111Equation Chapter 1 Section 1 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 explains 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 with a special focus 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)/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. 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 an indispensable and practical technical discipline devoted 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 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], and motion capture system for human body movements [6, 7]. On the other hand, psychological characteristics are not a measurable value. It can only be estimated using measurable physical characteristics or interviews [8]. Okasaka et al. proposed an estimation method for the state of human activity using fNIRS (functional near-infrared spectroscopy) [9]. 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 [10]. Mitsukura et al. proposed an evaluation method for human preference based on an 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. As an example, Chugo et al. [12-14] 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.

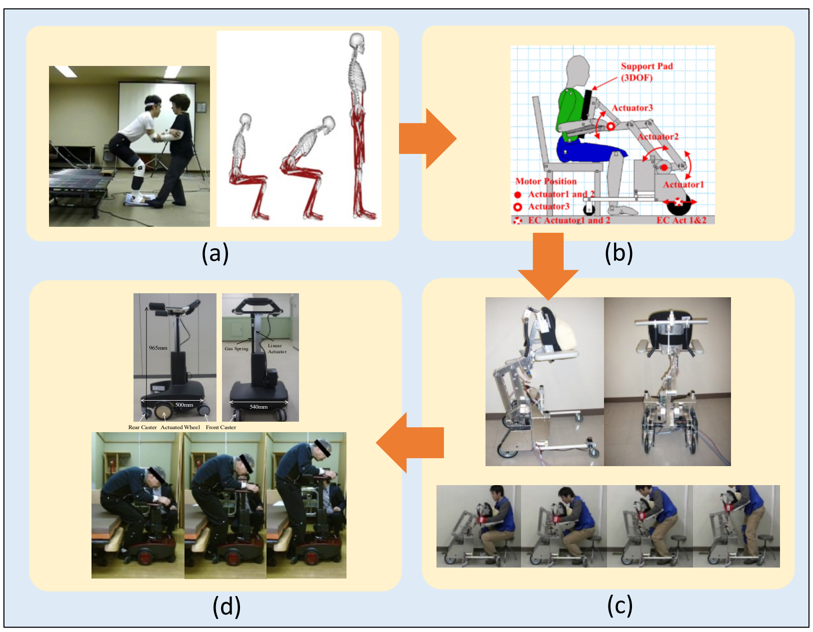

Fig. 1. Development phases involving human factors principles for a robotic walker with standing and seating assistance [12-14]: (a) measuring human motion characteristics, (b) designing fundamental mechanism, (c) prototype design and laboratory evaluation, (d) commercial product and empirical evaluation.

B. Future challenges

Human Factors should cover varieties of outcomes considering individual cognitive or psychic characteristics [15] with social relationship such as healthcare [16], improvement the quality of communications [17] and removal of physical or cognitive handicaps [18]. 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 [19], such as face authentication, fingerprint authentication [20], iris authentication [21], and gait authentication [22], 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 [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 (Erreur : source de la référence non trouvée): 1. Adaptability to new technologies, 2. Multi-discipline, and 3. Multi-culture.

With the years, industrial electronics became more complex and the programs requried 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]. They enhance the autonomous learning, as well as the interest and motivation toward the urgent topics in the area [34].

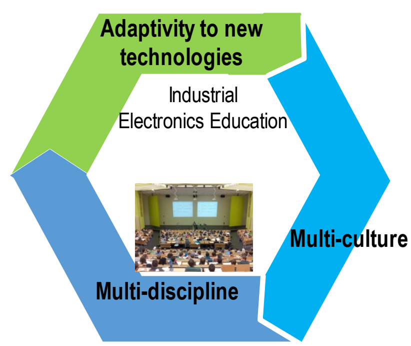

Fig. 1. Three distinctive features of industrial electronics (IE) education.

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

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 [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 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 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 [43], the Texas Instruments LaunchPad [44], and Raspberry Pi [45]. The conventional laboratory sessions are complemented also with the virtual or remote laboratories, which allow students to perform 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 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 [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 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* [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. 2. [50].

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.

