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A Conceptual Review of Cyber-Physical Systems

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Abstract: Smart devices are becoming more sophisticated with increased capabilities while they remain a relatively low-cost technology. Also, many of these smart devices rely on the prevalence of high-speed wireless networks, including 4G cellular networks. With the Internet of Things, every object can retrieve information from the environment and then manage and share that information with other devices or users. The IoT aims to the synergy of computational and physical components, specifically the use of cyber-physical systems (CPSs), led to the advancement of Internet of Things implementations. CPSs introduce cooperation among elements of the cyber and physical space, by integrating computational resources. CPSs often support real life processes and provide operational control of Internet of Things objects, which allow physical devices to sense the environment and modify it. In this paper mainly concentrate on cyber physical system, theoretical foundation, automotive scenario, Medical cyber-physical systems and Education and training challenges in the era of cyber physical systems.
Keywords: Cyber-physical systems, Theoretical Foundations and challenges, automotive scenario, Medical cyber-physical systems, Education and training challenges in the era of cyber physical systems.
Synergy of cyber and physical worlds: Internet of Things (IoT) is a disruptive technology that provides the potential for innovations and significant improvements to societal and business environments. With IoT technologies, you can create adaptive and intelligent applications that can better manage resources and provide more efficient systems. IoT and CPSs are designed to support applications that can manage enormous amounts of data and a wide variety of data from the environment. Thus, CPSs can boost the smart city vision by using information and communication technologies for more efficient and effective resource management. Smart cities focus on providing innovative and better quality services to its citizens by improving the infrastructure of the city while reducing the overall costs.

I. CYBER-PHYSICAL SYSTEMS

A. Introduction

In a cyber-physical system (CPS), computing elements coordinate and communicate with sensors, which monitor cyber and physical indicators, and actuators, which modify the cyber and physical environment where they are run. CPSs often seek to control the environment in some way. CPSs use sensors to connect all distributed intelligence in the environment to gain a deeper knowledge of the environment, which enables a more accurate actuation. In a physical context, actuators act and modify the environment where users live. In a virtual context, CPSs are used to collect data from the virtual activities of users, such as their involvement on social networks, blogs, or e-commerce sites. Then, CPSs react in some way to that data to predict actions or needs of users as a whole. With software solutions such as IBM Web Sphere Sensor Events you can connect to and analyze sensor-based, real-time data and events, and integrate those events into smarter solutions.

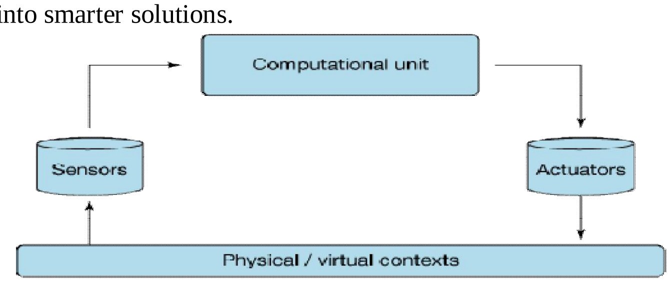

Figure1. CPS architecture

Some practical applications of cyber-physical systems include

1) In the manufacturing environment, CPSs can improve processes by sharing real-time information among the industrial machines, manufacturing supply chain, suppliers, business systems, and customers. Also, CPSs can improve these processes by self-monitoring and controlling the entire production processes and then adapting production to satisfy customers' preferences. CPSs provide a higher degree of visibility and control on supply chains, improving the traceability and security of goods.

