



The Internet of Things (IoT) will create the need for the

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The Internet of Things (IoT) will create the need for the Cyber-Physical System Technician

Abstract

During this decade and for the foreseeable future, we will witness the implementation of several large-scale technically enabled innovations involving the world's electrical power grid and our nation's interstate highway system and many other smaller, discipline specific, intelligent infrastructure systems that will enhance the efficiency, safety, and security of human endeavors. Many describe the process of adding intelligence and connectivity to these systems as the creation of the "Internet of Things" or IoT. Already, academic and industry experts in various technical fields have given catchy names to these proposed systems: Smart Grid, IntelliDrive, Smart Buildings, Smart Home, e-health care, are but a few names that have made it into the popular press. IBM calls this the building of "a Smarter Planet" while Cisco uses the term "Smart+Connected Communities." Recently, in engineering circles, these types of systems have become known as cyber-physical systems. These large-scale and not-so-large-scale applications are becoming possible due to the convergence of several key technologies. Essentially, through the use of networked embedded controllers (known as ambient intelligence) and complex sensors and actuators (i.e. sensor networks) one is able to create intelligent infrastructure systems that have the potential to change almost every aspect of mankind's interaction with the environment.

Presently, engineering technology education at the two-year college level does not produce technicians with the skill sets needed to install, evaluate, maintain, and up-grade these systems as they are envisioned. In fact, our present system of training IT workers and network technicians and those that deal with the so called physical layer (i.e. electronics/electrical/mechatronics technicians) tend to promote segregation of their respective skill sets. Many in these fields perceive a conflict (i.e. inability to communicate effectively) between the IT field and the physical layer people when it comes to applications involving computer controlled hardware. In fact, Cisco has built up their networking curriculum with the IT needs of the Enterprise as the only driving force while ignoring other networking applications. The implementation of cyber-physical systems, by necessity, brings these two worlds together. The understanding of the theory and operation of networks, embedded controllers and their interaction with sensors and actuators, data acquisition, and control software will be the required skills needed to deal with these emerging technology applications. The cyber-physical systems technician will need a skill set that spans several fields of technology. That type of curriculum does not presently exist but needs to be developed soon if the implementation of these systems occurs as predicted. This paper will lay out a possible path to achieve the goal of creating a cyber-physical systems technician.

Introduction

For those of us who have watched the field of electronics/electrical technology rapidly evolve in a seemingly exponential fashion over the years, it has always been enjoyable to speculate on where this ever changing technology will lead us and how it affects society. For many of the early years of this field, the evolution was not as fast paced as it is today. For decades the primary technologic innovation of this field was the vacuum tube and it provided the means to implement many electronic communications applications (post telegraph) involving the

transmission of voice, entertainment, music, and news through the use of the telephone and short and long wave radio technologies. From a sociological perspective one might say that these electronic based technologies heralded in the beginning of what was then considered to be the metaphorical shrinking of the world which today has morphed into what is commonly considered to be globalization. The ensuing invention and adoption of the solid-state transistor as the primary electronic workhorse of the field opened the door to many other types of electronic systems. With the development of the integrated circuit (IC) and the subsequent microelectronics era, the revolutionary field of electronic based digital computing gained momentum. This newly emerging field of digital electronics opened up the possibility of applications of electronics previously dismissed as too expensive or prohibitively large and/or unstable or just impossible or not conceived of. The world of electronics now consisted of two possible branches – analog technology for legacy applications or digital technology primarily for computation or digital control. During this era, the component centric aspect of the technology dictated how the technicians in this field were educated. The wide spread adoption of television, beginning in the middle of the last century, combined with newly vetted geosynchronous satellite technology started to shrink the world a little more in the late 1960s. In 1971, Intel’s first, microprocessor chip set can be looked at as yet another innovation that is still being played out today as we construct systems-on-a-chip with billions of transistors integrated on a silicon substrate smaller than the size of a dime. As these new applications evolved, buoyed by the accurate prediction of Moore’s Law (actually, only an observation) of future increases in microelectronics densities and lower costs, technology has become mainstream in today’s society. Finally, as computers and their use has become ubiquitous, the Internet (realized by computer networking technologies) has brought us clearly into the digital telecommunications era (think high definition television, 4G cell phones, and streaming video) and to the cusp of the next evolution in the use of electronics technology. Today, the emphasis on electronic systems has prompted debate on how the material in this field should be taught – component or system centric.

