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Using Industry 4.0 Technologies to Support Teaching and Learning*

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It is a known fact that students learn more effectively when theory is supplemented by a large component of laboratories. But laboratory based learning is most effective when students are able to practice laboratories multiple times to review their work, reflect on it, test different scenarios, and discuss the results with their peers and instructors. In the School of Engineering Practice and Technology (SEPT) at McMaster University we have achieved this by providing remote laboratories using Industry 4.0 technologies. These technologies have enabled us to build industrial networks laboratories that are accessible onsite, and remotely online through the Internet. We call them McMaster Internet Laboratories or MiLabs in short (pronounced as My Labs). This paper describes how Industry 4.0 technologies are used to enable remote access to MiLabs; and how we have designed our laboratory sessions and laboratories based projects to maximize learning. Furthermore, the paper presents general analysis of students' performance and feedback which show that MiLabs is an effective laboratory platform.

Keywords: Industry 4.0; teaching and learning; industrial networks; internet laboratories; internet of things

1. Introduction

With the increased use of technology in every aspect of human life, digital learning has become a very important form of teaching and learning. But the future of digital learning lies in the hybridization of courses, incorporating in-person components into online classes. This learning framework is generally referred to in literature as blended learning. Research shows that blended learning is exceptionally promising. Like purely digital learning, blended learning lacks the time and space constraints imposed by in-person courses, thus much more conducive for the expansion of learning time. But, unlike purely digital learning, blend learning includes opportunities for reflection and interaction with peers and teachers. Moreover, today's university students already lead blended lives. They access news, pay bills, search for vacation destinations online, and they communicate by email and social media [6]. On the other hand, they go to movies, shop in malls, and visit friends and family in-person. This makes blended learning an appropriate pedagogical paradigm for today's students. However, the need to carry out laboratory experiments during the course of engineering and science programs is a great challenge to the online component of blended learning.

Although Industry 4.0 technologies were developed to increase resource optimization in the manufacturing industry, they can be used to provide improved remote access to laboratory equipment. In fact, many innovative hardware and software solutions that are making massive changes to the industrial world in the context of Industry 4.0, are also being adopted to support teaching and learning. Common examples of such innovations include the following:

- Cloud server based learning management systems such as Moodle that support the offering of millions of courses to millions of students worldwide.
- Wikis which enables cooperative text production and different kinds of assessment modes of quizzes that give teachers the chance to test students whenever they want and as many times they want during the semester.

Digitally supported learning brings advantages to students in terms of awareness of the course content, as well as increased collaboration. Therefore, it is imperative that we use Industry 4.0 technologies in teaching; especially laboratory work as we prepare the next generation of engineers to work in Industry 4.0 enabled environment. This gives them the skills required to work in semi virtualized world that can be realized as in the following examples: Analyzing a defective machine, monitoring and optimizing energy consumption of multiple production sites, coming up with a logistics concept for a virtual factory, or designing a virtual car [12].

In engineering education computer-supported cooperative and collaborative learning have long been established as methods which support self-driven and work-related learning processes. Introducing online (Internet) laboratories lifts such common learning methods to a new level; and in this paper, we present a laboratory that we designed

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to be accessible online through the Internet. The laboratory uses Industry 4.0 remote data access technologies, and it is used onsite and online. Onsite, the laboratory is used to teach hardware configuration and integrated, and online, it is used to teach PLC programming, PLC automation data access, software applications integration, and Human Machine Interface (HMI) development. This paper describes the following:

- The laboratory architecture.
- The deployment of the laboratory in one of the course in the process automation program at McMaster University.
- The feedback we have received on the educative effectiveness of the laboratory.

The rest of this paper is arranged as follows: Section 2 covers work in literature that is related to MiLabs. In Section 3 we present the framework of the MiLabs while Section 4 deals with the deployment of the laboratories in a system integration course at McMaster University. Section 5 deals with the discussions, and the conclusion and future work are covered in Section 6.

2. Literature review

Laboratories play a critical role in the teaching and learning of science based courses. These laboratories fall under three general categories, namely: hands-on, simulated, and remote laboratories. Each laboratory categories have strengths and weaknesses, and there is no consensus in literature on a category that is the most effective [11].

2.1 General laboratory categories

Hands-on laboratories give students real data that shows discrepancies between theory and practice. Such experiences cannot be produced in simulated laboratories [2]. Moreover, there are many important soft skills such as handling laboratory equipment, following laboratory regulations, and responding to laboratory (workplace) emergencies, which can only be learned through hands–on laboratories. On the flip side, hands-on laboratories are generally expensive and place a high demand on space and instruction time [15].

Simulated laboratories imitate hands-on laboratories using infrastructure that is simulated on computers. This leads to the main strength of simulated labs, reduced cost and time required to setup and manage the laboratory infrastructure [11]. However, some in literature believe that excessive exposure to simulation may result in a disconnection between real and virtual worlds [2].

Remote laboratories use real infrastructure that requires space and management, just like hands-on laboratories. In remote laboratories, the experimenter is geographically detached from the laboratory equipment, as opposed to being collocated with the equipment as in hands-on laboratories [11]. It is generally agreed in literature that remote laboratories are increasingly becoming popular because of the following reasons:

- They can be shared among different institutions, resulting into a shared pool of real laboratory infrastructure; and hence reducing cost (note that remote laboratory equipment can be designed to be used in both remote and hands-on modes) [16].
- They have the ability to extend the capabilities of real laboratory equipment, making it accessible at any time, and from anywhere [7, 13].
- Some studies show that remote laboratories are at least as effective as hands-on laboratories [4, 13].

