Designing a Converged Plant-wide Ethernet/IP Lab for Hands-on Distance Learning: An Interdisciplinary Graduate Project

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Abstract

Industrial Internet of things (IIoT) is the application of the network of intelligent computers, devices and objects that share huge amounts of data within the manufacturing industry. The days of manually manipulating industrial processes are fading, and quickly being replaced by a complex array of sensors and smart devices that are enabling the fourth industrial revolution through machine-to-machine (M2M) communication and industrial big data analytics. This convergence of information technology (IT) and operations technology (OT) in the IIoT is driving unprecedented levels of efficiency, productivity, and performance. As a result, businesses in power and energy, oil and gas, manufacturing, healthcare, aviation, agriculture, and many other industries are experiencing transformative operational and financial benefits.

The implementation of the merging of IT and OT requires skills in both areas, but current programs in colleges and universities typically have the curricula separated. As businesses implement IIoT, the need for workers with combined IT and OT skills has increased. Unfortunately, there is not enough skilled labor to keep pace with the industry's evolution. This IIoT skills gap is one of the greatest challenges manufacturers face. There is a rapidly-growing need for manufacturing employees with certified skills in both IT and OT to design, secure, implement, and maintain these systems.

East Carolina University (ECU) endeavors to meet this need through a collaborative workforce development and STEM education network infrastructure to link the university with regional high schools and community colleges designed to prepare a workforce to fill the IIoT skills gap. Central to this education network infrastructure is a remotely accessible Converged Plant-wide Ethernet/IP (CPwE) hands-on lab environment that provides synchronous access to IIoT laboratory experiences.

This paper details an interdisciplinary project involving the design, development, and implementation of a remotely accessible lab environment that integrates enterprise IT with industrial automation and control systems (IACS) into a fully functional CPwE manufacturing infrastructure. The CPwE laboratory environment provides a platform for students and faculty from ECU and regional community colleges and high schools to develop critical IIoT skills through collaborative hands-on lab experiments.

The laboratory design is discussed in detail, including how the collaboration of differing, but related, disciplines are integrated to take advantage of synergies and enhance the knowledge base and skill sets of the related disciplines. Course outcomes, project cost, and future work are also shared.

Keywords

Industrial Internet of Things, Remote Labs, Industry 4.0, Industrial Engineering

Introduction

According to a survey by Morgan Stanley-Automation World Industrial Automation, twenty percent of companies cite a lack of skilled workers as a significant challenge to IIoT adoption [1]. Hence, it has become imperative to properly equip the aspiring manufacturing employees with the appropriate knowledge, tools and equipment to function effectively in today's manufacturing and technology world. IIoT will place new demands on information technology and operations staff, as well as the engineers, but a recognized shortage of qualified workers with the specialized skills required to design, deploy, maintain, and secure the IIoT is well documented.

While IIoT presents an exciting, game-changing opportunity for companies and their employees to work smarter, faster, and more effectively, the reality is that education and training for the needed workforce to operationalize IIoT lags far behind demand. Industry experts have noted that universities today are not preparing a workforce with skills that meet the needs of the IIoT. A better approach, however, would be to offer training to teach both IT and OT domains simultaneously, integrating class instruction with hands-on labs that encompass the knowledge and skill sets of both fields. To quote Richard Soley, Ph.D., the executive director of the Industrial Internet Consortium (IIC), "Nobody is doing that" [2].

ECU, with funding from a US Department of Agriculture (USDA) Rural Utility Services (RUS) Distance Learning and Telemedicine (DLT) grant, has launched a collaborative project with rural regional community colleges and high schools to close the IIoT skills gap. A core component of this project is the implementation of a CPwE hands-on lab environment that provides synchronous access to IIoT laboratory experiences to students anywhere at any time.

Hands-on experience is vital because it helps students understand the rudiments taught in theory, enhances learning and gives them a practical experience of what they have been taught and how to handle it in the real world [3]. Alex Dalton states in QA Education that "Addressing needs though this problem-solving, creativity bounded by constraints and combined with hands-on practical manufacture are the fundamental skills of an industrial economy" [4].

According to Rockwell Automation, "Factories and production facilities are seeing an explosion in connected smart assets, opportunities to employ mobility, advancements in security standards, and the availability of big data and analytics. To achieve the full value of these technologies requires individuals with a specific skill set; people who understand how to effectively apply IT technologies in an OT environment" [5].

The CPwE lab will provide a platform for students and faculty from ECU and regional community colleges and high schools to gain hands-on experience configuring real IT and OT equipment and develop critical IIoT skills.

The rest of this paper is organized as follows: first, background; second, a review of related programs; third, pedagogical considerations; fourth, the laboratory environment -which describes the remote lab access, lab pod design, challenges, lab control infrastructure; fifth, learning objectives and outcomes; finally, conclusions and future work.