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.

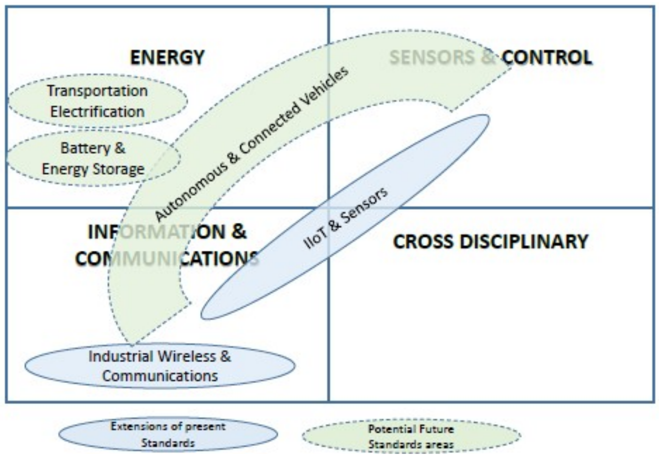

Fig. 2. IES Standards Trends – Present and Future [50].

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 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 [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 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 [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 advantage of 5G network interfaces for critical industrial applications.

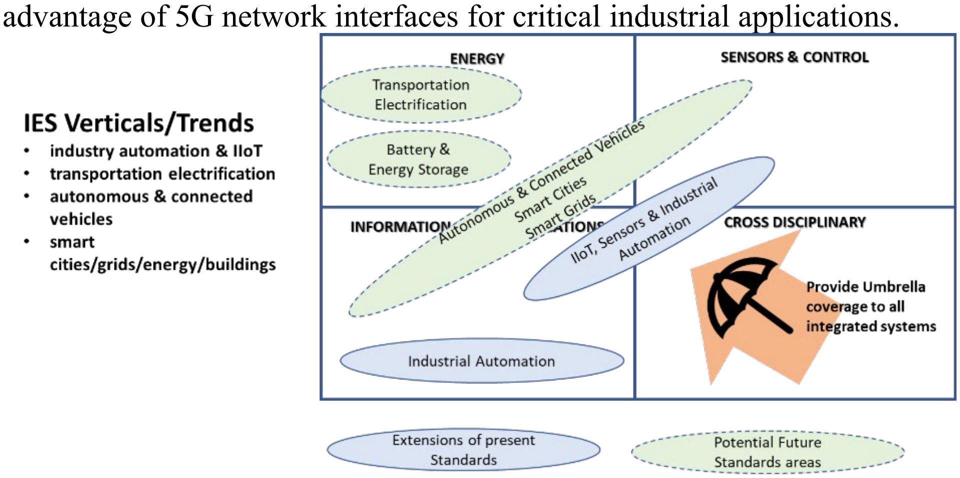

Fig. 3. Future Trends – IES Technologies and Standards.

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. 3., 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 [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 Fig. 4.. 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.

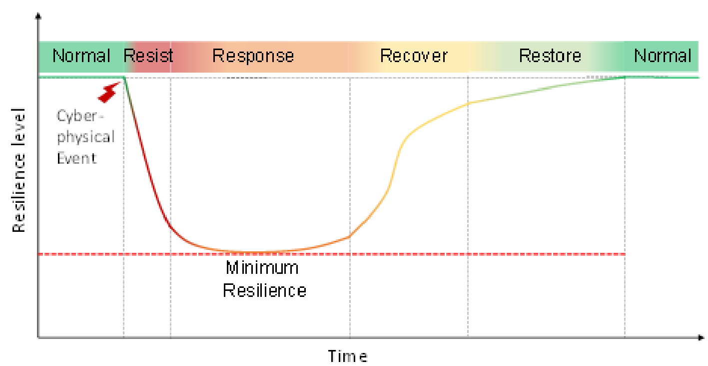

Fig. 4. Resilience curve illustration [60].