Web-based simulated laboratories and remote laboratories can be used to support online teaching and learning. But, while the framework for supporting online course content delivery is mature, the framework for supporting online laboratories is still lacking [3]. Therefore, the need to carry out laboratory experiments in engineering programs is a great challenge to the online component of blended learning. In their paper titled "A LabVIEW-Based Remote Laboratory Experiments for Control Engineering Education", Stefanovic et al. state that: "The idea of having a remote web-based laboratory corresponds to attempt to overcome different constraints and may be the next step in distance learning" [14].

It is important to note that there are efforts to solve the challenge of integrating remote laboratories into blended learning [19]. For example, in German, each of the seven universities that make up the LearnNet network has to provide a remote lab to all members [18]. In addition, Internet-based remote-access laboratory was developed, implemented, and piloted at Stevens Institute of Technology in 2005 [10]. In their implementation, the experimental equipment can be used in the traditional on-site fashion or it can be accessed remotely through the Internet. Generally, it is possible to use a combination of available technologies and specific methods to control, configure, and acquire data from experimental setups over the internet [19].

2.2 Using industry 4.0 technologies to support remote laboratories

It is generally agreed in literature that Industry 4.0 technologies are poise to transform manufacturing. But in the School of Engineering Practice and Technology (SEPT) at McMaster University, we are using these technologies to transform teaching and learning through online laboratories. Industry 4.0 is the new manufacturing paradigm that seeks to leverage the potential optimization in production and logistics caused by the following technologies [1, 8]:

- Modern industrial automation.
- Cloud computing and big data.
- Networking (Machine-to-Machine, SCADA, and Business-to-Business communication).
- Additive and smart manufacturing.
- Intelligent system monitoring, and control, and autonomous decision-making.

In our remote laboratory systems, we use industry 4.0 networking technologies that support machine-to-machine communication over the Internet. The technologies have proven reliability as well as inbuilt cybersecurity functionalities (Fig. 4).

3. Framework for the McMaster University iLabs

Since one of the main focuses of the School of Engineering Practice and Technology at McMaster University is hands-on learning, the McMaster iLabs (MiLabs) are based on a framework that supports both onsite and (remote) offsite lab access. Onsite students are able to configure, program and control laboratory equipment directly, while offsite students access the laboratory equipment through Internet of Things (IoT) gateways to remotely program and control it. Currently, the following laboratories are offered by MiLabs:

- The first set of laboratories focuses on network design, configuration, and wiring. These laboratories are primarily carried out onsite.
- The second set of laboratories can be offered onsite and offsite. They cover PLC programming with a focus on programming machine to machine communication integration of manufacturing and business automation software applications, and PLC automation systems data access.

3.1 MiLabs onsite laboratory equipment

Ethernet is ubiquitous, cost effective, uses common physical link for multiple applications, has high speed, and increasingly becoming deterministic. Therefore, it is poised to become the *de facto* protocol for industrial networks. That is why MiLabs focus on EtherNet IP as the plant level network [9]. The Onsite set of MiLabs covers concepts associated with the physical, data link, and network layers of the Open System Interconnection (OSI) communication reference model. With respect to EtherNet IP, such concepts include various network principles such as addressing structure, wiring requirements, and node power requirements. The main objective of this set of labs is to teach students the process of identifying useable IP addresses as well as assigning addresses to the network nodes. The laboratories also cover network configuration and programming using software tools such as CX Configurator, RsWorx, RsLogix5000, and Productivity3000. Fig. 1 show the main components of the MiLabs onsite equipment.

The figure shows that the laboratory equipment includes Eaton PowerXL DG1 Variable Frequency Drive (VFD), Eaton ELC-CAENET remote I/O module, and Ethernet IP complaint C411 Motor Insight monitor; connected together using Power Xport Ethernet switch to form the laboratory Local Area Network (LAN). MiLabs onsite equipment also supports SmartWire configuration and programming laboratories. SmartWire network (Fig. 2) integrates basic automation devices such as switches, LEDs, and relays with complex devices such as remote IOs and PLCs. We intend to use a Smartwire to EtherNet IP gateway to integrate SmartWire with EtherNet IP. This will enable the moving of process parameters at the basic technologies level of the IEC automation hierarchy to the enterprise level.

3.2 MiLabs online laboratory equipment

Figure 3 shows the network architecture of MiLabs online laboratory equipment. The equipment is designed to offer a wide variety of laboratories, ranging from PLC programming and IED configuration, to horizontal and vertical industrial and business systems integration required to support manufacturing under Industry 4.0 paradigm. The equipment depicts a plant that has a process automation system, and an electrical substation system. The process automation component of the equipment has an Automation Direct CLICK micro PLC and a Productivity 3000 PLC which is also used as an Integrated Electronic Device (IED) in some of the laboratories. The electrical substation is automated using IEC61850 compliant IEDs that have Modbus communication capabilities, as well as power meters that communicate using Modbus RTU.