Background

The IIoT encompasses the smart manufacturing systems and technologies that will empower the 4th industrial revolution, or Industry 4.0. The National Institute of Standard and Technology (NIST) defines smart manufacturing as "fully-integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the factory, in the supply network, and in customer needs" [6]. In other words, IIoT uses a collaborative network of devices or things to collect sensory data about and from the various workings within an industry manufacturing facility; and then relays this information to other things to be used. This process can be used to help automate systems or software based on specific conditions that need to be met, or to present verbose, real-time, up-to-date information to a user that can monitor it and make better, more informed decisions.

IIoT offers distinct advantages to manufacturers with respect to operational efficiency and overall competitiveness. IIoT is driving unprecedented levels of efficiency, productivity, and performance. And as a result, businesses in power and energy, oil and gas, manufacturing, healthcare, aviation, agriculture, and many other industries are experiencing transformative operational and financial benefits.

For example, at Bosch, tools are fully connected to the network and generating real-time production data. With information on the tools' location, calibration state, and other context, workers now have a detailed overview of the conditions of their tools at all times. As a result, Bosch has automated several routine tasks such as the replacement of worn parts on power tools. Bosch is also able to record the torque used to tighten hundreds of thousands of bolts and to store that information for quality, tracking, and traceability. This provides workers with clues as to the possible causes of torque faults and improves overall quality [5].

In another example, Shelburne Vineyards has installed a sensor system that monitors temperature, air, soil, degree of wetness of the leaves, and humidity every two minutes. This data is uploaded to the cloud for analysis, which then provides the vineyard needed information to make crucial management decisions. Shelburne Vineyards can compare temperature profiles from year to year to determine the best time for harvest, when to spray to prevent disease, and how to pioneer new grape varieties [5].

While these two examples provide only a small glimpse of the potential of IIoT, they clearly illustrate the workforce skills gap that the adoption of IIoT has created. Workers are progressively falling behind in the skills required to obtain well-paying industrial and manufacturing positions. These positions require increasingly complex skillsets, credentials, and more importantly, hands-on experience that simply cannot be obtained in their rural communities. High schools and community colleges have not kept pace with programs that include newly required skills, and do not possess the expertise or funds for equipment required to train an IIoT workforce.

Review of related programs

A review of Accreditation Board for Engineering and Technology (ABET) and Association of Technology, Management, and Applied Engineering (ATMAE) accredited degree programs was conducted. Neither ABET or ATMAE were found to have an accredited Internet of Things (IOT) or Industrial Internet of Things (IIoT) program. Both accrediting agencies have accredited Engineering Technology programs, such as Industrial Engineering Technology and Manufacturing Engineering Technology programs as well as Networking and Information Technology programs as separate programs. However, ABET and ATMAE show no converged IT and OT programs [7], [8].

A further search was then conducted outside of ABET and ATMAE accredited courses to identify other similar programs that might be in the development or early offering stages. Northwestern University's Master of Engineering Management Program offers a 10-week on campus non-credit pilot course on IIoT. The course is introductory and there is no record of hands-on lab development, although, the course instructor Shahid Ahmed indicates labs may be developed as the course progresses [9]. Florida International University offers a four-year degree in the Internet of things (IoT). The FIU's college of Engineering and Computing would be leading in this the technological shift addressing four major areas of IoT – hardware, software, communication, and cybersecurity even though it was not stated in the curriculum that an online laboratory environment has been created for this program [10], [11].

Pedagogic considerations

The development of the CPwE lab is driven by four pedagogic considerations. First, is that applied technology is a practical-sourced discipline. Learning and understanding requires hands-on practice and experimentation. Second, is that hands-on labs confirm the concepts covered in class lectures. Students have an opportunity to test operational principles for themselves. Third, it gives students an opportunity to develop their skills at configuration, documentation, troubleshooting, and problem-solving. And, fourth, to promote the student's ability to collaborate effectively with others, either face-to-face or at a distance, to carry out complex tasks.

With these four considerations in mind, all laboratory assignments are designed for both a distance education environment and a face-to-face environment. The delivery methods have two primary objectives; to reinforce theoretical concepts taught in the lecture part of the class and to provide students with hands-on experience with equipment the student is likely to encounter in a job environment. Through the unique lab environment described in this paper, distance education students can complete hands-on labs solely on their own or in real-time collaboration with face-to-face students.

The delivery methods for lab assignments will include remote lab access that allows students to gain access to simulated plant floor to solve a problem remotely and via tele-video technologies that allow live lab demonstration to reinforce lecture concepts and drive home course objectives. By blending these methods, students will develop a skill set that includes both IT skills and OT skills and can integrate both sets of skills to solve technical problems.

Laboratory environment

The CPwE remote laboratory environment is maintained in ECU's Academic Network Operations Center (ANOC). The ANOC is a complex half million-dollar network infrastructure used to deliver remotely accessible information and computer technology (ICT) and industrial engineering technology (IET) labs to students anywhere at any time [12]. At the heart of the ANOC is an NDG NETLAB+ network appliance that provides and manages web-based lab access to enterprise network devices, SCADA devices, and virtual machines that are logically grouped and physically interconnected into lab pods [13].