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 [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-the-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-the-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 and sensor networks [80], resilient communication networks against disasters and extreme event [81], resilient and reliable communication network design [82], etc. State-of-the-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 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 [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 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 [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.
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, 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) [102]. 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].
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. The latterFinally, 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 [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

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. At the same timeWhile, 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 for 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 [94], etc. It will 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 an 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 mixedmixed 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 [103].

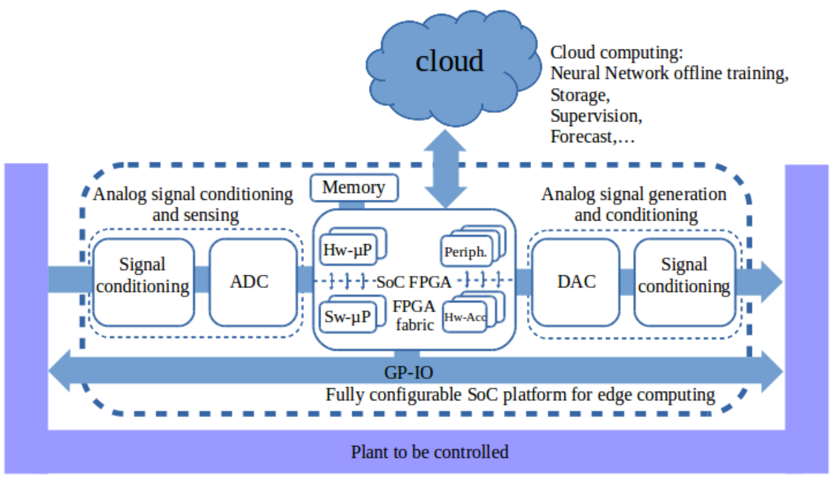

Fig. 5. Proposed fFully configurable SoC FPGA platform for edge computing.

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.