This laboratory equipment in Fig. 3 works as follows:

- An Automation Direct CLICK micro PLC is configured to read electrical parameters (voltage, current, power, and energy) from a power meter, through a Modbus RTU connection.
- The Human Machine Interface connected to the substation network in Fig. 2 can read the power parameter from the CLICK micro PLC through

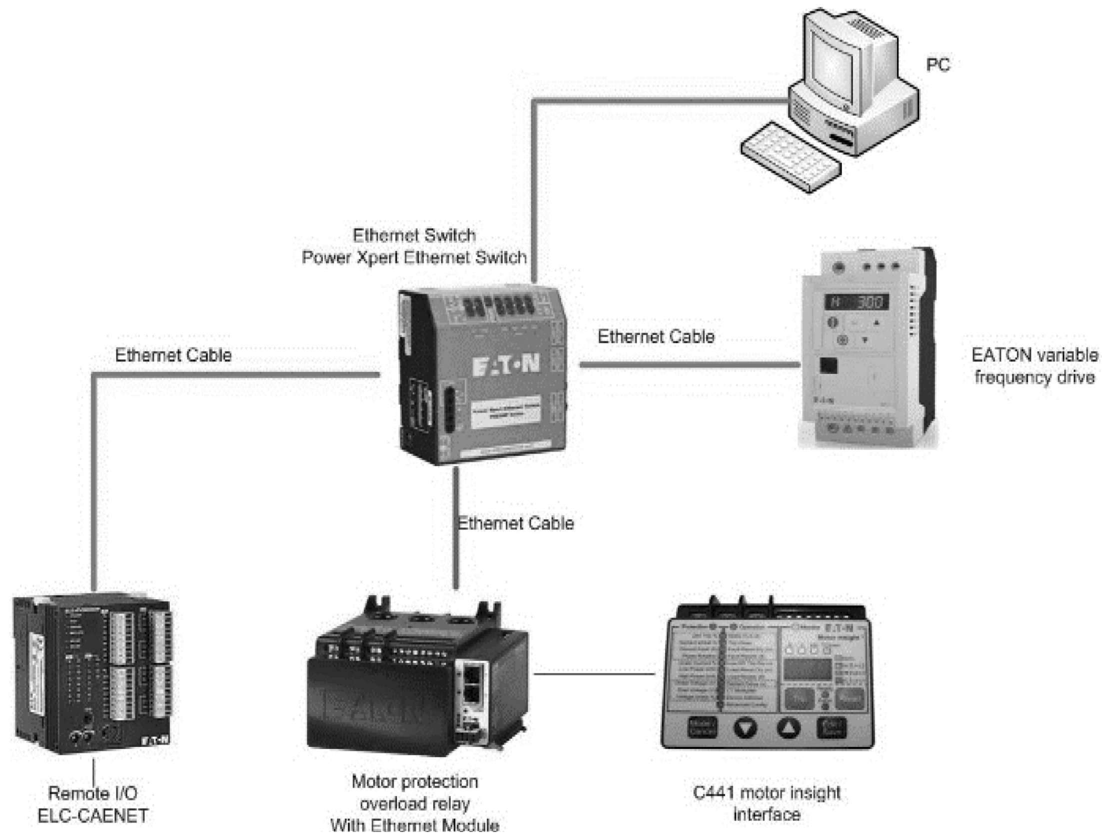


Fig. 1. Ethernet IP laboratory setup.

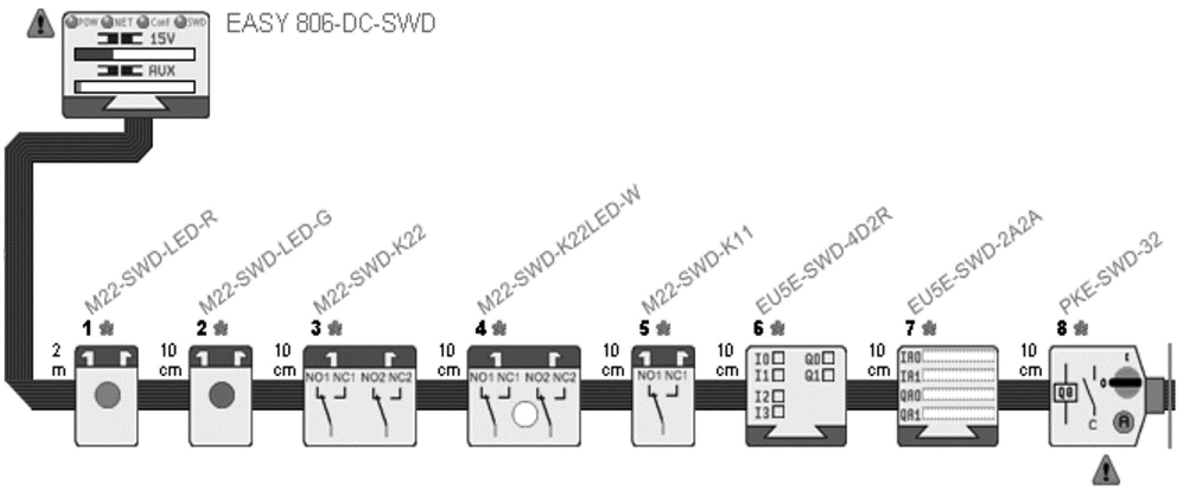


Fig. 2. MiLabs Smartwire Network.

the Schneider TSXETG100 Modbus RTU to Modbus TCP gateway. In this case, each register is read separately by the HMI. Since HMIs do not support logic instruction, the registers are read periodically, causing a great amount of traffic on the Modbus RTU network. This causes the HMI to flag a message timeout error from time to time. This issue is addressed by using a Productivity 3000 PLC as an IED to read the CLICK registers through the Modbus gateway, using a Modbus TCP read instruction.