A lab pod (or lab topology) is a logical group of equipment or lab gear that is physically interconnected and can be reserved by a student or instructor individually or as a team through a scheduling application on the NETLAB+ system. Students and instructors access and interact with a lab pod during the scheduled reservation time to perform hands-on lab assignments. Equipment in a pod can be both virtual, such as virtual machine, to act as a PC, or a physical device such as a sensor or actuator. Figure 1 shows a high-level view of access to a lab pod from remote students over the Internet. Inbound port requirement on the university firewall are TCP ports 2201, 80 and 22

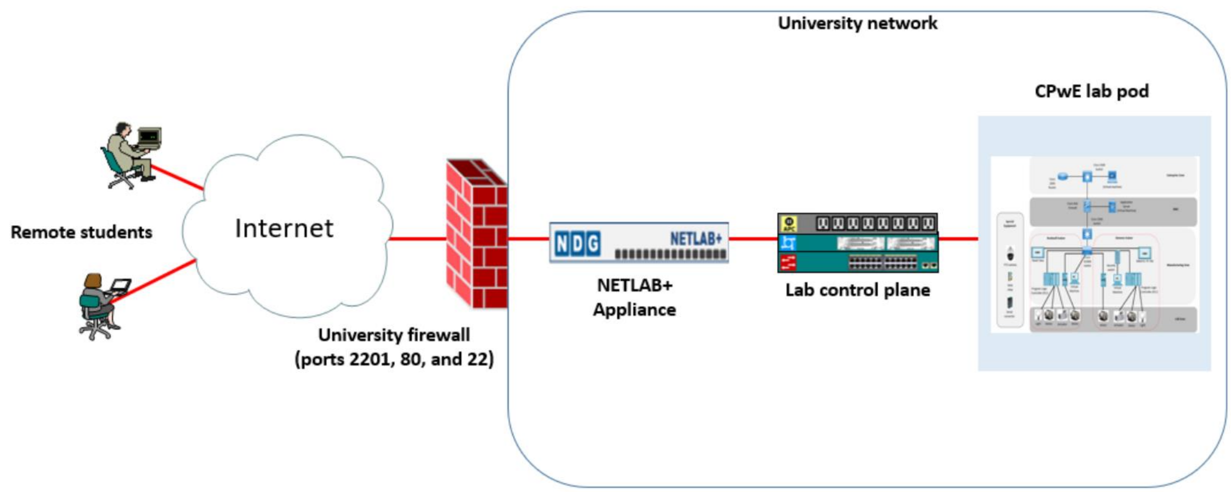

Figure 1. Remote students connecting to CPwE pod through Internet.

Lab pod design

Central to the design of the CPwE lab pods is the need for ICT students to learn and understand the IACS requirements and operating environment, and for IET student to learn and understand the enterprise network function and basic technologies and protocols. Students from both programs will gain experience in configuring the data networks and servers that deliver programs to industrial machinery.

With this interdisciplinary outcome in mind, the lab pods for this project are modeled after the CPwE architecture developed by Cisco and Rockwell Automation, which segments network and IACS devices into four logical zones: enterprise zone, demilitarized zone (DMZ), manufacturing zone, and cell zone [14], [15]. Each of the four zones of the CPwE is represented by specific equipment in the CPwE lab pod as detailed below:

The enterprise zone includes the devices and systems under management of the organization's IT department. The CPwE enterprise zone consists of a Cisco 2900 integrated services router, a Cisco catalyst 3560 multilayer switch, and a Windows Server 2016 virtual machine.

The demilitarized zone (DMZ) provides separation between the IACS network in the manufacturing zone and the enterprise network. The CPwE DMZ consists of a Cisco ASA 5510 security appliance firewall and a Windows Server 2016 virtual machine, which will host various application and operations services.

The manufacturing zone contains the IACS network, devices, and controllers that are used to control and monitor plant floor operations. The CPwE manufacturing zone consists of a Cisco catalyst 3560 multilayer switch, a Cisco Industrial Ethernet (IE) 3000 switch, and a Rockwell and a Siemens trainer each containing a human machine interface (HMI), programmable logic controller (PLC), variable frequency drive (VFD), and a Windows virtual machine.

The cell zone consists of basic control and process devices and on the CPwE this zone consists of two sets of lights, motors, and actuators that are controlled by the Rockwell and the Siemens trainers in the manufacturing zone.

Figure 2 shows the components of a CPwE lab pod as they correspond to the four CPwE zones. Student access equipment that is part of each lab pod is also shown. This equipment allows the student to perform tasks that would typically require physical access to the equipment such as viewing LED lights, operating single-pole single-through (SPST) switches and performing initial network configurations over serial lines.