References

[1] IEA. (2020, March 25 th). *What is ergonomics?* Available: https://www.iea.cc/whats/index.html
[2] J. Furukawa, T. Noda, T. Teramae, and J. Morimoto, "An EMG-Driven Weight Support System With Pneumatic Artificial Muscles," *IEEE Systems Journal,* vol. 10, no. 3, pp. 1026-1034, 2016.
[3] T. Hayashi, H. Kawamoto, and Y. Sankai, *Control method of robot suit HAL working as operator's muscle using biological and dynamical information*. 2005, pp. 3063-3068.
[4] D. P. T. V, T. H. Falk, and M. Maier, "MS-QI: A Modulation Spectrum-Based ECG Quality Index for Telehealth Applications," *IEEE Transactions on Biomedical Engineering,* vol. 63, no. 8, pp. 1613-1622, 2016.
[5] J. She, S. Yokota, and E. Y. Du, "Automatic heart-rate-based selection of pedal load and control system for electric cart," *Mechatronics,* vol. 23, no. 3, pp. 279-288, 2013/04/01/ 2013.
[6] V. Ganapathi, C. Plagemann, D. Koller, and S. Thrun, "Real time motion capture using a single time-of-flight camera," in *2010 IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2010, pp. 755-762.
[7] J. C. P. Chan, H. Leung, J. K. T. Tang, and T. Komura, "A Virtual Reality Dance Training System Using Motion Capture Technology," *IEEE Transactions on Learning Technologies,* vol. 4, no. 2, pp. 187-195, 2011.
[8] S. Yokota, D. Chugo, H. Hashimoto, and K. Kawabata, "Visual impression to robot motion imitating human - study on delay motion," in *2016 9th International Conference on Human System Interactions (HSI)*, 2016, pp. 435-439.
[9] S. Okasaka and Y. Hoshino, "Development of estimation method about activity states for NIRS-based BCI system," in *The 6th International Conference on Soft Computing and Intelligent Systems, and The 13th International Symposium on Advanced Intelligence Systems*, 2012, pp. 1144-1149.
[10] S. Yokota, H. Hashimoto, Y. Ohyama, J. She, D. Chugo, and H. Kobayashi, "Classification of body motion for Human Body Motion Interface," in *3rd International Conference on Human System Interaction*, 2010, pp. 734-738.
[11] T. Nakamura, S. Ito, Y. Mitsukura, and H. Setokawa, "A Method for Evaluating the Degree of Human's Preference Based on EEG Analysis," in *2009 Fifth International Conference on Intelligent Information Hiding and Multimedia Signal Processing*, 2009, pp. 732-735.
[12] D. Chugo, T. Asawa, T. Kitamura, J. Songmin, and K. Takase, "A motion control of a robotic walker for continuous assistance during standing, walking and seating operation," in *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2009, pp. 4487-4492.
[13] D. Chugo *et al.*, "Pattern based standing assistance adapted to individual subjects on a robotic walker," in *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2017, pp. 1216-1221.
[14] M. Koyama *et al.*, "Sitting Assistance considering with Posture Tolerance of its User," in *2019 IEEE 28th International Symposium on Industrial Electronics (ISIE)*, 2019, pp. 2321-2326.
[15] C. Lin, P. Lin, P. Lu, G. Hsieh, W. Lee, and R. Lee, "A Healthcare Integration System for Disease Assessment and Safety Monitoring of Dementia Patients," *IEEE Transactions on Information Technology in Biomedicine,* vol. 12, no. 5, pp. 579-586, 2008.
[16] W. H. Organization, *Human Factors: Technical Series on Safer Primary Care*. 2016.
[17] N. Mahyar and M. Tory, "Supporting Communication and Coordination in Collaborative Sensemaking," *IEEE Transactions on Visualization and Computer Graphics,* vol. 20, no. 12, pp. 1633-1642, 2014.
[18] R. Riener, L. Lunenburger, S. Jezernik, M. Anderschitz, G. Colombo, and V. Dietz, "Patient-cooperative strategies for robot-aided treadmill training: first experimental results," *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 13, no. 3, pp. 380-394, 2005.
[19] A. K. Jain, A. Ross, and S. Prabhakar, "An introduction to biometric recognition," *IEEE Transactions on Circuits and Systems for Video Technology,* vol. 14, no. 1, pp. 4-20, 2004.
[20] K. E. Wertheim, "Human Factors in Large-Scale Biometric Systems: A Study of the Human Factors Related to Errors in Semiautomatic Fingerprint Biometrics," *IEEE Systems Journal,* vol. 4, no. 2, pp. 138-146, 2010.
[21] Z. Sun, H. Zhang, T. Tan, and J. Wang, "Iris Image Classification Based on Hierarchical Visual Codebook," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* vol. 36, no. 6, pp. 1120-1133, 2014.
[22] Y. Iwashita, R. Baba, K. Ogawara, and R. Kurazume, "Person Identification from Spatio-temporal 3D Gait," in *2010 International Conference on Emerging Security Technologies*, 2010, pp. 30-35.
[23] A. K. Alhazmi and A. A. Rahman, "Why LMS failed to support student learning in higher education institutions," in *2012 IEEE Symposium on E-Learning, E-Management and E-Services*, 2012, pp. 1-5.
[24] K. Abhari *et al.*, "Training for Planning Tumour Resection: Augmented Reality and Human Factors," *IEEE Transactions on Biomedical Engineering,* vol. 62, no. 6, pp. 1466-1477, 2015.
[25] R. Dormido *et al.*, "Development of a Web-Based Control Laboratory for Automation Technicians: The Three-Tank System," *IEEE Transactions on Education,* vol. 51, no. 1, pp. 35-44, 2008.
[26] J. F. Reintjes, "Educating Engineers for Careers in Industrial Electronics," *IRE Transactions on Industrial Electronics,* vol. IE-9, no. 1, pp. 31-34, 1962.
[27] A. P. Dorey, *Electronics Education-the next decade*. Electronics Education Spring 1990.
[28] P. M. Grant and R. McMurtrie, "Continuing education for industrial electronics graduates," *IEE Proceedings A - Physical Science, Measurement and Instrumentation, Management and Education - Reviews,* vol. 131, no. 9, pp. 734-738, 1984.