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2) In the healthcare environment, CPSs are used for real-time and remote monitoring of the physical conditions of patients to limit patient hospitalization (for example, for patients who suffer from Alzheimer's disease) or to improve treatments for disabled and elderly patients. Moreover, CPSs are used in research in the neuroscience field to better understand human functions with the support of brain-machine interfaces and therapeutic robotics.
3) In the renewable energy environment, smart grids are CPSs where sensors and other devices monitor the grid to control it and provide better reliability and improve the energy efficiency.
4) In smart building environments, smart devices and CPSs interact to reduce energy consumption, to increase safety and security, and to improve inhabitants' comfort. For example, with CPSs you can enable energy monitoring and control systems usage, which help you achieve zero-energy buildings, or you can determine the extent of damage that buildings suffer after unexpected events and help prevent structural failures.
5) In the transportation environment, individual vehicles and the infrastructure can communicate with each other, sharing real-time information about traffic, location, or issues, in order to prevent accidents or congestion, improve safety, and ultimately save money and time.
6) In the agriculture environment, CPSs can be used to create more modern and precise agriculture. CPSs can collect fundamental information about the climate, the ground, and other data, in order to realize more accurate systems of agricultural management. CPSs can constantly monitor different resources, such as watering, humidity, plant health and others, through sensors and, thus, keep the ideal environmental values.
7) In computer networks, CPSs can boost cyber environments to better understand systems and users' behaviors, which can help improve performances and resource management. For example, applications can be optimized to work in relation to the contexts and to the users' actions, or to monitor available resources. Moreover, popular social networks and e-commerce websites store users' navigation information and users' web content, analyzes that information, and then tries to predict interests and make recommendation for friends, posts, links, pages, events, or products.

II. THEORETICAL FOUNDATIONS AND CHALLENGES

The behavior of CPS is characterized by the nonlinear interaction between discrete (computing device) and continuous phenomena (the physical substratum). For this reason, research on hybrid systems plays a key role in modeling and analyzing CPS. CPS are usually spatially distributed and they exhibit emergent behaviors (i.e. traffic jams, cyber-attacks), which result from interactions among system components, and which cease to exist when specific components are removed from the systems. Owing to their ubiquity and impact on every aspect of our life, one of the greatest challenges of this century is to efficiently predict the emergent behaviors of these systems. The complexity of their models, however, often hinders any attempt to exhaustively verify their safe behavior. An alternative method is to equip CPS with monitors and to predict emergent behaviors at runtime. This approach makes CPS self-aware, opening up new approaches to designing systems that can dynamically reconfigure themselves in order to adapt [1] to different circumstances. However, monitoring introduces a runtime overhead that may alter the timing-related behavior of the system under scrutiny. In applications with real-time constraints, overhead control strategies may be necessary to reduce the overhead to acceptable levels by, for example, turning on and off the monitoring. Gaps in monitoring, however, introduce uncertainty in the monitoring results. Hence, our current research [1] also focuses on efficient techniques to quantify this uncertainty and compute an estimate of the current state of the system.

III. AUTOMOTIVE SCENARIO

The extensive integration of sensor networks and computational power into automotive systems over recent years has enabled the development of various systems to assist the driver during monotonous driving conditions, and to protect the passenger from hazardous situations. This trend will inevitably lead to autonomous vehicles. In order to plan actions and reliably negotiate traffic, these vehicles need sensors capable of fault tolerant observation of their environment. Additionally, vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication technology – also known as V2X communication – will be integrated into future automotive systems. V2X communication allows exchange of information between vehicles and roadside units about position and speed of vehicles, driving conditions on a particular road, accidents, or traffic jams. Information exchange thereby allows traffic load to be distributed among several roads during rush hour, as well as preventing accidents and multiple collisions and sending automated emergency calls. Figure 1 schematizes different levels of an automotive system-of-systems consisting of sensor networks within a car, and the interaction of vehicles on a higher system level.

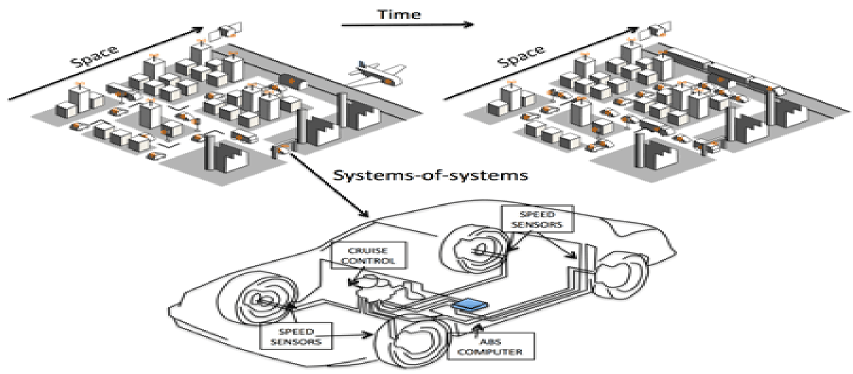

Figure 2: Multi-level CPS in the automotive domain.