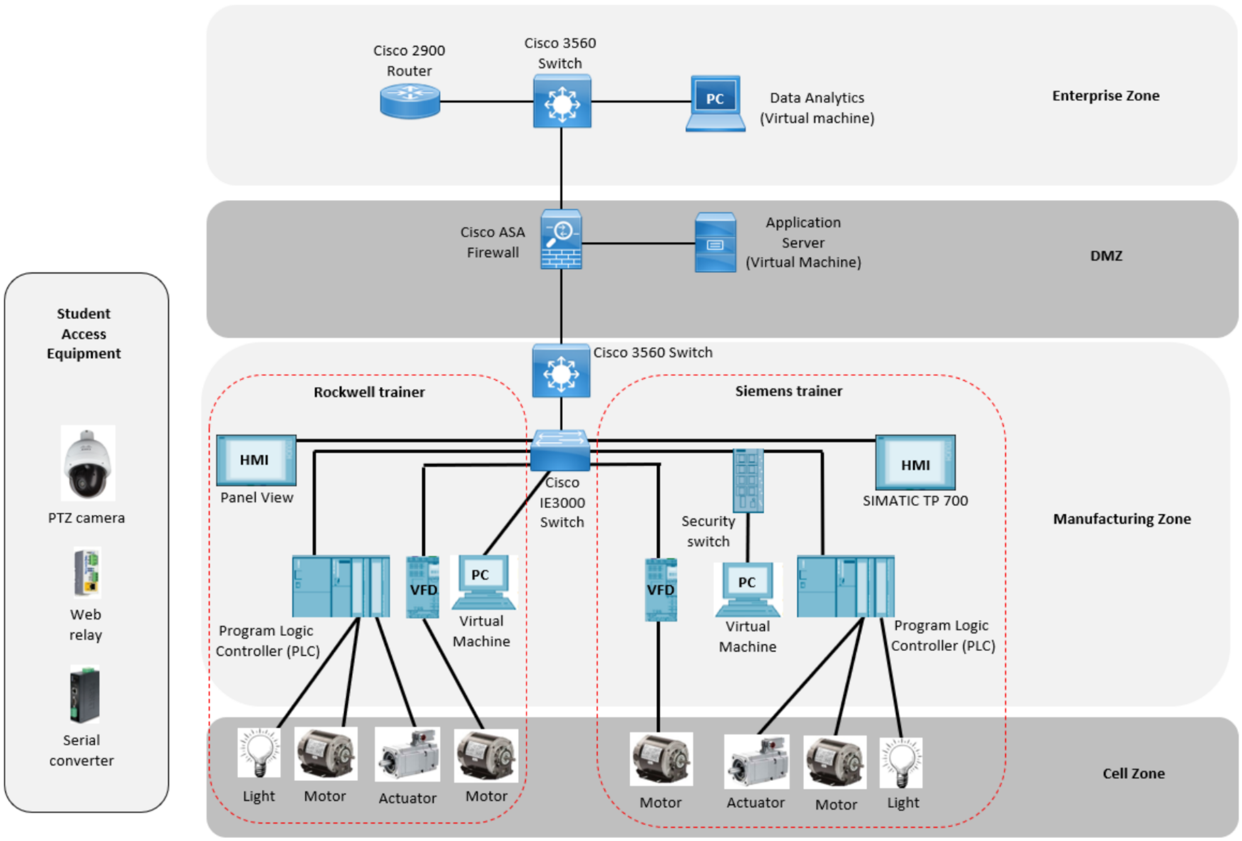

Figure 2. CPwE lab pod design as it aligns with the four CPwE zones.

Lab pod design challenges

Proposing the Rockwell and Siemens trainers in the manufacturing zone of the CPwE lab pod to allow remote students to control the IACS equipment presented three unique challenges. First, each trainer has eight SPST switches connected to inputs of the PLC to indicate logic levels 1 and 0. To allow the SPST switches to be controlled remotely by students a web relay device is connected in parallel with the corresponding SPST switches. The web relay device is controlled by the remote student through a desktop application on the PC virtual machine connected to the trainers in the manufacturing zone. To function properly however, face-to-face students using the SPST switches must remember to place all switches in the off position to allow proper web relay control by remote students.

Another challenge to overcome in the design was initial assignment of IP addresses through a serial port connection to the Rockwell and Siemens IACS equipment by remote students. This challenge was solved by incorporating an Ethernet to serial converter into the lab pod. This converter is controlled by the student through a desktop application on the trainer PC virtual machine and allows PC control software, RSLinx for Rockwell, and SIMATIC for Siemens, to connect directly to the equipment via a serial connection for initial network configuration.

The third challenge was visibility to the IACS and the basic control and process devices by remote students. To solve this challenge each lab pod is equipped with a high-definition pan-tilt-zoom (PTZ) video camera controlled by an application on the trainer PC virtual machine, allowing the student to not only assess achievement of results through appropriate programming, but also visually confirm results as he or she can watch the industrial process unfold.

