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. 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.

This paper covers recent advances and future trends in those areas that support the cross disciplinary view of industrial electronics, including electronic systems on chip, standards, resilience and security matters, human factors and educational aspects. The main current state-of-the-art technologies and techniques are presented, and their future trends and challenges are discussed, focusing on the cross disciplinary view inherent to industrial electronics.

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

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), 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. 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 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.

II. Human Factors

A. Current perspective

Human Factors/Ergonomics is indispensable and practical technical discipline to realize 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 researches 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 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 apply 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 requirement of system design. Here, Human characteristics are divided into mainly two categories: (i) Physical characteristics such as body motion and biological index and (ii) Psychological characteristics including preference, intention, etc. (i) Physical characteristics can be measured by various sensing technology, muscle activity by using EMG signal [2, 3], ECG [4], Exercise intensity using heart rate [5], human body movement by motion capture system [6, 7]. On the other hand, (ii) Psychological characteristics is not measurable value, this value is only obtained by estimation using measurable physical characteristics and interviews [8]. Okasaka et al. proposed estimation method for human activity state using fNIRS (Functional near-infrared spectroscopy) [9]. Human body motion interface for electric wheelchair utilized estimated human control intention by Self Organizing Map with human body motion data from pressure sensors on the backrest [10]. Mitsukura et al. proposed evaluation method for human preference based on electroencephalogram (EEG) analysis [11].

Even when the obtained human characteristics are applied to system design, it is also necessary to integrate knowledge and skills in many different domains. Here is one example. Chugo et al. [12-14] proposed the Robotic Walker for the elderly, which assists standing and seating while effectively utilizing the remaining their muscle strength. This development include characterizing forces and movements Fig. 1(a), musculoskeletal simulation Fig. 1(b), prototype evaluation Fig. 1(c), and the final product conception Fig. 1(d). At every design phase in the above, it can be seen that understanding and application of human characteristics by measuring and estimating psychological and physical states, which are the basis of Human Factors.

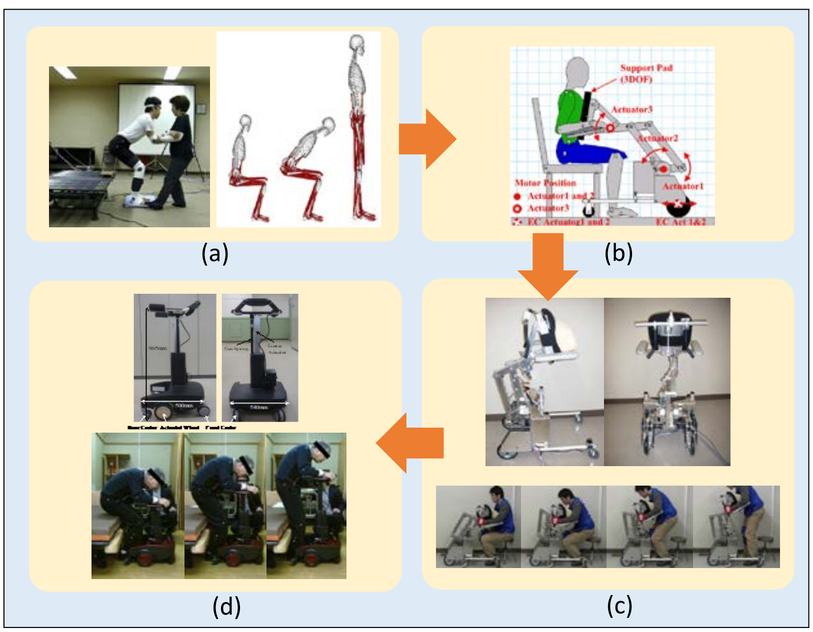

Fig. 1. Development phases involving Human Factors principles for the Robotic Walker with standing and seating assistance [12-14]: (a) measuring human motion characteristics, (b) designing fundamental mechanism, (c)prototype design and laboratory evaluation, (d)commercial product and empirical evaluation.

