition to education, tremendous amount of standardization effort is needed to synchronize academic research and industrial innovations.

VI. Electronics Systems on Chip Approaches

A. Current perspective

As mentioned above, one of the main feature of IE is its wide range of fields of application (IIoT, Smart Grid, Robotics, etc.) and as such, it is a trans-disciplinary topic but for sure, all these applications need to be implemented in the real world and doing so, these implementations have to be as much optimized as possible whatever in terms of performances, cost, consumed energy, integration, flexibility, obsolescence, etc. So, based on this optimization objective and in-phase with the Moore’s law stating that the integration capacity of digital components is doubling every two years [93], System-on-Chip (SoC) concept has prevailed in industrial electronics over the last 15 years. But beyond this seducing term that is supposed to mean that everything an industrial electronic system needs to be controlled and supervised can be integrated within a single chip, there is a large diversity of situations, successes and limitations that are now shortly discussed.

Probably one the main pillar of the huge SoC development during the last 15 years is the adoption by the silicon industry main players of the ARM processor ecosystem [94]. Indeed, taking advantage of the boom on mobile applications, the ARM Holdings has developed a very successful business model, selling to most of the semiconductor companies its processors IP cores. Among the large family of ARM-based SoC components, those including a field programmable gate array (FPGA) fabric [95] are probably the most interesting in terms of flexibility and scalability. Indeed, these so called SoC FPGAs (sometimes also named FPSoCs for Field Programmable SoC) allow the designer to customize his SoC device by designing/upgrading dedicated peripherals and/or hardware accelerators, taking advantage of the inherent parallelism offered by the distributed and plethoric internal resources of current FPGA fabrics. This definitely can make the difference on the market in areas such as IoT [96] because of their ability to cope with the main challenges of this field, that is to say, flexibility, scalability, power efficiency, security, communication and integration, or electrical energy applications [97], thanks to their ability to control with accuracy and fast enough always more numerous and stringent power electronic applications.

Another interesting branch of SoC device family for IE applications is the SoC Digital Signal Processor (DSP) branch. Such SoC DSPs are mainly produced by Texas Instruments like the Delfino devices. These components are more devoted to hard real-time applications like the control of electrical motors, including a dual 32-bit floating point DSP cores, many dedicated HW accelerators (like a trigonometric math unit) and, last but not least, very performing pulse width modulation (PWM) and analog/digital converter (ADC) units. Besides, in order to reduce even further the cost while at the same time increasing the level of reliability and the performances, one need to get efficient and configurable mixed analog/digital SoCs, like the PSoC from Cypress Semiconductor. This allows better interfacing the powerful digital resources of a SoC with the industrial system to be controlled and in some cases adding front end analog treatments in order to smartly alleviate the computing load of the digital part of the SoC.

Having presented the main technological solutions, the authors are now briefly reviewing the trends in terms on development and verification tools associated to such SoC devices since the quality of such tools are of course critical to reduce the time-to-market. Regarding the development tools and face to an always increasing complexity of the designs to be implemented, a huge trend in the FPGA world is a rise of the level of abstraction of the design entry code, moving from standard structural Register Transfer Level (RTL) descriptions in VHDL/Verilog to new behavioral descriptions in C/C++, system C, OpenCL or even MATLAB language. This high abstraction behavioral description is called High Level Synthesis (HLS) [98]. Along the same trend one can also add the long term and continuous improvements of the automatic code generation tools which allow to transform a Simulink scheme in an executable software program on an ARM or DSP processor core (embedded coder MATLAB/Simulink toolbox) and/or in a netlist for programming an FPGA fabric (SysGen, DSP Builder Simulink toolbox and HdL Coder MATLAB/Simulink toolbox). These tools are simplifying the life of the designers in generating C/VHDL code in an automatic way directly from a MATLAB piece of code or a Simulink, LabView or other similar software scheme, and by easing functional verification [99].