Lab control plane infrastructure

Extensive detail has so far described the equipment and devices that comprise a CPwE lab pod, however, there is a complex infrastructure of networking components that are required in order for the student to have access to the equipment configuration interfaces and for the pod to function. This complex infrastructure is the NETLAB+ control plane and it forms the foundation required to interconnect the various components on the CPwE lab pods. The control plane consists of three types of components: control switches, access servers, and switch outlet devices.

Control switches provide internal connectivity between access servers, the virtual environment, and switched outlet devices. The connectivity between lab pod devices can be dynamically configured by modifying the VLAN configuration on the control switches. Since the topology of our POD design is fixed, the VLAN configuration is static. Future work will include multiple POD topology options that would be chosen at the time a reservation is made. Access servers provide console connections to pod routers, switches, and firewalls so that the student can access and configure those devices. These console connections are serial connections to the physical console port on the individual lab pod devices and are command line driven. Switched power outlets provide managed electrical power so that lab pod devices can be power cycled on and off remotely by the student.

The number of control plane infrastructure devices required depends on the number of CPwE lab pods. Figure 3 shows a high-level view of the NETLAB+ control plane infrastructure required to support four CPwE lab pods. In addition to the NETLAB+ appliance, the main control switch, and the VMWare virtual environment, the control plane would need four switched power outlets, one control switch, and one access server. This control plane infrastructure would be repeated for every four CPwE lab pods added. To provide a better understanding of how devices on the CPwE lap pod are interconnected, Figure 4 shows the physical connections to the control plane and to other lab pods devices from the perspective of the Cisco ASA firewall in the DMZ.

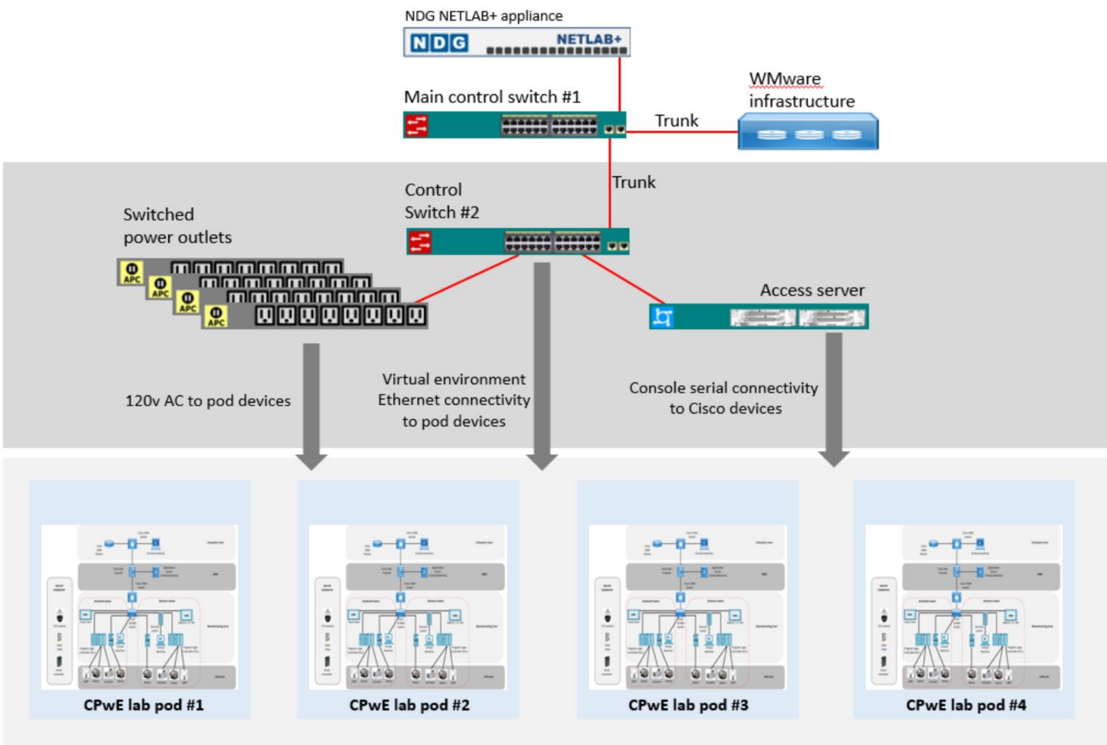

Figure 3. Control plane infrastructure required to support four CPwE lab pods.