Today, unless one is living off-the-grid, technology has taken center stage in our lives. Nowhere is this more evident than in the field of consumer electronics. All media (voice, music, and video) is digitized for storage, display, transmission, or processing. While most consumer electronics products are typically considered to be used as entertainment devices, this distinction is blurred when one considers the ever available PC, smart phones and/or other portable Internet devices like tablets. These devices taken together with terms like social media, streaming, and video gaming have redefined what we consider to be entertainment and social interaction. However, what is not so obvious to the casual observer is that although the aforementioned devices are prominent in our everyday activities, they are only the tip of the iceberg, so-to-speak, in the installed base of electronic systems. Although there are billions of wireless cell phones in use¹ and billions of PCs have been sold, the vast majority of electronics is embedded in products² which one typically does not consider as being electronic devices. This perception is most likely due to the fact that these products historically did not originally contain electronics to control their operation(s) or to make them more functional, efficient, reliable, secure, and safe. Furthermore, the interface between the user and the electronics has typically been designed to further remove the user from the operation of the electronics in an effort to make the products “user friendly”. This overarching design goal allows a larger class of users from various backgrounds and/or with differing technical abilities, access to the countless product that contain

embedded electronics without the need for extensive training or large numbers of support personnel employed by the manufacturers of the products.

Earlier, it was mentioned that we are at the beginning of the next evolution in the possible uses of electronics technology. During this decade and for the foreseeable future, society will witness the implementation of several large-scale technically enabled innovations involving the world's electrical power grids, our nation's interstate highway system and other country's roadways, other types of mass transportation systems (air, rail, water) and many other smaller, discipline specific, intelligent infrastructure systems that will enhance the efficiency, safety, and security of human endeavors³. Many describe the process of adding intelligence and connectivity to these diverse systems as the creation of the "Internet of Things" or IoT. Already, academic and industry experts in various technical fields have given catchy names to these proposed systems: Smart Grid, IntelliDrive, Smart Buildings, Smart Home, e-health care, are but a few names that have made it into the popular press. IBM in various advertisements calls this the building of "a Smarter Planet"⁴ while Cisco has recently started using the term "Internet of Everything or IoE"⁵ to differentiate this technology from IT. Recently, in science and engineering circles, these types of complex configurations have become known as cyber-physical systems. These large scale and not so large scale applications are becoming technically and economically feasible due to the convergence of several mature enabling technologies implemented with electronics. Essentially, through the use of networked embedded controllers (known as ambient intelligence), complex networked sensors and actuators (i.e. sensor networks), and applications software one is able to create intelligent infrastructure systems that have the potential to change almost every aspect of mankind's interaction with its environment.

In the future, the number of devices connected to the Internet will climb exponentially and eventually dwarf the number of devices used for human interaction and communications. There will be tens of billions of machines or machine like devices that will talk to other machines or machine like devices⁶ without human interaction other than in supervisory or diagnostic roles.

Why the shift to cyber-physical systems?

One might question the push to implement cyber-physical systems. Beyond the obvious reasons of a desire to make our lives more convenient, safer, and secure, we also want the infrastructure used to achieve these goals to be efficient and effective. From this author's perspective, as human beings, we tend to design systems that mimic how we perceive - how we ourselves sense and react to physical situations. Without going into detail, humans utilize their sensory organs and their network of nerves in conjunction with our brains to make decisions about physical situations as they are presented to us. What has just been described is the basic structure of cyber-physical systems – systems that sense and respond in real-time.

Since the beginning of mankind, humans have had the desire to extend our senses beyond earshot and eyesight for purposes of survival and communication. Over the course of the beginnings of electronic/electrical technology, mankind initially used the technology to extend our ability to communicate over large distances. As technology evolved so did its applications. Computers, high definition television, cell phones, etc. are now ubiquitous appliances connected via the Internet. Most of the applications of electronics have been intended to increase the productivity and quality of life of humans and have been designed to facilitate our use of it. At this point in

time, the technology to implement extensive, sophisticated, real-time cyber-physical systems exists – the next step in the evolution of humankind’s use of technology. One would assume that this trend to design these types of systems will continue on into the future with the added goals of preserving the planet’s resources and its environment⁷.