[29] B. Chambers, "A short-duration industrial project scheme," *IEEE Transactions on Education,* vol. 31, no. 1, pp. 21-25, 1988.
[30] L. Costas, J. Fariña, and J. J. Rodríguez-Andina, "A configurable framework for the education of digital electronic control systems," in *2009 3rd IEEE International Conference on E-Learning in Industrial Electronics (ICELIE)*, 2009, pp. 7-12.
[31] H. Sarnago, J. M. Burdío, and O. Lucía, "A versatile hardware platform for teaching resonant power conversion courses," in *IEEE International Symposium on Industrial Electronics*, 2018, vol. 1, pp. 890-894.
[32] Z. Zhang, C. T. Hansen, and M. A. E. Andersen, "Teaching Power Electronics With a Design-Oriented, Project-Based Learning Method at the Technical University of Denmark," *IEEE Transactions on Education,* vol. 59, no. 1, pp. 32-38, 2016.
[33] O. Lucía, J. M. Burdío, J. Acero, L. A. Barragán, and J. R. García, "Educational opportunities based on the university-industry synergies in an open innovation framework," *European Journal of Engineering Education,* vol. 37, no. 1, pp. 15-28, 2012.
[34] L. D. Dunai, I. L. Lengua, and G. P. Fajarnés, "Improving skills with project based learning in engineering," in *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, 2017, pp. 3983-3988.
[35] P. Sanger and J. Ziyatdinova, "Project based learning: Real world experiential projects creating the 21st century engineer," *Proceedings of 2014 International Conference on Interactive Collaborative Learning, ICL 2014,* pp. 541-544, 01/21 2015.
[36] B. Warin, O. Talbi, C. Kolski, and F. Hoogstoel, "Multi-Role Project (MRP): A New Project-Based Learning Method for STEM," *IEEE Transactions on Education,* vol. 59, no. 2, pp. 137-146, 2016.
[37] B. Kerr, "The flipped classroom in engineering education: A survey of the research," in *2015 International Conference on Interactive Collaborative Learning (ICL)*, 2015, pp. 815-818.
[38] F. Shahnia and H. H. Yengejeh, "Various Interactive and Self-Learning Focused Tutorial Activities in the Power Electronic Course," *IEEE Transactions on Education,* vol. 62, no. 4, pp. 246-255, 2019.
[39] B. Larry, "Applying Flip/Inverted Classroom Model In Electrical Engineering To Establish Life Long Learning," Chicago, Illinois, 2006/06/18, Available: https://peer.asee.org/491
[40] C. Demetry, "Work in progress — An innovation merging “classroom flip” and team-based learning," in *2010 IEEE Frontiers in Education Conference (FIE)*, 2010, pp. T1E-1-T1E-2.
[41] Y. Zhang, Y. Dang, and B. Amer, "A Large-Scale Blended and Flipped Class: Class Design and Investigation of Factors Influencing Students' Intention to Learn," *IEEE Transactions on Education,* vol. 59, no. 4, pp. 263-273, 2016.
[42] A. Singh, S. Rocke, A. Pooransingh, and C. J. Ramlal, "Improving Student Engagement in Teaching Electric Machines Through Blended Learning," *IEEE Transactions on Education,* vol. 62, no. 4, pp. 297-304, 2019.
[43] C. Carlson, G. Peterson, and D. Day, "Utilizing Portable Learning Technologies to Improve Student Engagement and Retention," *IEEE Transactions on Education,* vol. 63, no. 1, pp. 32-38, 2020.
[44] N. He, W. Huang, and N. Mereddy, "Work-in-progress: Experience of teaching Internet-of-Things using TI ARM based connected launchpad," in *Proc. ASEE Annu. Conf. Expo.*, Seattle, Wa. USA., 2015, pp. 6144-6149.
[45] X. Zhong and Y. Liang, "Raspberry Pi: An Effective Vehicle in Teaching the Internet of Things in Computer Science and Engineering," *Electronics,* vol. 5, no. 3, p. 56, 2016.
[46] R. Marques, J. Rocha, S. Rafael, and J. F. Martins, "Design and Implementation of a Reconfigurable Remote Laboratory, Using Oscilloscope/PLC Network for WWW Access," *IEEE Transactions on Industrial Electronics,* vol. 55, no. 6, pp. 2425-2432, 2008.
[47] M. M. Pandini, A. D. Spacek, J. M. Neto, and O. H. Ando, "Design of a Didatic Workbench of Industrial Automation Systems for Engineering Education," *IEEE Latin America Transactions,* vol. 15, no. 8, pp. 1384-1391, 2017.
[48] J. Hung, "Molding the Future Through Standards [Message from the President]," *IEEE Industrial Electronics Magazine,* vol. 8, no. 4, pp. 3-4, 2014.
[49] V. Huang, "Standards - The Lifeblood of Industry," *IEEE Industrial Electronics Magazine,* vol. 9, no. 3, pp. 50-51, 2015.
[50] V. K. L. Huang *et al.*, "Past, present and future trends in industrial electronics standardization," in *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, 2017, pp. 6171-6178.
[51] V. K. L. Huang, Z. Pang, C. J. Chen, and K. F. Tsang, "New Trends in the Practical Deployment of Industrial Wireless: From Noncritical to Critical Use Cases," *IEEE Industrial Electronics Magazine,* vol. 12, no. 2, pp. 50-58, 2018.
[52] CDW. (March 25th). *Digital Transformation: The Future Of It Arrives*. Available: https://www.cdw.com/content/dam/CDW/solutions/internet-of-things/white-paper-digital-transformation.pdf
[53] 3GPP. (2020, March 25th). *3GPP, A Global Initiative on the Mobile Broadband Standard Release 16*. Available: https://www.3gpp.org/release-16
[54] 3GPP. (2020, March 25th). *3GPP, A Global Initiative on the Mobile Broadband Standard Release 17*. Available: https://www.3gpp.org/release-16https://www.3gpp.org/release-17.
[55] S. Rogers. (2019, March 25th). *The Arrival Of 5G Will Unlock The Full Potential Of VR And AR*. Available: https://www.forbes.com/sites/solrogers/2019/01/30/the-arrival-of-5g-will-unlock-the-full-potential-of-vr-and-ar/#111de7567bcc
[56] C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecology and Systematics,* vol. 4, no. 1, pp. 1-23, November 1973.