Indeed, this last advantage is fundamental. By using Matlab/Simulink environment as design entry tool, the designer can therefore make all the necessary simulations and verifications of a controller since the earliest stages of the development. Finally, the verification process can be also greatly simplified improved by the quasi systematic use of hardware-in-the-loop (HIL) tests to avoid the use of real plants during development and test phases. In the field of IE, HIL has been widely used [100]. It involves only signal exchanges which means that there is only signal coupling between the SoC under test and the virtual system (accurate model of the final plant).

B. Future challenges

As explained in the former section, the SoC devices are good candidates for implementing innovative controllers. Thus, based on their ever-growing computing capability, a natural trend is to try to embedded always more sophisticated control algorithms. However due to the recent and significant progress of the cloud computing, this trend has also to be achieved in accordance to an important change of paradigm which is occurring in the industrial electronics community and which consists in the progressive replacement of the standard embedded controllers by new Edge Computing (EC) platforms. Indeed, by “embedded controllers” one understands a fully local controller dedicated to the control of a given plant. Instead, by “EC platform” one means a controller not only able to perform the former mentioned local control tasks, but also a device which is an active element of a collaborative computing platform that integrates as well Cloud Computing (CC) services. Seeing things in this way significantly open the possibilities in terms of digital control of a system. This new vision is mainly supported by the three following observations made by many IE designers: From the application perspective, many standard control issues at a component scale like vector control of an AC motor are now mature while many others at the system scale like the energy management of micro-grids and/or cluster of micro-grids are open problems. While, from a digital technology perspective, the SoC devices are becoming very powerful not only by themselves (i.e., their ability to solve an online multi-objective optimization problem) but also by their ability to communicate easily via Internet and be connected to cloud computing (CC) services. Finally, from a theoretical perspective, new and powerful paradigms have emerged like machine/deep learning, pushed by significant advancements in (big) data driven theory. All these observations are thus conducting the designers to ask themselves an important question: What computing tasks of my IE control system have to be achieved locally (EC) and what have to be executed remotely in the cloud (CC)? Of course, there are no simple answers to this question. It depends on the targeted application, the dynamics of the corresponding tasks, the cost, the nature and the quality of the channels of communication involved, the expected level of security and privacy [101], etc. It is going to be the task of future SoC researchers and technical communities such as IES, which is already very active with initiatives such as new standards for industrial EC nodes (IEEE P2805.1/2/3), to be ready for the future.

In Fig. 6 authors are presenting briefly their vision of a highly flexible, computing intensive and low energy consuming EC platform. It is based on a modern SoC FPGA device, whose numerous advantages have been presented in the former section and surrounded by helpful analog functionalities. Ideally, these analog functionalities should be integrated within the same device than the SoC FPGA but analog-digital mixed integration is unfortunately not very easy to produce, mainly because the analog interfaces are difficult to standardize, thus making a universal EC platform of this kind difficult to design. However, this concept is achievable since for a booming market like the 5G, such kind of chips already exists [102].

Finally, knowing that IE products are cost constrained, the proposed fully configurable SoC FPGA platform may of course be too much oversized for a lot of low-end applications, and as such not to be recommended for them. However, looking toward the future, authors are convinced that such high performing and configurable platforms will play a key role in the implementation of new and innovative solutions for IIoT and microgrid edge computing applications.

VII. Final remarks

IE community faces a fascinating future full of technological advances and ever increasing technical and societal challenges that makes innovation a must. In this context, cross-disciplinary areas will play a key role as enabling technologies and supporters for advances in all the IE main areas of interest. In this paper, the state-of-the-art and future challenges of areas such as human and educational factors, standards, resilience and SoCs have been reviewed.