B. Future challenges

Human Factors is the technical discipline adapting tasks, environments and systems to human characteristics. Currently, Human Factors should cover many varieties of outcomes requiring the approaches that should consider individual cognitive or psychic characteristics [15] with social relationship such as healthcare [16], improvement the quality of communications [17] and removing physical or cognitive handicaps [18]. In particular, the optimization of the interface among human, society and system becomes one of the most important subjects of current Human Factors, such as human-human communication, human-system communication and preference or thought about health which people have. Here, human perception-recognition-action process is quite complicate and is not uniform. Besides it is reported that 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 multi disciplines for this contribution. For example, biometric authentication technologies [19] such as face authentication, fingerprint authentication [20], iris authentication [21], gait authentication [22] to solve the tradeoff problems among convenience, **security** and privacy cannot be realized without integrated circuit (**SoC**) 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** are also important subjects for human life. Moreover, the development of technologies for e-learning or **education** systems [23] is required to solve various problems of the skill education [24, 25] 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. Since the beginning of the 20th century, electronics has progressively become part of everyday life (TV, vehicles, radio, electricity, etc.), changing most human routines [26]. 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 defined for the university educational levels were redesigned to adapt them to this spectacular development [27-29]. 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 [30], 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 [31] 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) [32], as well as a boosted interaction within the industrial context [33], etc., that enhance the autonomous learning, as well as the interest and motivation toward the topics threaten in the area [34].

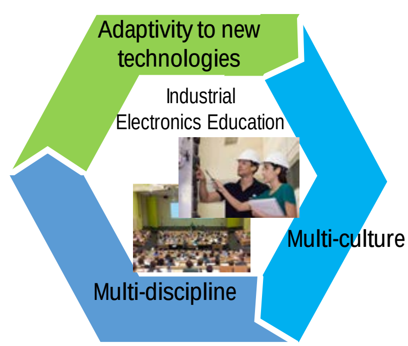

Fig. 2. Three distinctive features of industrial electronics (IE) education.

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 exams, reports and interviews in which they must demonstrate the acquired knowledge and skills [35]. During these 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 [36].

B. Future challenges

The adaptation of education on IE to the 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 [37, 38]. The flip learning is known also as inverse learning, whose benefits are: self-learning [39], cooperation between students and professors, problem-based learning [40], and finally versatile of the materials [41]. Sigh et al. [42] describe the results of blended learning based on flip teaching and online assessments. The proposed method improved student’s interest in the course as well as increased learning flexibility, interaction between students and professors.

The traditional 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 [43], the Texas Instruments LaunchPad [44], and Raspberry Pi [45]. The traditional laboratory sessions are complemented also with the virtual or remote laboratories, which allow the students to realize their laboratory experiments from distance [46, 47]. Remote laboratories in IE allow monitoring, control and interaction with real equipment and offer a high level of experimentation. This practice help students and professors to overcome limited resources as the number of students allowed to use the equipment at a specific our, etc.

Taking into consideration 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 national 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 [48]. Standards utilized in the world today provides ease of use for public and industry consumption and drives down the cost of development [49].

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 IES are in emerging areas such as *Industrial Sensors and Systems*, *Industrial Communications*, *Industrial Agents, and Industrial Power and Energy Systems (Smart Grids)*, and *Industrial Wireless Technologies* [50, 51].

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 [50]. These are *IIoT and Sensors, Industrial Wireless and Communications*, which are extensions of present standards development.

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 Internet of Things (IoT) Devices and Systems.

Another innovative area in industrial electronics sensors are in electronic 'sense of smell'. IES is engaged in IEEE P2520 Standard in Testing Machine Olfaction Devices and Systems, as a joint sponsor together with the IEEE Sensors Council.