Fast error detection, fault tolerant system designs and new planning strategies are required to cope with the increasing failure rates of microchips owing to continuous shrinking of devices, as well as reliance on unreliable sources of information (e.g., information sent by other vehicles). Some of these problems can be solved by knowledge-based techniques, such as autonomous reconfiguration and substitution of faulty subsystems and components by using system ontologies [2].

IV. MEDICAL CYBER-PHYSICAL SYSTEMS

Medical CPS refers to modern medical technologies in which sophisticated embedded systems equipped with network communication capabilities, are responsible for monitoring and controlling the physical dynamics of patients' bodies. Examples include proton therapy machines, electro-anatomical mapping and intervention, bio-compatible and implantable devices, and robotic prosthetics. Malfunctioning of these devices can have adverse consequences for the health of the patient. The verification, validation and certification of their reliability and safety are extremely important and still very challenging tasks, owing to the complexity of the involved interactions. The modelling and efficient simulation of the patient body will play a key role in the design and validation of Medical CPS and in the development of personalized treatment strategies. To this end, our research has largely focused on modelling and analysis techniques for cardiac dynamics to predict the onset of arterial and ventricular fibrillation. In [3] we show that with a normal desktop with GPU technology, it is possible to achieve simulation speeds in near real-time for complex spatial patterns indicative of cardiac arrhythmic disorders. Real-time simulation of organs without the need for supercomputers may soon facilitate the adoption of model-based clinical diagnostics and treatment planning.

Figure: 3 Medical Cyber-Physical Systems

V. EDUCATION AND TRAINING CHALLENGES IN THE ERA OF CYBER PHYSICAL SYSTEMS

Education and training face several challenges as our society is evolving to become increasingly dependent on Cyber-Physical Systems (CPS). We present and discuss how education is impacted, leveraging mainly a cross-domain investigation of CPS challenges of the EU CyPhERS project. In particular, the investigation revealed challenges that go beyond engineering education and that were found to be common across domains; (i) the need to consider and to include a broader set of stakeholders including policy makers and the general public to raise awareness of CPS technology implications (opportunities, risks and challenges), (ii) emphasizing human centered perspectives including sustainability and privacy in CPS education to make sure we end up with a human centric CPS-based society, (iii) improving the status of teaching,and (iv) supporting educational platforms and life-long learning capabilities. We conclude by discussing implications for educational systems.

A. *Introduction And Motivation*

The increasing connectivity, significance of software-defined functionality and an increasing penetration of electronics and software into virtually all facets of our lives, results in a society which is becoming dependent on smart devices that are part of and form inter-connected Systems of Systems. Different research communities refer to these systems by different names, such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Ubiquitous Computing, the Fog and the Swarm, but all share the same paradigm of immersive and distributed sensing and computing. In this paper, we will refer to these technologies collectively as CPS.

It is clear that there is a large demand for CPS engineers. For ex-ample, according to an investigation by ARTEMIS and ITEA2, the global market of Digital Technology is currently estimated at USD 3,300 billion, corresponding to approximately 50 million jobs, and is predicted to have continued strong growth [1]. The term Digital Technology was used in [1] to account for software, embedded software, IT services, internal IT as well as hardware encompassing semiconductors, PCs, tablets, servers, storage, and peripherals. The nature of CPS, however, implies a paradigm shift in the way systems are designed. Distinguishing "embedded" from "IT" used to be simple, as were the corresponding curricula. However, the connectivity and software intensiveness in all sorts of new applications imply that the traditional separation into various disciplines and domains is no longer adequate. Given this evolution, it is not surprising that CPS education is facing challenges in view of a growing demand from industry and public administrations, and considering innovation opportunities that lie in systems oriented services and products (cross discipline and domains). University programs are not producing the numbers of CPS specialists required and need to improve when it comes to balancing the skills provided. The paradigm shift motivates extra efforts for revising education programs. Indeed, university educators are actively engaged in discussing how to reform programs to educate the CPS engineers of tomorrow. Balance and synergy lie at the core of developing CPS programs.