Human factors and resilience have proved to be essential to provide comfortable and reliable environments in the personal and industrial contexts. These areas are aimed in next years to include the latest technologies such as biometrics and cybersecurity, among others, to provide improved living conditions. Educational aspects are also called to play a more important role in the next years, including not only undergraduate education but also lifelong learning in a much more complex and challenging context, where industry-academia synergies and e-learning will present, at the same time, important advantages and challenges for future education. All these advances will be enabled, in part, by modern digital electronic platforms, being system on chips one of the most relevant architectures. This will be an inherent part of future advances in key technologies and infrastructures such as the Internet-of-Things and Industry 4.0, cloud and edge computing, and 5G technology, among others. Finally, in order to ensure the success and the smooth development and deployment of advances in all these areas, standardization will play a key role. Future challenges will include to establish a standardized methodology for technology development in the IES context, as well as the need for an extraordinary adaptation capacity to a wide range of future technologies. All these technical areas are called to play a vital role in future development and to be key players in providing inter-operability among the IE technical areas.

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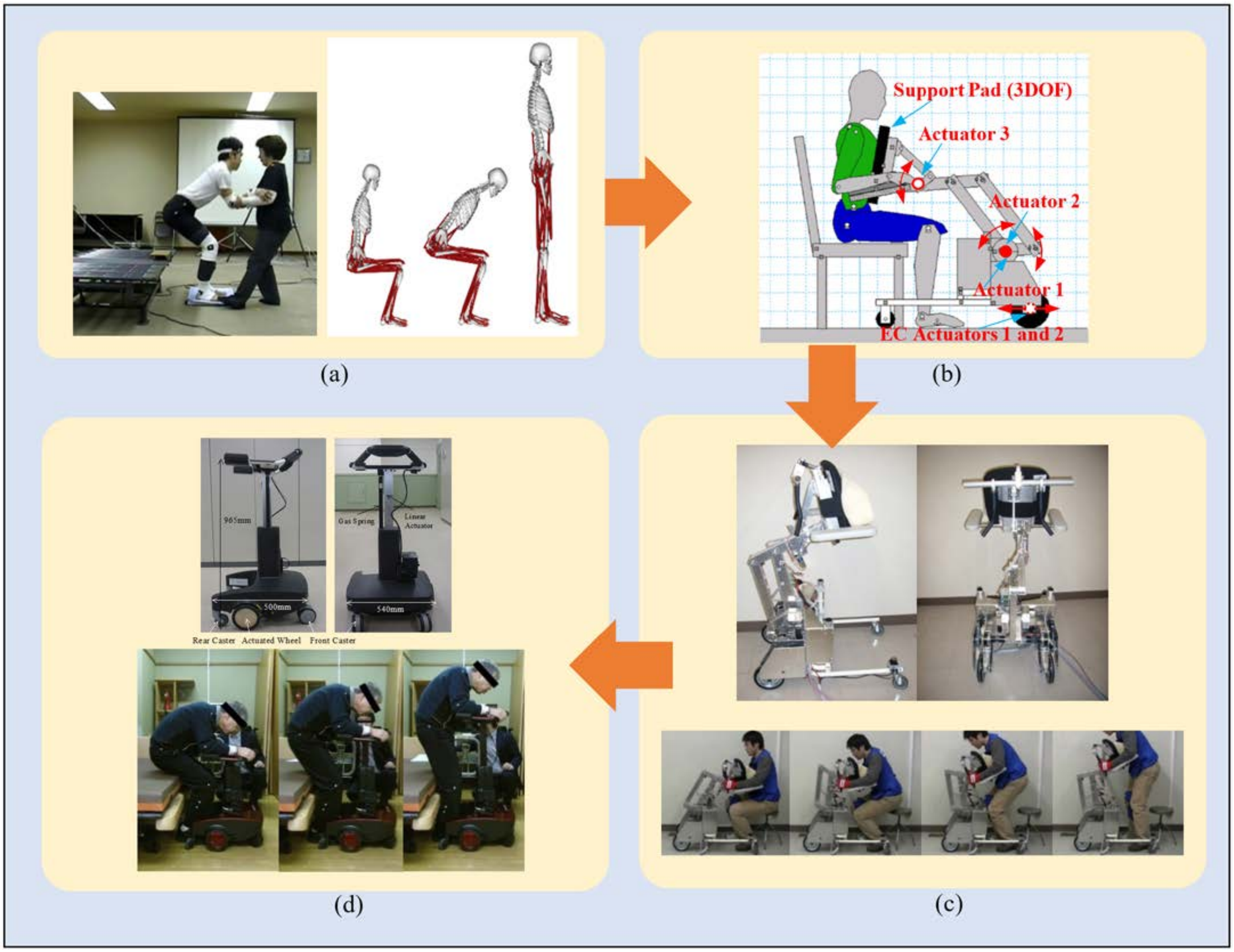