Now let’s consider how sensor networks allow us to extend our limited senses not just in distance but also in geographic scope. That is, we can use sensor networks to gather data from large geographic areas to evaluate mesoscale phenomena such as weather events⁸ or conversely observe events at vast distances away such as is being done by the Mars Rover Curiosity. Usually, data gathered in this way is processed and used for various purposes (application dependent). This type of activity is typically known as “remote sensing”. In the past, the number of sensors used in these applications tended to be very limited and the data also limited in type and scope. Networked sensor system can extend the reach and scope of remote sensing activities and their ability to provide useful information about the sensed variables. Sensor networks are able to extend our senses in other ways. Using sensors, we can view wave energy from regions of the electromagnetic spectrum that our eyes don’t respond to due to lack of visible light transmission or objects that are beyond our range of view. Radar and Lidar are two examples of the latter technology. This allows us the ability to “see” things that we cannot normally detect. The medical field uses several imaging technologies all based on electronic systems to see within our own bodies in a non-invasive way. Lastly, at the other end of the size scale, devices like scanning electron microscopes allow us to see phenomena at the nanoscale level. The ability to build sensor networks that provide rich real-time data sets allows us to interact with our environment and learn about its status or physical condition in ways not possible in the past. Combining this technology with embedded control, one has the ability to control and increase the efficiency of large geographical situated systems like the electrical grid, highway systems, mass transit, etc. On a smaller scale, building and home efficiency are perfect candidates for this technology for increased energy efficiency, infrastructure health, and personal security. Lastly, on the smallest scale, this technology or variations of it is envisioned to enable many applications of nanotechnology.

Moreover, in the field of health care, wireless sensor networks are poised to revolutionize how we care for the elderly or people with health issues⁹. Additionally, combining networked sensor and actuator technology with networked embedded control gives rise to a myriad of possibilities in the biomedical/robotics field. From exoskeletons for the handicapped to artificial pancreases that produce insulin or artificial eyes to provide sight to the sightless¹⁰ there is very little limit to what the future might bring. Some futurists have looked at this type of technology and pose the concept of a merging of man and machine – recall Lee Majors and the (bionic) *Six Million Dollar Man* or the many other recent science fiction movies about this concept. Time wise, just around the corner, if we believe the automobile industry hype, is the mass production of the autonomous car (as already demonstrated by Google¹¹) that drives itself. This writer would prefer to consider this innovation as a type of transportation robot. In essence, a vehicular robot that can deliver the passenger(s) to a particular destination over the highway system, safely, without a human driver. The United States Department of Transportation’s (USDOT) Connected Vehicle Research program (formerly known as, IntelliDrive) isn’t as ambitious as the Google project but still shares the same goals¹². Recently, the USDOT has called for a “Connected Vehicles Mandate” that would provide for vehicle-to-vehicle (V2V) communications for new

cars in the next several years. This type of anti-collision technology and self-driving automobiles does not seem very far-fetched if one considers present day drone technology, wireless data communications (IEEE 802.11) or the auto-pilot on a commercial jet air craft.

It appears that technology has evolved to the point where we now envision it as a means to increase our knowledge of our weather systems, monitor and improve our health, and provide control of our infrastructure systems and how they interact with our environment. The cyber-physical systems required to implement these goals employ embedded control systems that are tightly coupled to the physical world and require timing to perform their function¹³. Hence, an electronically implemented network (nervous system) with application software to process the gathered sensor data and embedded intelligence to both process and transmit sensor data and control actuators required for the particular application. This very same technology, implemented with electronics, mimicking how our human biological systems work, that provides information about the surroundings and how real world physical systems or humans should respond to it.

The Problem(s)

Traditionally, the engineering technology disciplines have been structured to provide students studying these various fields the skill sets required by the industry that the particular technology field serves. ABET presently lists¹⁴ twenty-three specific criteria for programs that have been recognized as viable technology disciplines. Even though ABET provides language to account for subtle name differences (e.g. Bioengineering Technology and Similarly Named Programs) the specific program criteria are very prescriptive in the definition of program graduates skill sets. ABET is constantly revising and updating the particular criteria to reflect changes within the technology. However, the twenty-three program criteria effectively form technology silos with very little cross-over from one technology to another and to some extent discourage interdisciplinary programs. Furthermore, the two-year college graduates of these programs typically deal with the hardware or physical infrastructure associated with the particular technology field as technicians while four-year engineering technology graduates or technologists typically have additional skills in the design of technology systems used in their field.

Presently, engineering technology education at the two-year college level does not produce technicians with the skill sets needed to install, evaluate, maintain, and up-grade these systems as they are envisioned. In fact, our present system of training IT workers and network technicians and those that deal with the so called physical layer (i.e. electronics/electrical/mechatronics technicians) tends to promote segregation of their respective skill sets. This occurs in many instances: due to a lack of space for new topics in the program's curricula and so that programs will be in compliance with ABET criteria. This fact probable also reflects the faculty's lack of cross-disciplinary training or experience.