Beyond engineering education, the large-scale implications of CPS imply that other educational and training efforts are important to make it possible to develop “CPS based societies”. In this paper we summarize and discuss such educational related findings, obtained mainly within the EU Project CyPhERS, an effort to create a CPS roadmap and agenda for Europe.

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. The main findings of CyPhERS were intended to define actions that could help to ensure sustainable and smooth adoption of CPS.

CyPhERS took a broad perspective of CPS; the main findings relevant to education are as follows: Training and education require inclusion and consideration of a broader set of stakeholders including policy makers and the general public, in order to raise awareness of CPS opportunities, challenges and risks. Programs should be human-centered and should address sustainability and privacy to ensure that we develop a CPS ecosystem that is useful to humans and society. Improving the status of teaching.Stronger needs for life-long learning and continued education for engineers and other stakeholder. The needs are emphasized by the pace and variety of technological development, for example the integration of consumer electronics with industrial electronics. In addition, there are needs tosupport the development of educational platforms.

The paper is laid out as follows. Section 2 provides information about the investigations carried out. Section 3 summarizes the main findings, whereas Section 4 discusses these findings. Section 5 concludes the paper with recommendations for further work.

B. *Under Lying Investigations*

The findings described in this paper draw mainly on the CyPhERS project. The CyPhERS project was an EU-funded support action intended to establish a strategy and roadmap for CPS in Europe CyPhERS had a broad remit covering, for example, technology trends and the impact of CPS on markets, e.g. identifying potential for disruption, including displacing incumbent suppliers. Some of CyPhERS’ work was generic, e.g. considering trends in technology, whereas some was domain specific. For example, the project considered smart grids, manufacturing, healthcare, road transportation and smart cities as application domains for CPS.

The core members of the CyPhERS project drew on their own expertise, but sought insight froma wide range of sources. As a consequence the project ran several workshops, carried out state-of-the-art surveys, and undertook in depth analysis, including SWOT analysis, for the five selected domains.

The findings in the selected domains were different in detail, but there was clear commonality in the core issues they identified. The findings were also supported by industrial and academic views expressed at a number of the workshops. The project produced recommendations to the EU on actions that could be taken to strengthen and protect the position of Europe in CPS, and the five domains investigated in more detail.

While the findings from the CyPhERS project were centered on a European perspective, the investigations also partly covered Asia, USA and Australia, by involving experts from these areas.