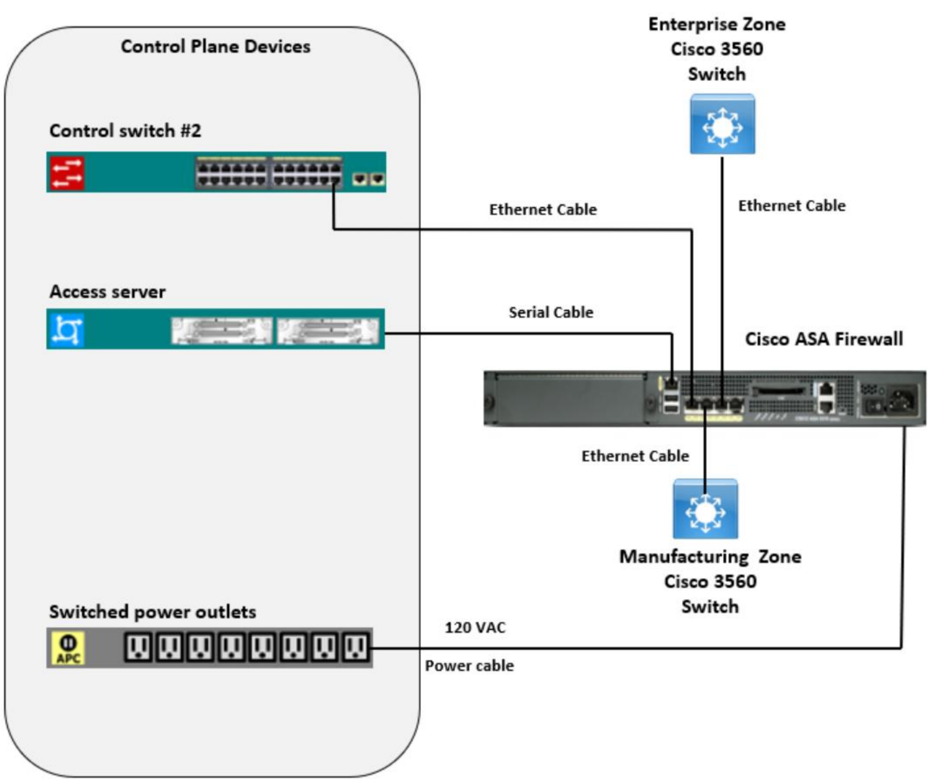

Figure 4. Detailed view of control plane and lab pod connections to the Cisco ASA firewall.

Lab costs

CPwE lab pods require significant capital investment. While prices can vary widely based on vendor discounts and existing purchasing agreements, a rough estimate of retail equipment costs for major CPwE lab pod components are shown in Table 1.

Table 1. CPwE lab pod equipment prices

Data Plane		
Device	**Quantity**	**Est Price***
Enterprise zone devices		
Cisco 5510 Adaptive Security Appliance	1	$1,750.00
Cisco C3650 24 port Catalyst Switch	2	$2,730.00
DMZ devices		
Cisco 2901 Integrated Services Router (ISR)	1	$698.00
Industrial network and SCADA equipment		
Cisco Industrial Ethernet Switch 3000	1	$1,400.00
Siemens SIMATIC ET 200SP Digital PROFINET I/O	1	$670.00
Siemens SIMATIC HIM TP700 COMFORT PANEL	1	$560.00
Siemens SIMATIC CPU 1516F PN/DP with Software, I/O and PS	1	$2,185.00
Siemens SIMATIC ET 200 SP Safety I/O	1	$760.00
Siemens SCALANCE 623 Security Switch	1	$1,940.00
Rockwell 5069-L310ER Allen Bradley 5380 PLC CPU	1	$2,500.00
Rockwell 5069-IB16 Digital Input Module	1	$650.00
Rockwell 5069-OB16 Digital Output Module	1	$650.00
Rockwell 5069-IY4 Analog Input Module	1	$1,100.00
Rockwell 5069-Of4 Analog Output Module	1	$900.00
Rockwell 25B-A011N104 PowerFlex 525 VFD	1	$1,250.00
Rockwell 2715-T10CD 10” HMI	1	$2,800.00
Other equipment		

Pan Tilt zoom, Power over Ethernet, with InfraRed night vision	1	$315.00
x-332 Web enabled advanced I/O (16 controllable relays)	1	$550.00
CYT-200SC RS485/RS232 to TCP/IP Converter	1	$150
Total per lab pod =		**$23,358**
Total for 24 lab pods =		**$560,592**

In addition to the costs of the CPwE lab pod equipment is the cost of the NETLAB+ appliance, the VMware environment, and the control plane equipment.

Current pricing for NETLAB + can be found on the NDG web site and varies based on number of active lab pods. Supporting up to 16 lab pods is currently listed at $9,995. A VMware infrastructure is required to host lab pod virtual machines. Table 2 lists the control plane equipment needed to support up to four lab pods.

Table 2. CPwE lab pod control plane equipment prices

Control Plane			
Device	**Quantity**	**Price each**	**4 lab pod total**
Cisco 2901 Integrated Services Router (ISR) - Access server	1	$698.00	$698.00
Cisco 2960 24-port Catalyst switch - Main control switch	1	$780.00	$780.00
Cisco 2960 48-port Catalyst switch - Control switch	1	$1700.00	$1700.00
APC 16 outlet switched PDU - Switched power outlet	4	$800.00	$3200.00
Cisco serial and asynchronous modules for Access server	1	$792.00	$792.00
Total for up to 4 lab pods			**$7170.00**

Learning objectives and outcomes

The CPwE lab environment is part of a larger project to promote learning the skills required for the IIoT. As such, it is designed to meet the objectives and outcomes of IET, ICT, and other advanced manufacturing and information technology courses. Table 3 lists course objectives and outcomes in the IET and ICT programs at ECU that will be met with the CPwE lab environment.