- The Productivity 3000 PLC can be configured to communicate with the CLICK micro PLC, the SEL IEC61850 Relay, and the Power meter through the Modbus serial network using Modbus RTU, or through the Ethernet network using Modbus TCP. In addition, the PLC can communicate with the Eaton ELC-CAENET

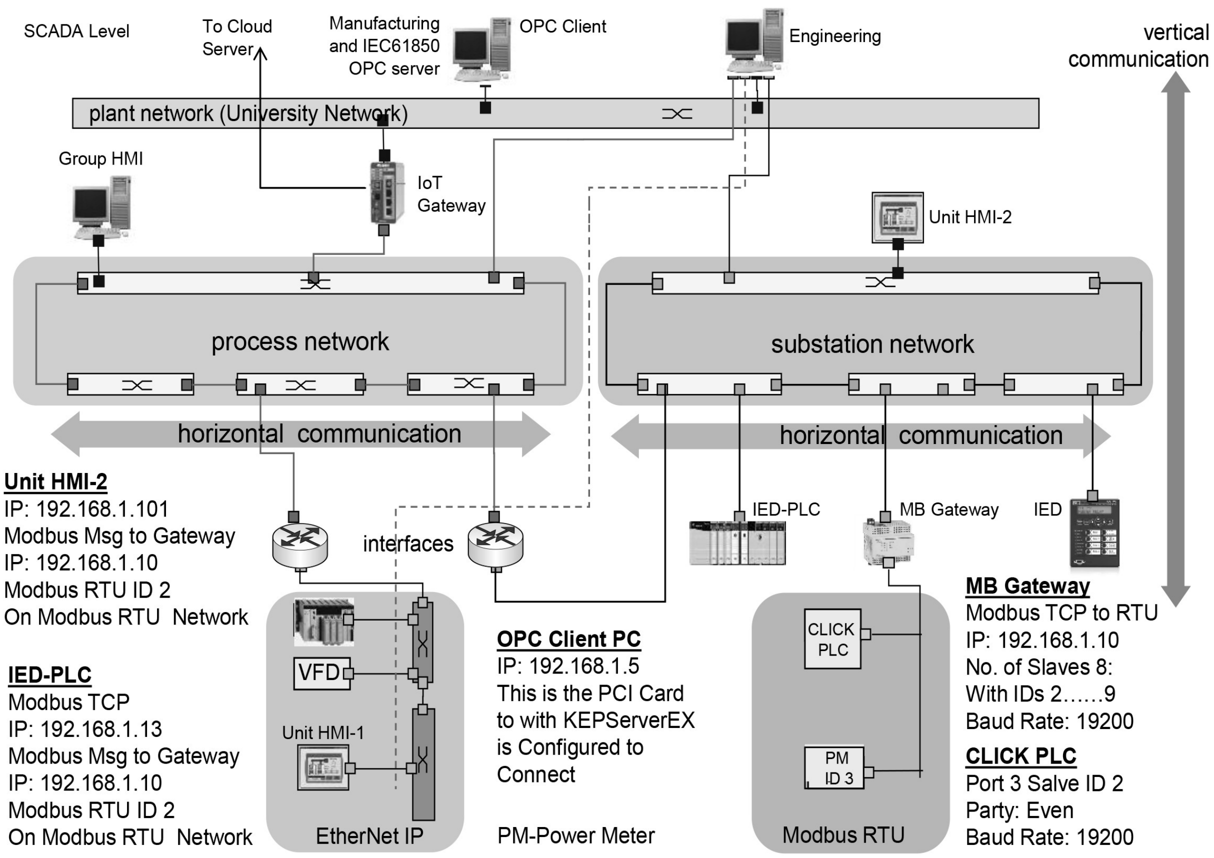


Fig. 3. Ethernet IP, Modbus Serial, and Modbus TCP Remotely Accessible Laboratory Setup.