Fig. 1. Development phases involving human factors principles for a robotic walker with standing and seating assistance [13, 14, 103]: (a) measuring human motion characteristics, (b) designing fundamental mechanism, (c) prototype design and laboratory evaluation, (d) commercial product and empirical evaluation.

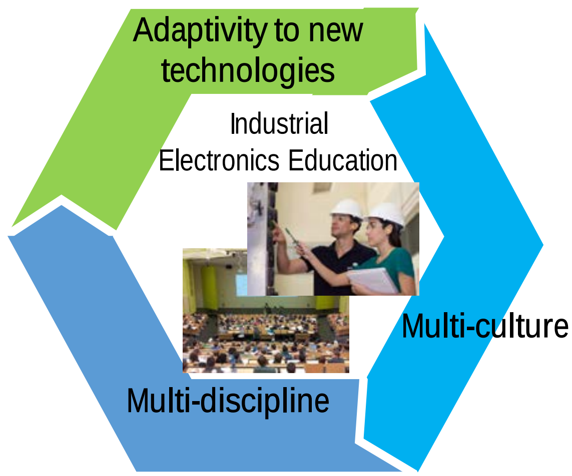

Fig. 2. Three distinctive features of industrial electronics (IE) education.

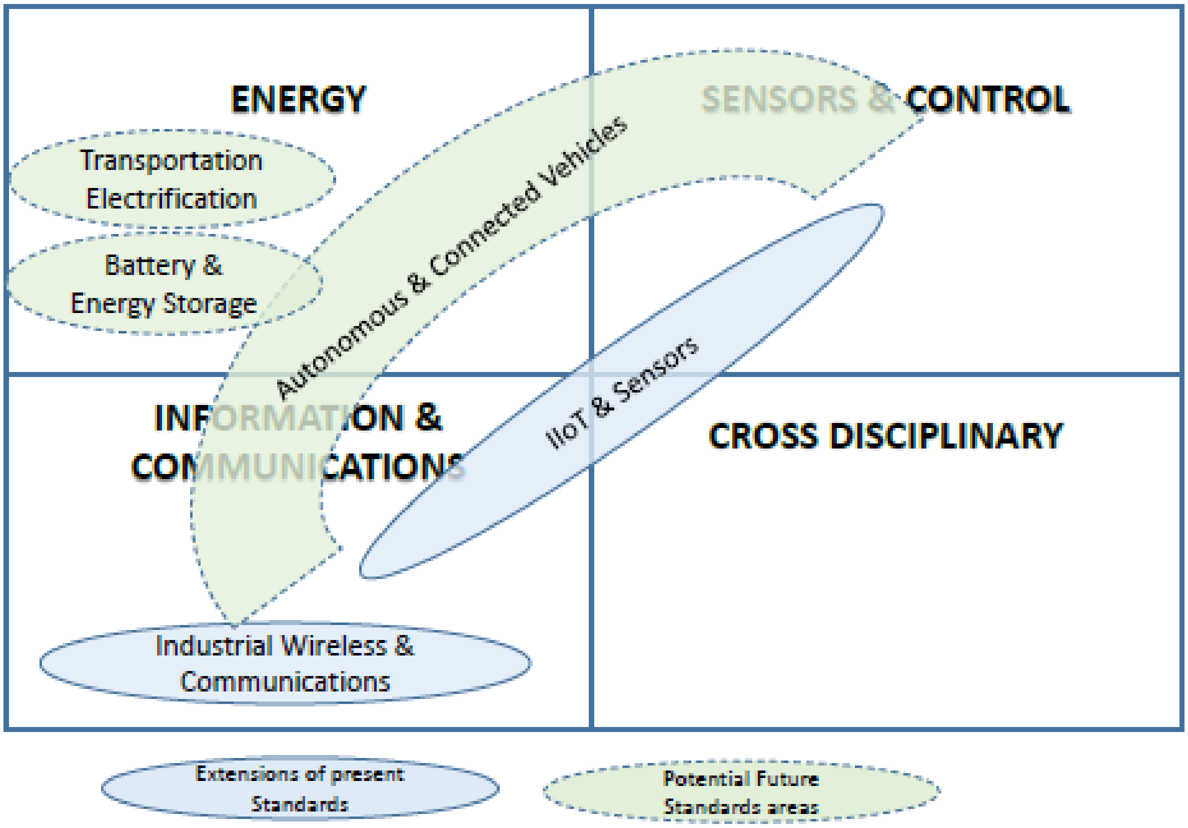

Fig. 3. IES Standards Trends – Present and Future [55].

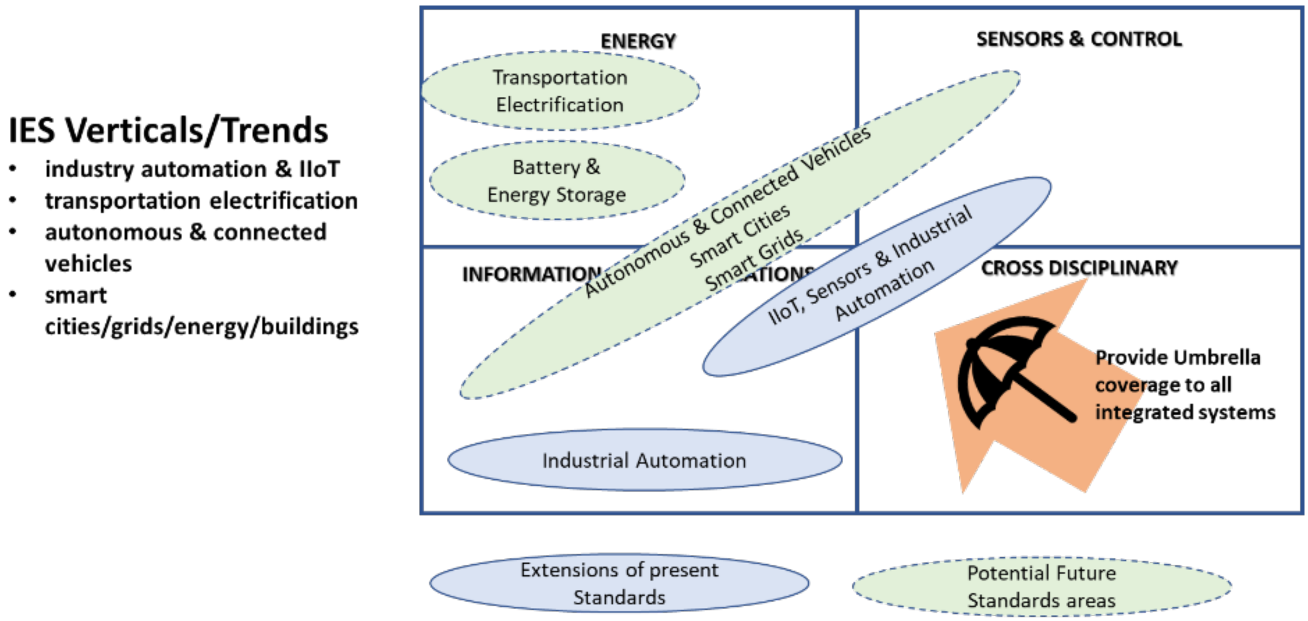

Fig. 4. Future Trends – IES Technologies and Standards.