From this author's perspective there are additional underlying problems. In particular, how most electronic/electrical AS degree programs presently teach their students. During the past decade, several knowledge leaders in the ET/EET field have presented "position" papers^{15,16,17,18,19,20,21} that have pointed out continuing problems with out-of-sync curricula in these programs at regional and national conferences. Without going into a detailed discussion of this topic, suffice to say there are basically two schools of thought on teaching the ET/EET subject matter in a traditional "parts centric" fashion or adopting a "systems" approach. This topic can be debated

into the future but in the end the reality of the workplace will eventually dictate the direction that is finally taken.

One may question the role of IT in the implementation of cyber-physical systems. Presently, the common approach to implementation is to configure separate computer networks for the cyber-physical system. These networks are thus secure and also not bothered by contention for service on the network from non-control related data transmission. Recall that cyber-physical systems work in real time! Therefore, it appears that there needs to be two separate computer/data/control networks. One network for an Enterprise’s IT needs (business oriented) and another network for an “operations” network where the type of application determines the types of operations that are enabled through the network. Many in these fields perceive a conflict (i.e. an inability to communicate effectively) between the IT (administrative/applications oriented) and the physical layer people when it comes to applications involving computer controlled hardware. In fact, Cisco has built up their networking curriculum with the IT needs of the Enterprise as the only driving force while ignoring other networking applications. Notwithstanding this fact, Cisco’s recent introduction of the “Internet of Everything” concept points out their understanding or at least their recognition of the differences between IT and IoE. The implementation of cyber-physical systems, by necessity, brings these two worlds together even if those two worlds are not ready to co-exist in the same house. The understanding of the theory and operation of wired and wireless networks, embedded controllers and their interaction with sensors and actuators, data acquisition, and control software will be the required skills needed to deal with these emerging technology applications. Thus, the cyber-physical systems technician will need a skill set that spans several fields of technology. That type of curriculum does not presently exist but needs to be developed soon if the implementation of these systems occurs as predicted.

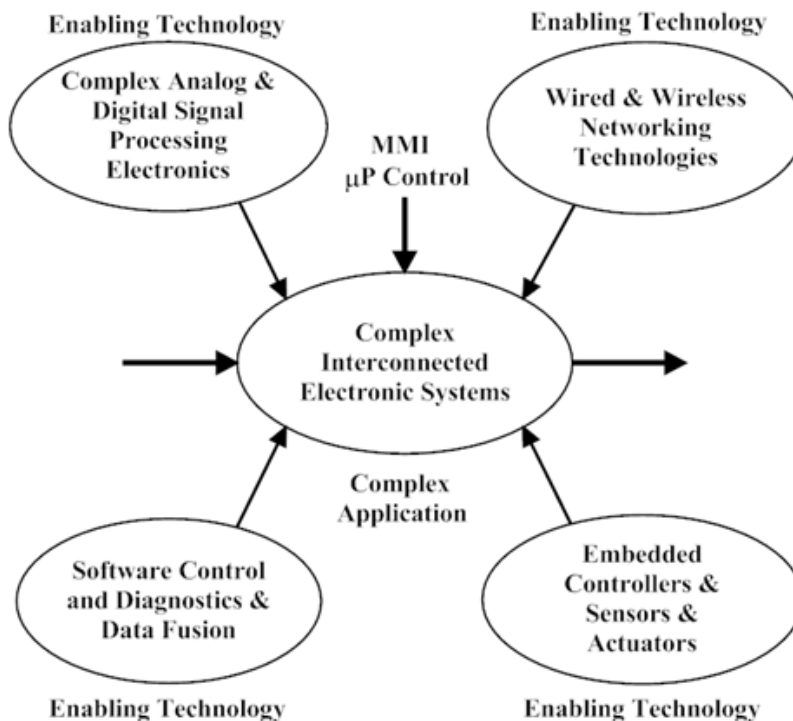


Figure 1 – The underlying technologies of the Internet of Everything (IoE)