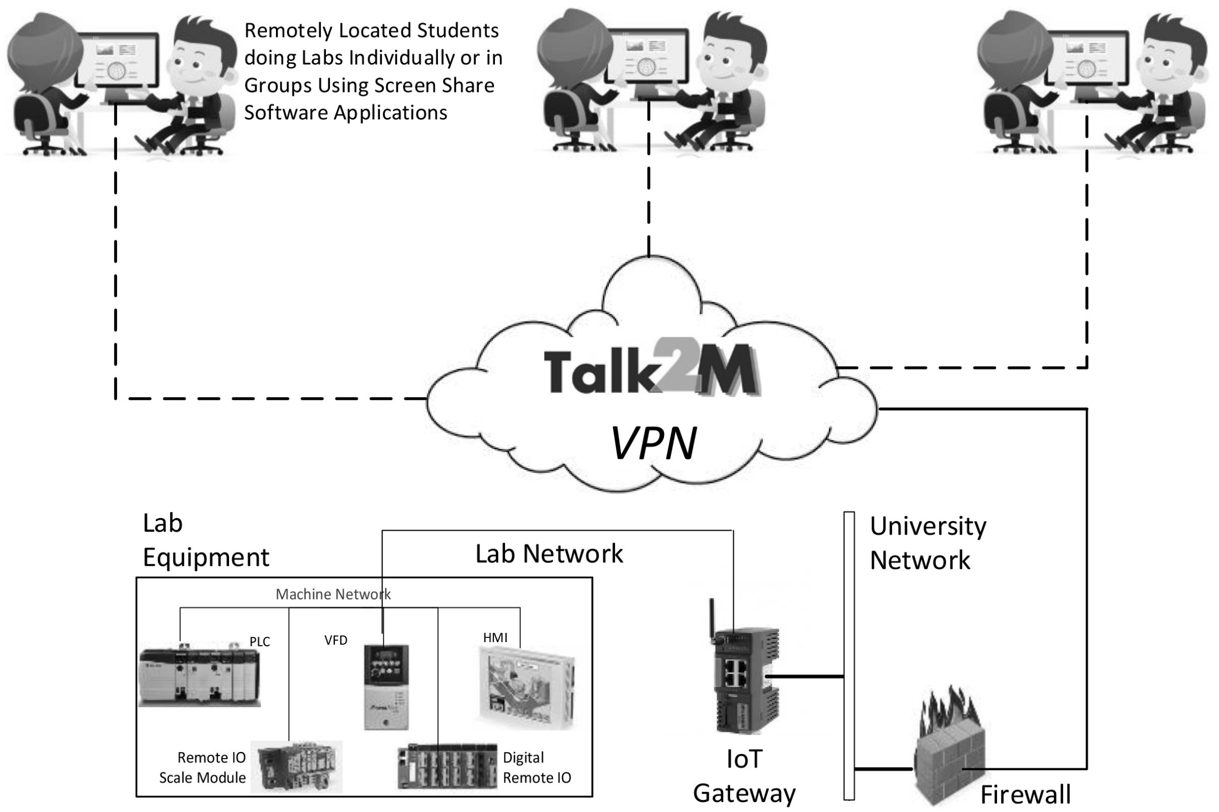


Fig. 4. Laboratory Remote Access Using Internet of Things Router.

remote I/O and the PowerXL DG1 or Powerflex40 VFD through Ethernet IP.
- Students configure and program the network devices using a laboratory computer that functions as an engineering station shown in Fig. 3. The station has two network cards. One that connects to the process, and the electrical substation networks; and the other that connects to the plant (university) network.

The laboratory equipment is accessible remotely through Industry 4.0 compliant eWON Cosy gateways as shown in Fig.4. The gateway creates a Virtual Private Network (VPN) via a cloud server called Talk2M to support the laboratories as follows:

- The eWON Cosy connects to the Talk2M server.
- One group member uses eCatcher client to remotely log into his/her Talk2M account. Thereafter the student selects the laboratory equipment he/she wants to connect to.
- A fully secure VPN tunnel is set up between the student and the equipment. The student can then go live with any devices connected to the eWON Cosy's LAN ports.
- If the group members are located remotely from the student who has logged into the Talk2M VPN, he/she share his/her computer screen with the other group member using the Learning Management System (LMS) screen share functionality. Moreover, students can communicate over voice or instant messaging functionality provided by the LMS.

The eWON Cosy uses an outbound connection across the laboratory LAN (HTTPS port 443 or UDP 1194). This makes the eWON Cosy to be isolated from Internet by working with private IP address, non reachable from the Internet. No IT/firewall changes are needed to establish communication [5]. A key asset to the laboratory set up process.

4. Deployment of MiLabs

In the fall of 2015, we offered four related laboratories and a course project using the MiLabs equipment. The first two laboratories were done in house to enable students to know each other and develop working relationships. Thereafter the following laboratories were offered online:

- Lab 3 (a)—OPC Server Configuration.
- Lab 3 (b)—OPC DataHub Applications.

The OPC laboratories deal with the integration of the process automation system with the electricity substation automation system (horizontal integration of systems at the plant level), and the laboratory sessions were structured as follows:

- A two hour onsite trail was held to prepare students to do labs remotely.
- Although students accessed the laboratory equipment remotely, the laboratories were scheduled and done synchronously.
- Students worked individually or in groups of two or three, and in some cases the students in a group were remotely located from each other. In those cases, one student logged in the laboratory system and shared his/her screen with the other students. This way the group would agree on actions to be taken, and the logged in students would take those actions on behalf of the group.
- Each student was required to record their screen to prove that they participated in the laboratory, and to show how the group arrived to the solution.
- Some students were allowed to work onsite, but they had to log into the laboratory equipment through the campus network.
- All students were required to log into a chat room where help queries were posted. Everyone was free to respond to the queries.

After the laboratories had been held, students carried out a laboratory based project in accordance with the pedagogical paradigm of laboratory based project for experiential learning [20]: In the project, students were required to carry out the following tasks:

- TASK 1: Complete the HMI of the Temperature Control and Energy Monitoring System used in labs 3a and 3b.
  1. Add more SEL relay tags to the HMI.
  2. Develop the HMI using the guidelines presented in the paper, A High Performance HMI: Better Graphics for Operations Effectiveness, by Bill Hollifield, available at http://isawwsymposium.com/wp-content/uploads/2012/07/WWAC2012-invited_BillHollified_HighPerformanceHMIs_paper.pdf.
- TASK2: Implement one of the following functions of OPC DataHub software application:
  1. DDE: Provide data access to excel, MatLab, or Database.
  2. Scripting.

The project was done individually, and the students accessed the laboratory equipment remotely for a period of three weeks. It focused on vertical industrial systems integration, in which plant floor data is moved up to the business level, where it is integrated with data from other sources using business software applications such as Microsoft Excel.