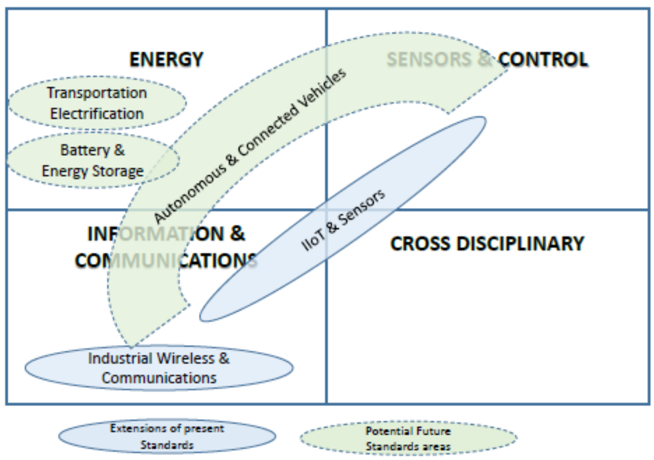

Fig. 3. IES Standards Trends – Present and Future [50].

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 at the heels of these trends, industrial communications impact to industrial automation as well as 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 characteristics of 5G network will serve well as an accelerator and a facilitator of 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 [52], 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) [52]. The challenge here will be generating standards and standardization.

B. Future challenges

Existing standards development will progress in its field of innovation, providing 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 the betterment of 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 (IEEE P2048.1 - .12, Standards for Virtual Reality and Augmented Reality); the use of digital transformation (IEEE 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 (IEEE P2805.1, P2805.2, P2805.3).

Currently 5G devices, networks, and service plans are still in the early days and there are still a number of challenges to make it all functional and achievable. In fact, a great deal of evolutions and enhancements are being made to the 5G standards and 5G networks. 3GPP Release 16 that is to be released in June 2020 will specify 5G system Phase 2, V2X, Industrial IoT, URLLC, higher efficiency and NR based access to the unlicensed spectrum while Release 17 is to be completed in September 2021. To support the capability of Releases 16 and 17, it requires new devices and upgraded networks [53-55]. 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 advantages of 5G network interfaces for critical industrial applications as shown in Fig. 4[1].

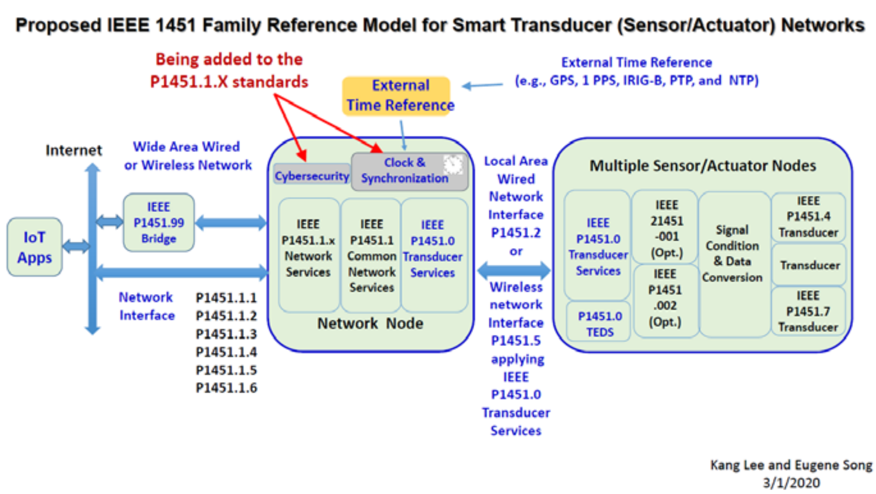

Fig. 4. IEEE 1451 Architecture with Transducer Interface.

From a cross disciplinary view, standards touch the full range of all of IES FoIs and its TCs, namely industry automation, power and energy, industrial communications and control, as well as with its cross

[1] New IEEE 1451 Network architecture standards proposal (Kang Lee, Eugene Song, Standards Chairs)

disciplinary partners such as education, resilience and human factors. In subsystems areas, standardization in electronic systems on chip (ESOC) is realizable in special circumstances. As shown in Fig. 5, 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 IEEE 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.