C. Main findings

1) Societal level training and preparation the widespread adoption and penetration of CPS will affect most daily tasks and actions performed by any person. CPS will also in effect impact most aspects of a society, for example in terms of legislation, insurances, investments, governmental procurements, and privacy. One of the key findings is that training and education consequently require the inclusion and consideration of a broader set of stakeholders than just engineers and system developers. A very broad set of stakeholders need basic understanding (and thus some form of education) about CPS! If used effectively, CPS will enhance our daily lives and contribute to a sustainable society. If used and/or designed inappropriately, they may lead to unacceptable risks, for example causing shut-down of critical systems for transportation, energy provision and/or healthcare. They may also cause accidents and loss of energy and information. Because societies will rely on CPS it is of paramount importance not only that they are effectively engineered, but also well understood and Decisions makers will, for example, be involved in risk assessments and trade-offs regarding choices in procuring CPS-based systems. Without basic insights, certain vulnerabilities and risks may be disregarded or devalued. A typical example of this would be decision makers for smart cities and transportation systems. Awareness of CPS is also likely to increase the likelihood of CPS-based innovation and societal improvements. Involving the general public to a larger degree may also help to limit the "digital divide". The immense opportunities offered by CPS, and the trade-offs involved (for example referring todata sharing vs. privacy, open-ness vs. security threats), would benefit from elaboration and investigation involving end-users. Essentially, "any system could be built" – the question is – what type of CPS-based societies would we like to create? For this purpose we recommend larger scale demonstrators and pilotsto involve end-users. To raise CPS awareness, education and training for a broader set of stakeholders needs to be addressed, ranging from early schooling to continuing education The engineering training and education needs to focus on CPS traits and the characteristics of SoS, including: Increasing openness, adaptability and autonomy, in contrast with traditionally closed systems, with single jurisdiction, limited adaptability and autonomy. The extensive inclusion of off-the-shelf (OTS) parts perhaps with limited knowledge about their pedigree; Continual evolution, as individual CPS are upgraded;The ability to integrate across domains, e.g. to link smart grid with (charging for) electrics vehicles. There is also a need of specialist training for system integrators and architects focusing, inter alia, on emergent properties, controlof system configuration, system audit and monitoring.
2) *Sustainable Technologies :*Electronics is already being embedded "everywhere" in our societies, and the CPS evolution will pave the way for even more electronics. CPS further creates important business opportunities for largely automated technological systems. The implication is that economic, social and environmental sustainability must be considered now in order to ensure that planning, adoption and deployments of CPS sufficiently consider such aspects, in turn ensuring that humans remain in the center stage of a CPS-based society. Important sustainability considerations that should be part of an all-around education program include Scarcity of earth's natural resources. Incentives to drive sustainable solutions towards a circular economy are important. CPS technology can contribute by providing including architectures and modularization schemes to support this. Management and maintenance of systems, mastering and limiting their complexity. Software and network based systems easily contribute unintended (and difficult to control) complexity into systems. Privacy, security, safety and reliability/availability considerations, and their trade-offs with usability and performance. Technological systems are all too often developed by technicians with limited understanding of behavioral science, user experience, cognition and psychology. This results in systems that are hard and annoying to use. We cannot afford this to scale to societal CPS systems. Research, innovation, development and deployment activities must therefore include expertise encompassing the understanding of humans (anthropology, sociology), together with engineering, business and legal aspects. The presented topics are important both for research and education. There is a general need to bring sustainability issues including forward in engineering education.

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3) Promoting the status of teaching has a low status in universities in Europe, and also in proceeding schools (high-schools and earlier), and, consequently is not rewarded with the attention it deserves. This issue was recognized unanimously in workshops with academia (with our sources drawn from Europe, US and Australia). Similar concerns have been raised by national authorities. It is interesting to note that this issue was often met with surprise from industrial stakeholders, who however expressed very strong support in improving the situation. The lowered status of teaching might originate from marketing and performance strategies imposed on higher education institutions. Initiatives to improve the status of teaching and management of teaching are therefore urgently needed.
4) *Educational platforms and life-long learning.:* There is a need to create new teaching and training approaches leading to a new generation of scientists and engineers qualified and interested in working in CPS. CPS is a dynamic field that requires an increased emphasis on multidisciplinary skills and significant enhancements in engineering curricula, renewed emphasis on systems sciences and engineering. Due to their rich infrastructure and set of basic services, future CPS can accelerate the construction of innovative added-value services. To exploit these opportunities, we need dynamic training programs for engineers, operators, and users of these systems to create pathways for keeping the workforce on top of new developments as they emerge. Engineers must experience practical, cross-discipline technologies to familiarize themselves with the necessary - often more technical and practical than theoretical - capabilities to enable these innovations. Thus, the establishment of private-public cooperation and open source initiatives for the operation of educational platforms, facilitating experimentation with new technologies and interdisciplinary learning, including technology kits for CPS labs, "open labs", "hacker spaces" and "maker spaces". An educational platform for CPS, as illustrated in Figure 1, should incorporate theory, CPS labs as well as more realistic industrial test beds. In such a platform the Lab component plays an important role in dealing with the identified concepts and new technologies of CPS in preparing trainees for the real world. It exposes training engineers to practical experimentation and interdisciplinary learning throughout labs and CPS design projects, with adequate hands-on experiments. Educational Platform for CPS. Due to the disruptive nature of CPS and the fast innovation cycles in information and communication technology, the half-life of state of the art knowledge in several involved disciplines and technologies is short. To ensure the necessary re-qualification, an academic-industrial alliance should engage established engineers in life-long learning through alumni-programs or training courses offered by academic and industrial educational institutions and supported by industry. It is clear that there needs to be another shift in education and training in that it can no longer be viewed as a focus from (say) ages 15 to 25; instead it needs to start from early school and continue in a life-long learning scenario.