4.1 Sample of the students' work

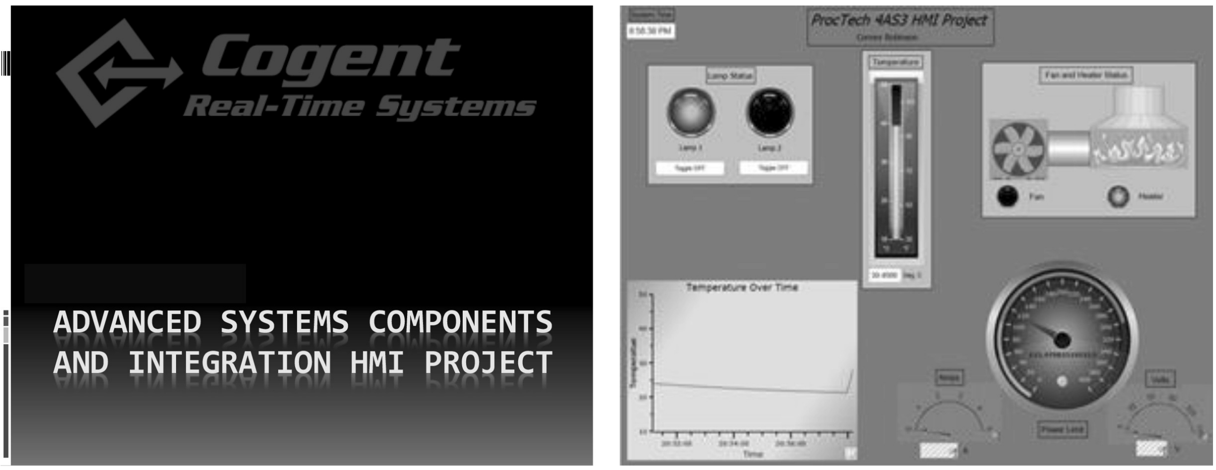
While a wide range of solutions were developed by students, the sample solution presented in this paper is good representation of the nature of all the solutions. The student developed an HMI in accordance with the guidelines presented in the paper titled "A High Performance HMI: Better Graphics for Operations Effectiveness", by Bill Hollifield. Fig. 5(a) is the first page of the HMI, while Fig. 5(b) is the second page. The first page of the HMI does not have any controls as well as data visualization, which is a good design. However, it would have been better if the data visualization on page two was separated from the system control inputs.

Figure 6 show automation data displayed in a business application (Microsoft Excel). This data can be integrated with any other business data to produce actionable information.

What is important to note is the fact that students were able to do a laboratory based project without having to physically come to the laboratory. The amount of time that students need to access the equipment would have made it impossible to carry out the project if the project was to be scheduled on the laboratory time table. In addition, because of being accessible online, 53 students were able to do individual project using one piece of equipment.

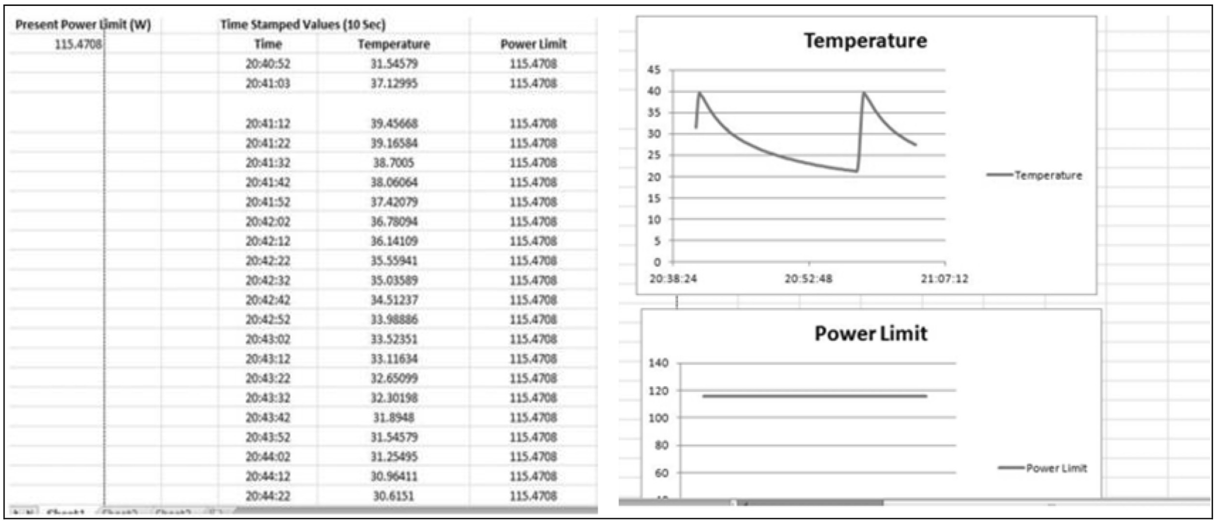
4.2 Student's experience

The online laboratories brought far more to bare than what we expected. The two hour trail run was a learning experience. Here students learned to configure software applications used to access remotely located hardware. This in itself is a highly desirable skill in industry. They also learned how to use collaboration software application so as to share their computer screens with other group members.



(a) First Screen of HMI (b) Second Screen of HMI

Fig. 5. Sample Student's HMI Solution for MiLabs based Course Project.