[57] F. Berkes and N. J. Turner, "Knowledge, Learning and the Evolution of Conservation Practice for Social-Ecological System Resilience," *Human Ecology,* vol. 34, no. 4, pp. 479-494, October 2006.
[58] M. Rutter, "Annual Research Review: Resilience - clinical implications: Resilience: clinical implications," *Journal of Child Psychology and Psychiatry,* vol. 54, no. 4, pp. 474-487, April 2013.
[59] S. L. Cutter, K. D. Ash, and C. T. Emrich, "The geographies of community disaster resilience," *Global Environmental Change,* vol. 29, pp. 65-77, November 2014.
[60] T. Vu, B. Nguyen, Z. Cheng, M.-Y. Chow, and B. Zhang, "Cyber-Physical Microgrids: Toward Future Resilient Communities," *IEEE Industrial Electronics Magazine,* 2020.
[61] P. Bocchini, D. M. Frangopol, T. Ummenhofer, and T. Zinke, "Resilience and Sustainability of Civil Infrastructure: Toward a Unified Approach," *Journal of Infrastructure Systems,* vol. 20, no. 2, p. 04014004, June 2014.
[62] P. Smith *et al.*, "Network resilience: a systematic approach," *IEEE Communications Magazine,* vol. 49, no. 7, pp. 88-97, July 2011.
[63] S. Meerow and J. P. Newell, "Resilience and Complexity: A Bibliometric Review and Prospects for Industrial Ecology: Resilience and Complexity in Industrial Ecology," *Journal of Industrial Ecology,* vol. 19, no. 2, pp. 236-251, April 2015.
[64] J. Wang, W. Zuo, L. Rhode-Barbarigos, X. Lu, J. Wang, and Y. Lin, "Literature review on modeling and simulation of energy infrastructures from a resilience perspective," *Reliability Engineering \& System Safety,* vol. 183, pp. 360-373, March 2019.
[65] A. Cox, F. Prager, and A. Rose, "Transportation security and the role of resilience: A foundation for operational metrics," *Transport Policy,* vol. 18, no. 2, pp. 307-317, March 2011.
[66] W. J. Zhang and C. A. van Luttervelt, "Toward a resilient manufacturing system," *CIRP Annals,* vol. 60, no. 1, pp. 469-472, 2011.
[67] J. Park, T. P. Seager, P. S. C. Rao, M. Convertino, and I. Linkov, "Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems: Perspective," *Risk Analysis,* vol. 33, no. 3, pp. 356-367, March 2013.
[68] J. L. Carlson *et al.*, "Resilience: Theory and Application," ANL/DIS-12-1, 1044521, February 2012, Available: http://www.osti.gov/servlets/purl/1044521/.
[69] X. Zhang, S. Mahadevan, and K. Goebel, "Network Reconfiguration for Increasing Transportation System Resilience Under Extreme Events," *Risk Analysis,* vol. 39, no. 9, pp. 2054-2075, September 2019.
[70] A. A. Ganin, A. C. Mersky, A. S. Jin, M. Kitsak, J. M. Keisler, and I. Linkov, "Resilience in Intelligent Transportation Systems (ITS)," *Transportation Research Part C: Emerging Technologies,* vol. 100, pp. 318-329, March 2019.
[71] W. Sun, P. Bocchini, and B. D. Davison, "Resilience metrics and measurement methods for transportation infrastructure: the state of the art," *Sustainable and Resilient Infrastructure,* pp. 1-32, April 2018.
[72] S. Yao, P. Wang, and T. Zhao, "Transportable Energy Storage for More Resilient Distribution Systems With Multiple Microgrids," *IEEE Transactions on Smart Grid,* vol. 10, no. 3, pp. 3331-3341, May 2019.
[73] S. Lei, C. Chen, Y. Li, and Y. Hou, "Resilient Disaster Recovery Logistics of Distribution Systems: Co-Optimize Service Restoration With Repair Crew and Mobile Power Source Dispatch," *IEEE Transactions on Smart Grid,* vol. 10, no. 6, pp. 6187-6202, November 2019.
[74] Y. Lin and Z. Bie, "Tri-level optimal hardening plan for a resilient distribution system considering reconfiguration and DG islanding," *Applied Energy,* vol. 210, pp. 1266-1279, January 2018.
[75] J. Duan and M.-Y. Chow, "A Resilient Consensus-Based Distributed Energy Management Algorithm Against Data Integrity Attacks," *IEEE Transactions on Smart Grid,* vol. 10, no. 5, pp. 4729-4740, September 2019.
[76] J. Najafi, A. Peiravi, and J. M. Guerrero, "Power distribution system improvement planning under hurricanes based on a new resilience index," *Sustainable Cities and Society,* vol. 39, pp. 592-604, May 2018.
[77] B. Kaviarasan, R. Sakthivel, C. Wang, and F. Alzahrani, "Resilient control design for consensus of nonlinear multi-agent systems with switching topology and randomly varying communication delays," *Neurocomputing,* vol. 311, pp. 155-163, October 2018.
[78] H. Yuan and Y. Xia, "Resilient strategy design for cyber-physical system under DoS attack over a multi-channel framework," *Information Sciences,* vol. 454-455, pp. 312-327, July 2018.
[79] Y. T. Kalai and L. Reyzin, "A survey of leakage-resilient cryptography," in *Providing Sound Foundations for Cryptography: On the Work of Shafi Goldwasser and Silvio Micali*, S. Weizmann Institute of and O. Goldreich, Eds.: Association for Computing Machinery, 2019.
[80] K. E. Benson, G. Wang, N. Venkatasubramanian, and Y.-J. Kim, "Ride: A Resilient IoT Data Exchange Middleware Leveraging SDN and Edge Cloud Resources," in *2018 IEEE/ACM Third International Conference on Internet-of-Things Design and Implementation IoTDI*, Orlando, FL, 2018, pp. 72-83: IEEE.
[81] W.-P. Chen, A.-H. Tsai, and C.-H. Tsai, "Smart Traffic Offloading with Mobile Edge Computing for Disaster-Resilient Communication Networks," *Journal of Network and Systems Management,* vol. 27, no. 2, pp. 463-488, April 2019.
[82] E. Gourdin, D. Medhi, and A. Pattavina, "Design of reliable communication networks," *Annals of Telecommunications,* vol. 73, no. 1-2, pp. 1-3, February 2018.
[83] T. Tomiyama and F. Moyen, "Resilient architecture for cyber-physical production systems," *CIRP Annals,* vol. 67, no. 1, pp. 161-164, 2018.