As shown by Figure 1 above, the underlying technologies of the Internet of Everything consist of several enabling technologies. The cyber-physical system technician will still need to have knowledge of the basic fundamental DC and AC concepts, be aware of signal characteristics, and have the ability to use instrumentation and make measurements. Additionally, they will need to be knowledgeable about: embedded controllers and have the ability to interface signals to these devices (i.e. a familiarity with sensors, actuators, A-to-D and D-to-A converters, and signal processing [amplifiers, filters, etc]), basic networking systems including TCP/IP protocols, IP addressing, and routing, wireless technologies, system structure and operation (i.e. electronic system building blocks, programming, and operating systems), and the ability to perform software diagnostics/downloads. All of this coupled with knowledge of electromechanical systems and skills and dexterity with small hand tools. Like today, in the future, system failures will still occur due to power supply failures, mechanical fatigue, and interconnection problems and the technician will still need to be able to deal with these issues. But there will be new issues involving security, networking, software, and a host of system level failures that will need to be dealt with. The remainder of this paper will lay out a possible path to achieve the goal of creating a cyber-physical systems technician.

The cyber-physical systems technician will need to be a person with inter-disciplinary skills. Part electronic technician (ET), part network technician (NT), and part embedded controller/programmer technologist. It will not be easy to get from where we are today (in silos) to where we need to go but it can be done and in this writer's opinion will need to be done as we go down this evolutionary road of technology.

The following table presents a list of technical courses/topics that might be extremely germane to this new type of technician. As can be seen from this listing, it is possible that a program could

| Topics/Course Titles | |
|--|---|
| DC & AC Concepts | Embedded Controllers & Programming |
| Introduction to Networking Concepts | Industrial Networking Technologies |
| Sensors and Data Acquisition | Sensor Systems & Networks |
| Fundamentals of Electronic Systems | Sensor System Applications |
| Home and Small Business Networking | Network Security |

Table 1

be constructed from parts of several programs. However, in this writer's opinion that is usually not the optimum solution since as pointed out previously, technical programs tend to have their own mutually exclusive goals. At this time, the best solution might be to add options to pre-existing programs that include the new material. However, there would need to be demand for this new skill set before any new programs would be viable and introduced by two-year schools. Today, this writer is seeing workers in the field returning to school to pick up expertise in computer networking and electronics - areas not covered in their degree field. Consider the present amount of electronics and the predicted wireless technology that will become embedded in an automobile and one quickly gets the picture that many non-electronics based technologies students need some additional training in fields that are foreign to the faculty in those fields. Presently, it is this writer's opinion that there are many road blocks to the implementation of

such inter-disciplinary programs. But change will be necessary if this country is to remain a leader in technological innovation. This change will need to be driven by industry and educational leaders that are willing to think “out-side-the-box”.

Conclusion

Electronics/Electrical technology has always been one of the most rapidly changing fields and will most likely continue to morph and evolve with time. In the past, derivative fields such as computer technology and laser technology have spun off from ET when they had developed sufficient material and lore to be stand-alone programs. The skill sets needed by a cyber-physical system technician are cross-disciplinary (at least at the present time), systems oriented, and have their roots in electronics/embedded control. It would require substantial retooling of a typical ET program to change the focus to cyber-physical systems. Furthermore, the projected fields where these systems will be employed are quite diverse: the power industry (smart grid), automotive industry (smart cars), healthcare industry (e-health care), transportation industry, and building automation industry are the most probable early adopters. Again, there is a need for these various industries to step up to the plate and give guidance to the two- and four-year technology programs in this country. A great way to achieve this goal would be to partner with a college and utilize the National Science Foundation’s (NSF) Advance Technology Education (ATE) program for funding to support this effort. A good recent example of this type of industry/education partnership is the new building automation program at Laney College located in Oakland, CA²².

In closing, one should look to the enabling underlying technologies that allow for the implementation of cyber-physical systems for guidance to what the curricula should consist of. These following technologies are common to all cyber-physical systems regardless of the employing industry/field: networked embedded controllers, computer networks (wired and wireless), control software/operating systems, and electrical and analog and digital electronics concepts are the key players in these scenarios. Recently, there has been some uptick in the number of ET programs teaching embedded controllers²³ which is understandable since that technology is “owned” by the ET field and (this writer feels) should be a part of any ET programs curricula. However, program “ownership” of computer networking and computer software are another matter. This issue will need to be resolved before anyone will be able to offer a cyber-physical systems technician program. Also, there has been some movement in the effort to change the teaching of electronics from parts centric to a systems centric viewpoint thanks in large part to several NSF grants²⁴ and the creation of some appropriate systems centric teaching materials²⁵. Like anything in life, it will take some time to convince the powers-to-be that the time has come for an inter-disciplinary program that breaks down the present silos of instruction.

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