D. Discussion

The validity of the findings is sustained by the coverage of five domains (which we believe to be representative), multiple world-wide regions, academic and industrial viewpoints.

The findings were also compared toother investigations, see e.g. the ITEA ARTEMIS-IA High-Level Vision 2030, the German Agenda CPS and additional investigations referenced in the CyPhERS deliverables (for example in Deliverable D5.2).In particular, other investigations identified needs for life-

long learning, finding (iv). Findings (i) – involvement and training of a broader set of stakeholders, and (iii) – status of teaching and educational platforms, appear to be unique to our electronics. CPS further creates important business opportunities for largely automated technological systems. The implication is that economic, social and environmental sustainability must be considered now in order to ensure that planning, adoption and deployments of CPS sufficiently consider such aspects, in turn ensuring that humans remain in the center stage of a CPS-based society.

Important sustainability considerations that should be part of an all-around education program include

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The presented topics are important both for research and education. There is a general need to bring sustainability issues including forward in engineering education.

E. Promoting the status of teaching

Teaching has a low status in universities in Europe, and also in proceeding schools (high-schools and earlier), and, consequently is not rewarded with the attention it deserves, . This issue was recognized unanimously in workshops with academia (with our sources drawn from Europe, US a nd Australia). Similar concerns have been raised by national authorities, . It is interesting to note that this issue was often met with surprise from industrial Stakeholders, who however expressed very strong support in im-proving the situation.

The lowered status of teaching might originate from marketing and performance strategies imposed on higher education Institutions, . Initiatives to improve the status of teaching and management of teaching are therefore urgently needed.

F. Educational platforms and life-long learning

There is a need to create new teaching and training approaches leading to a new generation of scientists and engineers qualified and interested in working in CPS.

CPS is a dynamic field that requires an increased emphasis on multidisciplinary skills and significant enhancements in engineering curricula, renewed emphasis on systems sciences and engineering. Due to their rich infrastructure and set of basicservices, future CPS can accelerate the construction of innovative added-value services. To exploit these opportunities, we need dynamic training programs for engineers, operators, and users of these systems to create pathways for keeping the workforce on top of new developments as they emerge.

Engineers must experience practical, cross-discipline technologies to familiarize themselves with the necessary - often more technical and practical than theoretical - capabilities to enable these innovations. Thus, the establishment of private-public cooperation and open source initiatives for the operation of educational platforms, facilitating experimentation with new technologies and interdisciplinary learning, including technology kits for CPS labs, “open labs”, “hacker spaces” and “maker spaces”. An educational platform for CPS, as illustrated in Figure 1, should incorporate theory, CPS labs as well as more realistic industrial test beds. In such a platform the Lab component plays and important role in dealing with the identified concepts and new technologies of CPS in preparing trainees for the real world. It exposes training engineers to practical experimentation and interdisciplinary learning throughout labs and CPS design projects, with adequate hands-on experiments. Figure 3. Educational Platform for CPS. Due to the disruptive nature of CPS and the fast innovation cycles in information and communication technology, the half-life of state of the art knowledge in several involved disciplines and technologies is short. It is clear that there needs to be another shift in education and training in that it can no longer be viewed as a focus from (say) ages 15 to 25; instead it needs to start from early school and continue in a life-long learning scenario.

G. Discussion

The validity of the findings is sustained by the coverage of five domains (which we believe to be representative), multiple world-wide regions, academic and industrial view points. The findings were also compared to other investigations, see e.g.the ITEA ARTEMIS-IA High-Level Vision 2030, the German Agenda CP,and additional investigations referenced in the CyPhERS deliverables (for example in Deliverable D5.2), In particular, other investigations identified needs for life-long learning, finding (iv). Findings (i) – involvement and training of a broader set of stakeholders, and (iii) – status of teaching and educational platforms, appear to be unique to our investigation in the context of CPS education. While finding (i) is implied by some investigations, it is rarely spelled out explicitly.