[84] I. M. Cavalcante, E. M. Frazzon, F. A. Forcellini, and D. Ivanov, "A supervised machine learning approach to data-driven simulation of resilient supplier selection in digital manufacturing," *International Journal of Information Management,* vol. 49, pp. 86-97, December 2019.
[85] J. Wang, P. Zheng, W. Qin, T. Li, and J. Zhang, "A novel resilient scheduling paradigm integrating operation and design for manufacturing systems with uncertainties," *Enterprise Information Systems,* vol. 13, no. 4, pp. 430-447, April 2019.
[86] R. F. Babiceanu and R. Seker, "Cyber resilience protection for industrial internet of things: A software-defined networking approach," *Computers in Industry,* vol. 104, pp. 47-58, January 2019.
[87] G. Strawn and C. Strawn, "Moore's Law at Fifty," *IT Professional,* vol. 17, no. 6, pp. 69-72, 2015.
[88] S. Harris and D. Harris, *Digital Design and Computer Architecture: ARM Edition*. Morgan Kaufmann Publishers Inc., 2015.
[89] S. M. S. Trimberger, "Three Ages of FPGAs: A Retrospective on the First Thirty Years of FPGA Technology: This Paper Reflects on How Moore's Law Has Driven the Design of FPGAs Through Three Epochs: the Age of Invention, the Age of Expansion, and the Age of Accumulation," *IEEE Solid-State Circuits Magazine,* vol. 10, no. 2, pp. 16-29, 2018.