Table 3. Course objectives, outcomes, and assessment methods for industrial engineering technology and information and computer technology program courses

Course objective	**Course outcome**	**How assessed**
Industrial Engineering Technology program		
Identify and describe major components of programmable logic controllers	Integrate, control, and troubleshoot PLC programs to achieve desired plant floor outcome	Lab 1 - Introduction to Programmable Controllers skill assessment
Distinguish different type/ categories of PLCs	Integration of automated plant floor equipment	Lab 2 - Basic Programming skill assessment
Describe and perform basic Boolean functions	Integrate, control and troubleshoot PLC programs to achieve a desired plant floor outcome	
Design, develop, and integrate ladder diagrams		Lab 3 - Discrete Logic Motor Control skill assessment
Describe discrete-state process control systems		
Write, debug, test, and run programs on the PLC		
Interface, program, collect and analyze data from PLCs	Meet data integrity and plant audit	Lab 4 - Remote PLC motor control skill assessment
Configure internal and external networks and remotely control a plant floor system		Lab 5 - Configuring a controller across VPN
Information and Computer Technology program		
Configure base network device settings	Use Cisco command-line interface (CLI) commands to perform basic router and switch configurations	Lab 6 - Configure basic router settings
		Lab 7 - Basic switch configuration
Implement VLANs and VLAN trunking	Use Cisco command-line interface (CLI) commands to configure VLANs and VLAN trunking	Lab 8 - Static VLANs, trunking, and VTP
Mitigate threats to Cisco routers and networks using ACLs	Develop and implement security countermeasures to protect network elements as part of the network infrastructure	Lab 9 - Configure and verify access control lists.
Implement the Cisco ASA firewall		Lab 10 - Configure ASA basic settings and firewall
Implement a remote access VPN	Describe secure connectivity strategies and technologies using VPNs	Lab 11 - Configure remote access SSL VPN

Conclusions and Future Work

A new remote lab design for IIoT has been presented that offers many advantages:

- The labs integrate both the production IT network and the operational OT network including appropriate firewalls and security appliances.
- The labs are available 24/7 to any authorized student with a reliable Internet connection and allows for remote student visualization of the operation of the motors, actuators, HMI, and LED lights.
- The labs are also available for in-class laboratory exercises
- The labs contain equipment from two vendors giving the students exposure to different configuration tools and vendor products.
- The labs allow for hands-on exercises in initial configuration, automation design, troubleshooting, and network monitoring.
- The laboratory environment can be integrated with synchronous presentations using teleconferencing technologies with remote sites for both faculty and students.
- The laboratory environment utilizes virtual machines for the PC interface students use to monitor and configure the PLCs. This reduces cost by minimizing the hardware required.

Conversely the design, acquisition, and implementation of the lab environment also presented challenges:

- Cost: The laboratory access and scheduling hardware and software cost was approximately $9995.00 with a $2,995.00 yearly license. Additionally, each pod cost was approximately $23,358 and control plane infrastructure to support four lab pods was $7178.00 with plans to scale the infrastructure to 24 lab pods total.
- Labor: After design, the material acquisition and component integration, configuration, and troubleshooting is anticipated to take the full sixteen-week Spring semester and eleven-week summer term using approximately 320 hours of graduate assistant time and 160 hours of faculty time.
- Physical interface: Although the output of the HMI screen can be seen by a remote student using the PTZ camera, there is no current way to provide touch-screen input unless another student is present in the lab.
- Equipment ready state: The current wiring topology has physical single pole switches for on-campus students wired in parallel with remotely controlled relays for remote students. Since they are wired in parallel, the on-campus students must ensure that the switches are left open at the end of the lab period for the remote students to have control.

At the time of writing, only one pod topology has been initiated and laboratory exercises developed for one course utilizing this topology. Advanced lab exercises still need to be developed, and additional pod topologies may be required. Additionally, only the PC's in the lab environment were virtualized. Virtualization of other hardware components could potentially reduce the cost and allow for a wider variety of lab equipment and topologies.

Future work will involve replicating the first CPwE lab pod seven times and have eight lab pods operational and supporting classes and training by the 2018 Fall semester. Additional funding will be sought through federal and regional funding agencies and foundations to eventually scale the lab environment to 24 CPwE lab pods.

Since the environment is available 24/7 and the scheduling software allows for users to reserve time, the system could be shared among colleges and universities. However, this sharing would require the manual creation and management of multiple student user accounts. If the system is integrated with a federated authentication scheme such as Shibboleth, the management of user accounts could be greatly simplified [16].