While some aspects of human centered perspectives are frequently highlighted, issues such as privacy and sustainability Appear to be less often identified. Networking and collaboration will be instrumental in meeting CPS challenges, and this is also true for education and training. We notice stronger trends within and across industries / industrial domains to create learning networks and to increase collaboration with academia. Learning networks can help addressing several of the findings by bringing stakeholders together, focusing on com-mon challenges (such as sustainability and low status of teaching), and by joining efforts in order to strengthen, for example, continued training. We identify a consequent need for initiatives (e.g. through public funding) to support large scale "collaboration networks" that can remove barriers by incentivizing collaboration among disjoint groups of CPS stakeholders.

The complexity of CPS – not only with respect to each of the technologies involved, but also specifically with respect to the engineering-challenge of systems of that scale and heterogeneity– requires education and research in both theoretical foundation and pragmatic engineering. This should, as far as possible, build on opportunities made available by internet based learning (e.g. MOOC approaches), where the physical and hands on aspects of CPS will require specific considerations and further work.

It is likely that CPS will involve a technological paradigm shift, with potentially drastic implications for existing organizations and regions. Perhaps the greatest "defense" against the threat of disintermediation, is the agility on the part of developing organizations and societies to identify and exploit opportunities, matching the pace of innovation. Public (and private-public) initiatives can help by supporting innovation and education and training initiatives that can keep regions at the forefront in critical areas of CPS design, development and application.

VI. FUTURE CHALLENGES

For cyber-physical systems and smart cities to be successful, people need to think and act differently and get more involved in city life. Active communities that can aggregate the distributed knowledge of each individual and can complete synergistic actions to improve the city services are essential. Technology today allows for distributed computing and crowd sourcing, sharing information among users, and building a collective intelligence. Collective intelligence is one of the keys for the success of CPSs and smart cities. Collective intelligence uses the crowd sensing for the cooperative monitoring of the urban environment. It also targets cooperative actuation of operations to perform tasks of general interest in an efficient way. From the technical perspective, many hard challenges must still be solved, at least in an efficient and industrially applicable way. Some of the challenges are:

A. Data heterogeneity

Data heterogeneity is a significant issue that can affect communication performance and the design of communication protocols. Systems need to be able to support a great number of different applications and devices.

B. Reliability

CPSs are suitable to use in critical contexts like healthcare, infrastructure, transportation, and many others. Reliability and safety are basic requirements because of how actuators affect the environment. In fact, the impact of actuators can also be irreversible, and therefore the presence of unexpected behavior must be minimized. Moreover, the environment is not predictable so CPSs must continue to work under unexpected circumstances and adapt themselves in case of failures.

C. Data management

It is necessary to store and analyze big data from different connected devices, process them, and show real-time results. Data can be managed by using offline or online stream processing in relation to the goals of the system. In particular with an online stream, information can change frequently with real-time conditions and are based on adaptive and continuous queries.

D. Privacy

The challenge is to balance privacy concerns and personal data control, with the possibility to access data to provide better services. Because CPSs manage large amounts of data, including sensitive information like health, gender, religion, and many others, significant issues about data privacy are raised. CPSs require privacy policies in order to address privacy issues, thus a data anonymization management tool is required to have anonymized information before the system processes it.

E. Security

CPSs must ensure security during communications because all actions among devices are coordinated in real time. As CPSs expand and increase interactions between physical and cyber systems, security problems affect more CPSs. Traditional security infrastructures are not enough to address the issue and new solutions must be found. Security issues are critical on new data and stored data that was collected for future use. Lastly, CPSs are based on heterogeneous applications and wireless communications, which often raise critical security issues.

F. Real-time.

CPSs manage large amounts of data that is derived from sensors. The computations need to work efficiently and be timely, because physical processes keep going independently from the results of the computations. To satisfy this requirement, CPSs must ensure that they have the bandwidth or system capacity needed to meet time-critical functions because failures on time of actions can cause permanent damages.

VII. CONCLUSION

We must embrace the technological evolution that the Internet of Things, and CPSs in particular, bring to our everyday lives. These technologies will increase the quality of services and ultimately benefit the environment as they are implemented in smart cities throughout the world. CPSs, as a driver of innovation, involve many different disciplines. Industries as a whole have the opportunity to turn CPSs into an industrially applicable field. Moreover, CPSs require a highly skilled workforce, promoting collaborations and iterations between industries and universities. Finally, CPSs have a huge potential to change and improve every aspect of peoples' lives, addressing critical challenges for our society and exceeding today's distributed systems in security, performance, efficiency, reliability, usability, and many others.