[90] M. D. V. Pena, J. J. Rodriguez-Andina, and M. Manic, "The Internet of Things: The Role of Reconfigurable Platforms," *IEEE Industrial Electronics Magazine,* vol. 11, no. 3, pp. 6-19, 2017.
[91] E. Monmasson, L. Idkhajine, and M. W. Naouar, "FPGA-based controllers," *IEEE Industrial Electronics Magazine,* vol. 5, no. 1, pp. 14-26, 2011.
[92] J. Krizan, L. Ertl, M. Bradac, M. Jasansky, and A. Andreev, "Automatic code generation from Matlab/Simulink for critical applications," in *2014 IEEE 27th Canadian Conference on Electrical and Computer Engineering (CCECE)*, 2014, pp. 1-6.
[93] A. S. Vijay, S. Doolla, and M. C. Chandorkar, "Real-Time Testing Approaches for Microgrids," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 5, no. 3, pp. 1356-1376, 2017.
[94] W. Dai, H. Nishi, V. Vyatkin, V. Huang, Y. Shi, and X. Guan, "Industrial Edge Computing: Enabling Embedded Intelligence," *IEEE Industrial Electronics Magazine,* vol. 13, no. 4, pp. 48-56, 2019.
[102] J. Cong, L. Bin, S. Neuendorffer, J. Noguera, K. Vissers, and Z. Zhiru, "High-level synthesis for FPGAs: From prototyping to deployment," *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems,* vol. 30, no. 4, pp. 473-491, 2011.
[103] B. Farley, J. McGrath, and C. Erdmann, “An all-programmable 16-nm rfsoc for digital-rf communications,” IEEE Micro, vol. 38, no. 2, pp. 61–71, 2018.