Lastly, the implementation of simulated input to allow for complete remote-student interaction would enhance the learning capabilities of the lab and allow for a more complete remote-access experience. Input could include the HMI touch screens and other manual input.

Acknowledgements

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References

[1] Morgan Stanley, "The Internet of Things and the new industrial revolution," April 18, 2016. [Online]. Available: http://www.morganstanley.com/ideas/industrial-internet-of-things-and-automation-robotics. [Accessed November 15, 2017].

[2] B. Buntz, "Why the IIoT demands more flexibility from the workforce," Internet of Things Institute, January 26, 2017. [Online]. Available: http://www.ioti.com. [Accessed May 2, 2017].

[3] T. Grandin, "The Importance of Hands-On Learning," *Huffpost*, October 11, 2013. [Online]. Available: Retrieved from: https://www.huffingtonpost.com/temple-grandin/the-importance-of-handson_b_4086423.html. [Accessed November 15, 2017].

[4] QA Education, "The Importance of hands on learning in schools," *Headteacher Magazine*, October 27, 2016. [Online]. Available: https://www.qaeducation.co.uk. [Accessed January 5, 2018].

[5] Cisco, "Digital transformation with the Internet of everything - 100 customer stories," [Online]. Available: https://www.cisco.com/c/r/en/us/internet-of-everything-ioe/tomorrow-starts-here/index.html. [Accessed November 10, 2017].

[6] K. D. Thompson, "Smart Manufacturing Operations Planning and Control Program," March 17, 2017. [Online]. Available: https://www.nist.gov/programs-projects/smart-manufacturing-operations-planning-and-control-program. [Accessed February 2, 2018].

[7] ABET Accredited Program Search, Available: http://main.abet.org/aps/accreditedprogramsearch.aspx. [Accessed February 4, 2018].

[8] ATMAE Accredited Programs, Available: http://www.atmae.org/page/AccreditedPrograms. [Accessed February 4, 2018].

[9] Northwestern University School of Engineering, Available: https://www.mccormick.northwestern.edu/engineering-management/curriculum/iiot-pilot-course-outline.html. [Accessed February 2, 2018].

[10] Florida Institute of Technology, Available: https://internetofthings.fiu.edu/. [Accessed February 2, 2018].

[11] J. Lacayo "FIU to offer first Internet of Things in U.S.," June 27, 2017. [Online]. Available: https://news.fiu.edu/2017/06/fiu-to-offer-first-internet-of-things-degree-in-u-s/112824. [Accessed February 2, 2018].

[12] J. Pickard, T. Broach, P. Lunsford, and M. Angolia, "Building a Sustainable ICT Remote Access Lab through Student Lab Worker Projects," in *Proceedings of the 2017 ASEE Zone II Conference*, San Jose, Puerto Rico, USA, March 2 – 5, 2017.

[13] NDG NETLAB+ System Overview, Available: https://www.netdevgroup.com/support/documentation. [Accessed November 6, 2017].

[14] Rockwell Automation Industrial Internet of Things Curriculum, Available: https://www.rockwellautomation.com/global/capabilities/industrial-maintenance-support. [Accessed November 1, 2017].

[15] Cisco and Rockwell Automation, "Converged Plantwide Ethernet (CPwE) Design and Implementation Guide," Available: https://www.rockwellautomation.com/global/capabilities/industrial-networks/technical-data. [Accessed April 4, 2017].

[16] Shibboleth Consortium, "How Shibboleth Works: Basic Concepts," Available: https://www.shibboleth.net/index/basic/. [Accessed February 3, 2018].

Appendix A. Glossary of Acronyms

ABET	Accreditation Board of Engineering and Technology
ATMAE	Association of Technology Management and Applied Engineering
ANOC	Academic Network Operations Centre
CPwE	Converged Plant-Wide Ethernet/Internet Protocol
CLI	Command Line Interface
DLT	Distance Learning and Telemedicine
DMZ	Demilitarized Zone
FIU	Florida International University
HMI	Human Machine Interface
IIoT	Industrial Internet of Things
IoT	Internet of Things
IT	Information Technology
IACS	Industrial Automation and Control Systems
IE	Industrial Ethernet
IIC	Industrial Internet Consortium
ICT	Information and Computer Technology
IET	Industrial and Engineering Technology
LED	Light Emitting Diode
M2M	Machine to Machine
NIST	National Institute of Standards and Technology
OT	Operations Technology
PLC	Programmable Logic Controller
PC	Personal Computer
PTZ	Pan-Tilt-Zoom
RUS	Rural Utility Services
SCADA	Supervisory Control and Data Acquisition
STEM	Science, Technology, Engineering and Mathematics
SPST	Single-Pole-Single-Through
SSL	Secure Socket Layer
TCP	Transmission Control Protocol
USDA	United States Department of Agriculture
VFD	Variable Frequency Drive
VLAN	Virtual Land Area Network
VTP	VLAN Trunking Protocol
VPN	Virtual Private Network