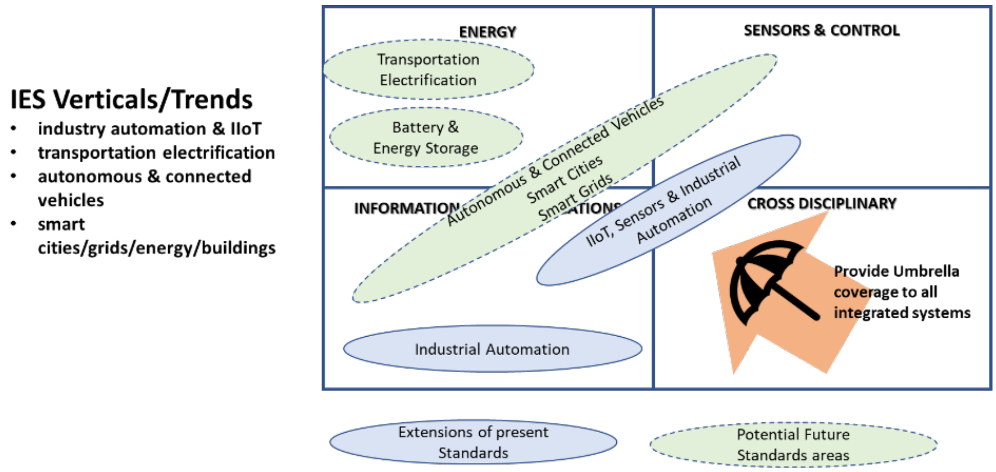

Fig. 5. Future Trends – IES Technologies and Standards.

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 [56]. This concept was soon adopted by many other disciplines including social-ecological systems [57], psychology [58], disaster and risk management [59], energy systems [60], civil/industrial engineering [61], computer networking [62], etc. The use of "resilience" term experienced an exponential growth in publications after 2000s accordingly to Web of Science statistics [63]. 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 [64], transportation system [65], communication system [62], manufacturing system [66], civil infrastructures [67], 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" [68]. 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 Figure 1. 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.

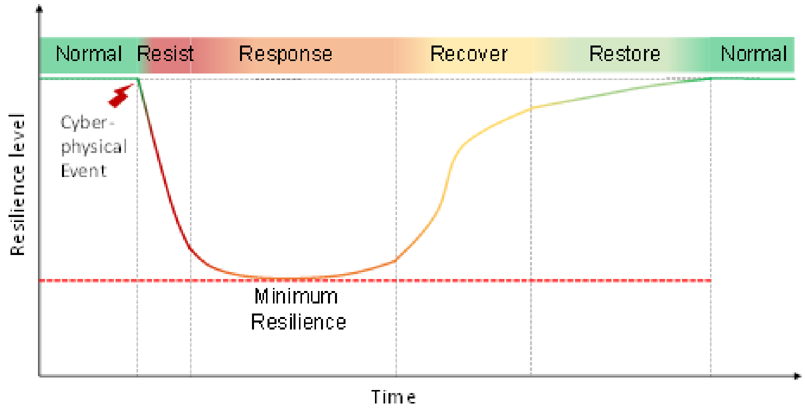

Fig. 6. Resilience curve illustration [60].

Resilience and security are two of the most focused themes for national security. Policy makers and government organizations around the globe have been directing resources and efforts to advance these objectives. US Department of Homeland Security has been issuing National Infrastructure Protection Plan (NIPP) in 2009 and 2013. Similar organizations in European countries, e.g. Germany, UK, etc., also lunched European Programme for Critical Infrastructure Protection. Similarly, in Japan, the National Resilience Program of Japan is launch in the wake of the 2011 earthquake.