Present Power Limit (W)	Time Stamped Values (10 Sec)		
115.4708	Time	Temperature	Power Limit
	20:40:52	31.54579	115.4708
	20:41:03	37.12995	115.4708
	20:41:12	39.45668	115.4708
	20:41:22	39.16584	115.4708
	20:41:32	38.7005	115.4708
	20:41:42	38.06064	115.4708
	20:41:52	37.42079	115.4708
	20:42:02	36.78094	115.4708
	20:42:12	36.14109	115.4708
	20:42:22	35.55941	115.4708
	20:42:32	35.03589	115.4708
	20:42:42	34.51237	115.4708
	20:42:52	33.98886	115.4708
	20:43:02	33.52351	115.4708
	20:43:12	33.11634	115.4708
	20:43:22	32.65099	115.4708
	20:43:32	32.30198	115.4708
	20:43:42	31.8948	115.4708
	20:43:52	31.54579	115.4708
	20:44:02	31.25495	115.4708
	20:44:12	30.96411	115.4708
	20:44:22	30.6151	115.4708

Fig. 6. Automation System Data Displayed in Business Software Application (Excel).

Students' participation in the chatroom was amazing. It felt like every student was both a laboratory attendee and a teaching assistant. Every time a question was posted one of the students quickly responded to it, and my role was reduced to summarizing and clarifying responses to queries. Students who did the laboratories onsite were very helpful too. Whenever I gave them some support, they were eager to give support to others facing similar challenges, through the chat room.

Students were generally excited about doing laboratories and the course project by accessing laboratory equipment online. Therefore, they gave us a lot of unsolicited feedback. The following is some of the feedback we obtained that are representative of the general view of the class about MiLabs:

1. "*. . . Performing labs 3a and 3b remotely was an overall good experience. It allowed me to focus more on the material as I was alone in a quiet area and could not become distracted by others. Troubleshooting was also more enjoyable as I had to rely solely on myself. I believe working remotely and alone would also stop other students from giving up on a problem easily as they do not have easy and instant access to the lab instructor and are forced to use critical thinking and problem solving skills. An area that could be improved is restricting the amount of access students have to certain tags in order to reduce the risk of shutting down or damaging the system. Configuring and accessing systems remotely is something that we will use when working in all industries so being able to experience it first hand in the lab was valuable to me. . .*"
2. "*. . . I am writing to you about OPC lab for 4AS3. Since I was a part of the lab in ETB B111 and I also went home and did the lab again, I have a more informed perspective of how the entire lab was run. The labs were very straight forward and were not a struggle for many of the students. Only problems that I experienced were due to miscommunication and lack of preparation from the other students. Make sure that the VPNs are set up and ready to go before attempting the lab especially from home. The learning environment was very good and the chat room that was set up really helped communication of issues. Having all of the software ready to go before hand really speeds things up and following the procedure was not difficult. The project idea is great and I also feel like we should spend more time on OPC and cover more of its abilities just due to how easy the remote access was from home. This new type of learning was a very good experience and I thoroughly enjoyed the labs. These labs should be continued and definitely added to, the remote access experience was very unique and I learned a lot. . .*"
3. "*. . . Referring to labs 3a and 3b, I found that these were well structured. It allowed the experimenter to get a bit of experience of using VPN to access a machine and checking parameters, status etc. It also allowed the individual to get experience creating an HMI to represent the information. . .*"
4. "*. . . I know many people now that are connected to their workplace 24/7, being able to watch systems run and make changes as needed. It is part of our future of big data, analysis, and optimizations. Next, it gives everyone the opportunity to work simultaneously on a system, and be able to ask and answer questions to get a better understanding of what is happening. For students that commute long distances, it can be a huge benefit. This term it benefited me extremely as I only had the one lab on Fridays. I didn't need to commute from Brantford to Hamilton in order to do the lab. It saves me time, money, and lets me sleep a little longer. Finally, it gives us a hands-on experience of the types of software we will be using in the field, and gives us better insight into how communication protocols relate and connect to each other. This is incredibly helpful. After the third lab I was able to much better understand the systems in place and I could troubleshoot most problems much more easily and quickly. Even though industry is evolving at a rapid pace, and the software is changing to accommodate that, updating this lab annually wouldn't be a problem as the majority of the software would still support legacy devices. . .*"

Towards the end of the laboratory module, students did a post laboratory test, followed with a laboratory based project. The students who did the laboratories associated with MiLabs remotely performed slight better than those who did the laboratories onsite in both the laboratory test and project. This can be attributed to the face that remotely located students hard far more access time to the equipment than their counterpart who had to come to the laboratory once a week.

5. Discussion

From the students' feedback as well as our own studying of the way MiLabs were deployed in the course PROCTECH4AS3—Advanced System Components and Integration at McMaster University, it is clear that students appreciate online laboratories if they are offered within the following structure:

- Run one or two laboratories onsite to start off the class so that the students develop working relationships and become acquaintances. This improves their collaboration during online laboratories.
- Hold pre-online laboratory preparation session. During this session, the students should install and test the applications that support remote access to the laboratory equipment. In addition, they should install and test applications that enable then to collaborate in their groups. Finally, test run the major instructions of the laboratory during this session. For example, in our laboratories the main instruction requires students to record their screen using an application called CamStudio. This recording provides extra proof of participation in the laboratory session.
- Run a few scheduled synchronous online laboratories, and use a simple conferencing mechanism such as a chatroom. This allows students to post

questions and get support from the instructor and colleagues, just as they would in onsite laboratories.

- It is good to add a small project which students do asynchronously without the chatroom support. This give them the freedom to try out different thing and learn from that experience.