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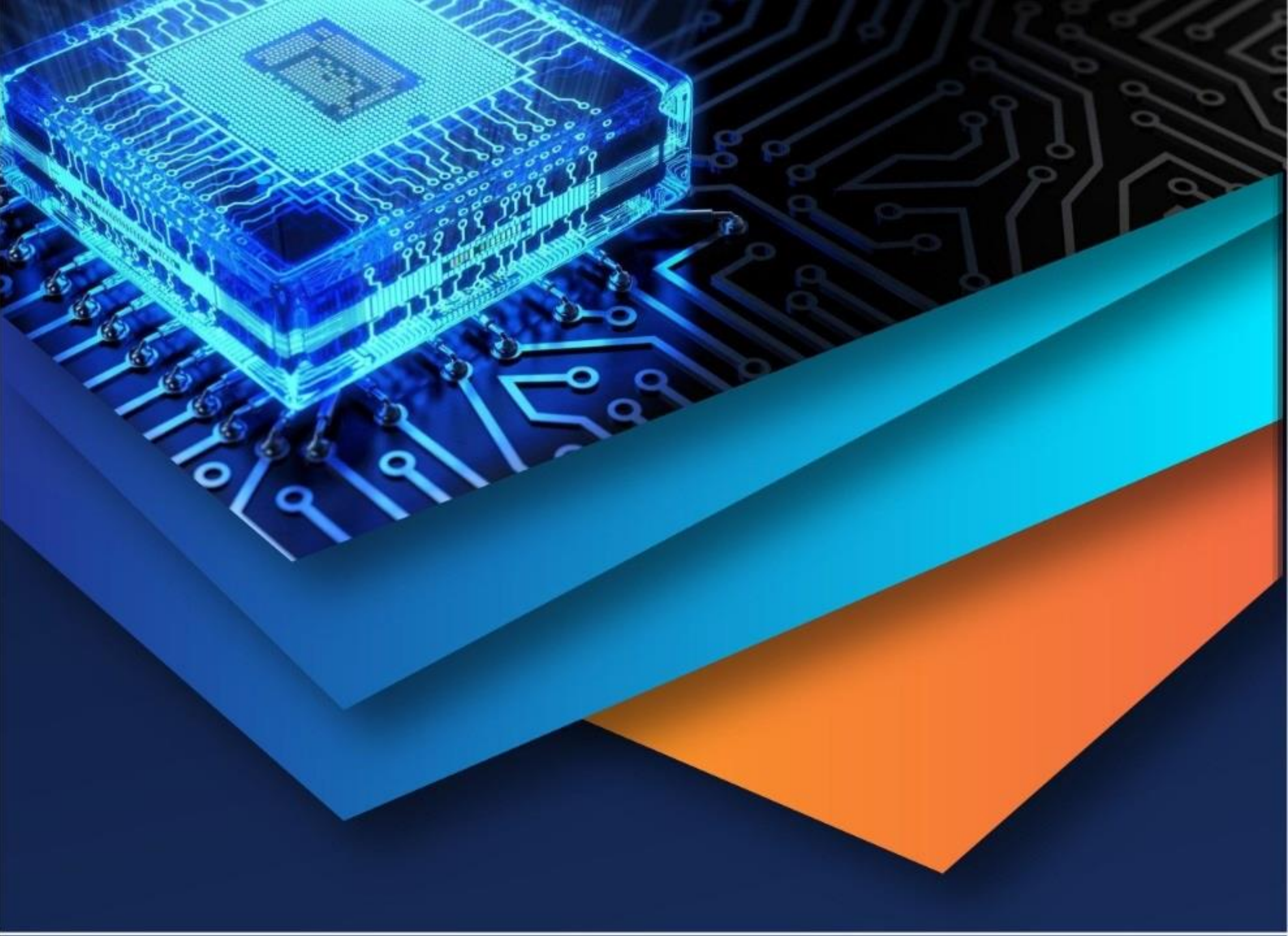

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