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-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 [69], resilient and secure controls to tackle the cyberattacks in the intelligent transportation system [70], resilient transportation system planning and management [71], collective resilience between transportation and energy systems [72], etc. State-of-art energy system research topics includes but not limited to post-disasters electrical service restoration [73], resilient networked microgrids [60], system hardening, reconfiguration, and self-healing to achieve resilience [74], resilient energy management system against cyber-attacks [75], resilient and secure smart grid planning [76], etc. State-of-art communication system research topics includes but not limited to resilient communication in distributed computer networks [77], resilient and secure communication network against cyberattacks [78], resilient cryptography [79], resilient and secure IoT (internet of things) and sensor networks [80], resilient communication networks against disasters and extreme event [81], resilient and reliable communication network design [82], etc. State-of-art manufacturing system research topics includes but not limited to resilient cyber-physical manufacturing system design [83], resilient supply chain [84], resilient task scheduling in manufacturing system [85], resilient and secure manufacturing system against cyberattacks [86], etc.

B. Future challenges

Moving into the future, the resilient and secure industrial applications are facing the following 3 challenges: (1) need for standardization: the consensus on these two terms, especially “resilient”, are yet to be established among the researchers and industry professionals. Standardization efforts are needed to develop qualitative and quantitative definitions and metrics for resilience and security in different fields. (2) human factor: in these large industrial systems, human play a critical role in the resilient and secure operation of these systems. Therefore, it is important to include these human factors and create cyber-physical-social model of the industrial systems. (3) need for resilience and security framework: for each industrial application, researcher tends to approach the problem from either top-down system perspective or bottom-up device perspective. 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 works are oriented around cyber-physical-social system topic. The designed resilient and secure controls and algorithms from this field will eventually be implemented on the electronics systems on chip. Thus, it is very important to secure the electronic SoC 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 many times above, one of the main feature of industrial electronics is its wide range of fields of application (IIoT, Smart Grid, Robotics,…) 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,.. 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 [87], 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 [88]. 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 [89] are probably the most interesting in terms of flexibility and scalability. Indeed, these so called SoC FPGAs (sometimes also named FPSoCs for Field Programmable System-on-Chip) 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 [90] 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 [91], 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.

However, 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 allow 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.

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. 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 [92]. The latter can be also greatly simplified by the quasi systematic use of Hardware-in-the-Loop tests to avoid the use of real plants during development and test phases. In the field of IE, hardware-in-the-loop (HIL) has been widely used [93]. 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

Among the challenges to which the IE research community is confronted in terms of implementation, probably the main one concerns the Edge Computing (EC). Indeed, many IE designers are doing the following observations: 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. At the same time, from a digital technology perspective, the SoC devices are becoming very powerful not only by themselves (i.e. their ability to solve online a 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 for 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… It will 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. An example of modern fully reconfigurable SoC FPGA devices (see Fig. 7) to the incoming complexity of advanced EC applications a better integration of analog functionalities is still required.

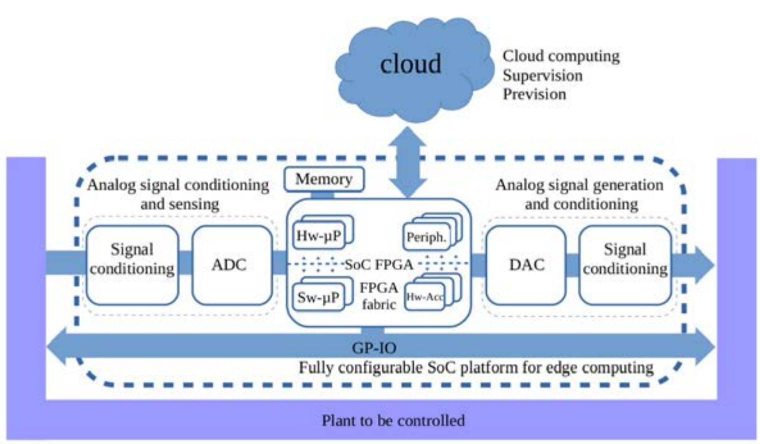

Fig. 7. Fully configurable SoC FPGA platform for edge computing

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. 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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