There were two main issues that students identified about MiLabs, namely failing to log on during high access volume, and students having to do extra work to prove that they logged onto the system. The first issue has been addressed by developing three new remote access laboratory stations; and the second issue has been address by making the new laboratory stations capable of recoding user access.

6. Conclusion and future work

Online laboratories have the potential to support increased access to laboratory equipment by providing virtual knowledge spaces. These innovative virtual knowledge spaces offer all kinds of possibilities for teaching, and for learning to work in times of industry 4.0. In order to use the new technologies for engineering education in a proper way, deeper insights in reception, cognition and communication in virtual environments are necessary. Simply providing the technical infrastructure does not automatically guarantee successful teaching and learning in fact many misunderstand online laboratories by thinking that they are met to simply replace in person laboratories for purposes of reducing cost and scheduling constraints. On the contrary, online laboratories require innovative delivery paradigms as discussed in Section 5.

Besides collapsing time and space for students, MiLabs enable and encourage instructors to include demonstrations of sophisticated laboratory experiments into their lectures. Moreover, this framework forms a strong basis for integrating experimentation into distance and electronic learning offerings. Consequently, we hope to share MiLabs with other institutions of learning in the future. This will increase our collaboration with learning institutions, including other departments in the university.

References

1. B. Bunse, H. Kagermann and W. Wahlster, Industry 4.0: Smart Manufacturing for the Future, *Germany Trade and Invest,* Berlin, German, July 2014.
2. D. J. Magin and S. Kanapathipillai, Engineering Students' Understanding of the Role of Experiments, *European Journal of Engineering Education*, **25**(4), 2000, pp. 351–358.
3. D. Koller and A. Ng, Coursera makes top college courses free online, Phys.org. http://phys.org/news/2012-07-coursera-college-courses-free-online.html. Accessed on 26 Feb. 2014.
4. E. Scanlon, C. Colwel, M. Cooper and T. D. Paola, Remote Experiments, Re-versioning and Re-thinking Science Learning, *Computer and Education*, **43**(1–2), 2004, pp. 153–163.
5. eWON, eWON Cosy 131 Installation Manual, Available at https://ewon.biz/sites/default/files/ig-022-0-en-ewon_cosy131.pdf, Accessed on 15 May 2016.
6. F. S. Glazer, Blended Learning: Across the Disciplines, Across the Academy, *Stylus Publishing, LLC*, 2011.
7. G. Canfora, P. Daponte and S. Rapuano, Remote accessible Laboratory for Electronic Measurement Teaching, *Computer Standards and Interfaces*, **26**(6), pp. 489–499.
8. G. Schuh, C. Reuter, A. Hauptvogel and C. Dölle, Hypotheses for a Theory of Production in the Context of Industrie 4.0. Advances in Production Technology, *Lecture Notes in Production Engineering*, **11**, 2015.
9. I. Singh, N. Al-Mutawaly and T. Wanyama, Teaching Network Technologies that Support Industry 4.0, *Proceedings of the Canadian Engineering Education Association Conference*, Hamilton—Canada, June 2015.
10. J. Del Alamo and V. Nikulin, Engineering laboratory accessible via the Internet, *Proceedings of the 2006 ASEE Annual Conference & Exposition, Session 1526*, Chicago, USA, June 18–21, 2006.
11. J. V. Nickerson, Hands-on, Simulated, and Remote Laboratories, *ACM Computing Surveys*, **38**(3), Article 7, 2006.
12. K. Schuster, K. Groß, R. Vossen, A. Richert and S. Jeschke, Preparing for Industry 4.0—Collaborative Virtual Learning Environments in Engineering Education, *The International Conference on E-Learning in the Workplace*, New York, NY, USA, June 10th–12th, 2015.
13. M. Cooper, A. Donnelly and J. M. Ferreira, Remote Controlled Experiments for Teaching over the Internet: A Comparison of Approaches Developed in the PEARL Project. *Proceedings of the ASCILITE Conference,* Auckland, New Zealand, 2002.
14. M. Stefanovic, V. Cvijetkovic, M. Matijevic and V. Simic, A LabVIEW-Based Remote Laboratory Experiment for Control Engineering Education, *Computer Applications in Engineering Education*, **19**(3), 2009.
15. P. A. Farrington, S. L. Messeimer and B. J. Schroer, Simulation and Undergraduate Engineering Education: The Technology Reinvestment Project (TRP). *Proceedings of the 1994 Winter Simulation Conference,* Lake Buena Vista, Florida, USA, 1994.
16. R. Sell, Remote Laboratory Portal for Robotic and Embedded System Experiments, *International Journal of Online Engineering*, **9**(8), 2013, pp. 23–26.
17. R. V. Krivickas and J. Krivickas, Laboratory Instruction in Engineering Education, *Global Journal of Engineering Education*, **11**(2), 2007.
18. S. K. Scapolla Esche, M. G. Prasad and C. Chassapis, A remotely accessible laboratory approach to undergraduate education. *Proceedings of the 2004 ASEE Annual Conference & Exposition*, Session 3220, Salt Lake City, UT, United States.
19. S. Tumkor, S. K. Esche and C Chassapis, Design of Remote Laboratory Experiments Using LabVIEW Web Services, *Proceedings of the International Mechanical Engineering Congress and Exposition*, **5**, Education and Globalization; General Topics, 2012.
20. T. Wanyama and I. Singh, A Training Demonstration for Experiential Learning in OPC based Process Automation data Access, *Proceedings of the Canadian Engineering Education Association Conference*, June 2013, Montreal, QC, Canada.

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