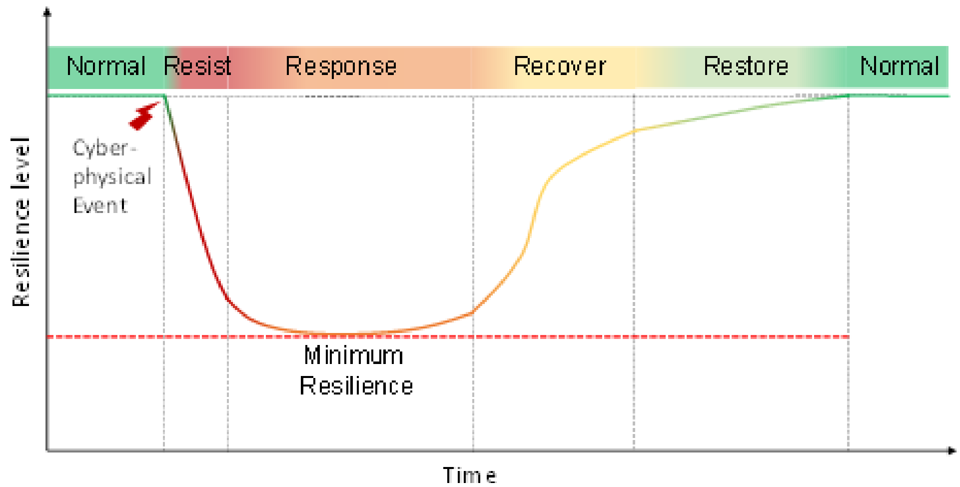

Fig. 5. Resilience curve illustration [66].

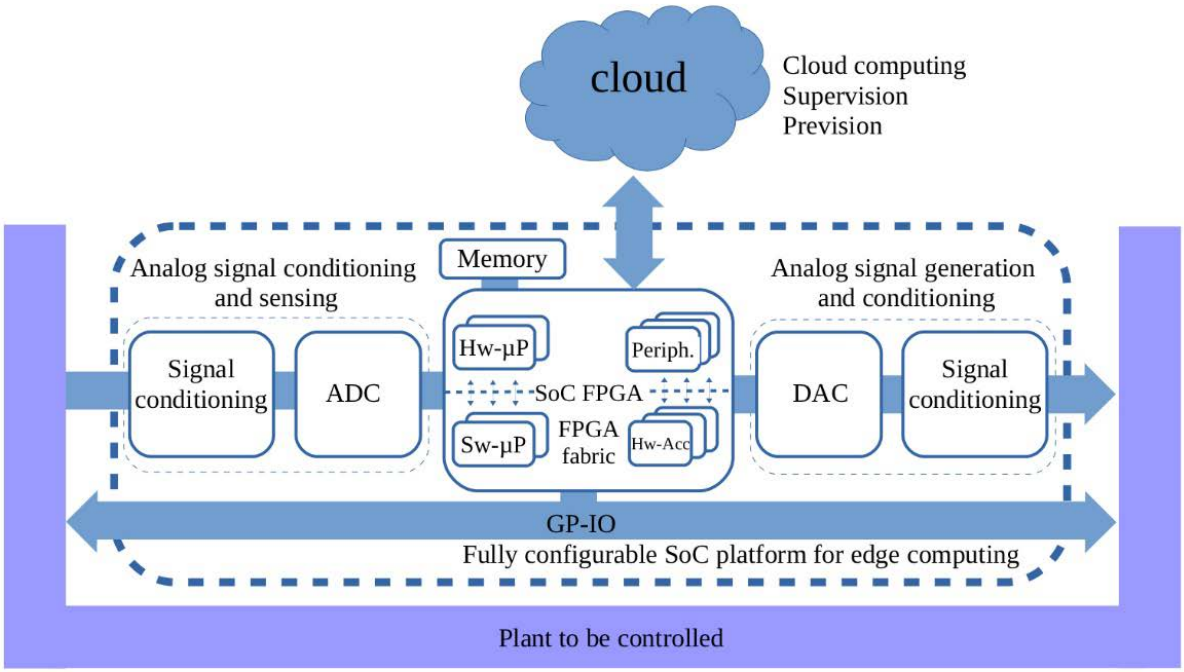

Fig. 6. Proposed fully configurable SoC FPGA platform for edge computing.