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A Pilot Program in Internet-of-things with University and Industry Collaboration: Introduction and Lessons Learned

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Introducing a Pilot Program in Internet-of-Things with University and Industry Collaboration - Lessons Learned

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Abstract

Internet-of-Things (IoT) is one of the most prominent and burgeoning technological ecosystems The IoT ecosystem uses well-established technologies in many fields; and it adds new and often challenging requirements on extant techniques. At University of New Haven, we have embarked on offering a sequence of two-courses to prepare interested students for this market. The first course, piloted in Fall 2017 as a graduate elective course, covered all theoretical and applied aspects pertaining to the end-to-end IoT ecosystem. According to the anonymous feedbacks, the course was very well received both in terms of the breadth and in terms of the depth of the topics. The follow on course will be a more hands-on experiential course to complement the first course. In this endeavor, we collaborated with Keysight Technologies who has developed a robust IoT-specific educational platform. We evaluated the board as the main tool for the second course in our curriculum. The evaluation was performed by a team of students under the supervision of a faculty member. A number of experiments were conducted and the results indicated that the platform, when supervised properly, is a valuable tool to teach the concepts and functionalities of the IoT technologies.

Keywords: IoT, educational tools, curriculum upgrade

Introduction

IoT being one of the technological ecosystems with an estimated market size of up to $11.1 Trillion per year in 2025 (McKinsey Global Institute) [1] is becoming a prominent source for new hires in the engineering field. The IoT ecosystem uses well-established technologies in many fields; however, it adds new and often challenging requirements on extant techniques. Proliferation of the cyber physical devices and the need to handle large data sets calls for special skill sets by new graduates. Many wireless schemes have been or are being redesigned to address battery life and cost of solution issues. At the same time, the industry needs to hire and retrain many technical personnel to address these issues and support this newly evolving ecosystem in many different markets.

These facts culminate in the need for engineering students to be skilled to handle the new challenges and match the hiring market needs. As importantly, the more experienced technical personnel need to be retrained to understand this evolving ecosystem. In this light, we have taken parallel symbiotic steps to address these challenges. We have piloted a course in IoT covering the most critical technologies in a typical end-to-end IoT system, including various access technologies and higher layer protocols and standards as well as prominent cloud services. Our industry partner, Keysight Technologies (formerly part of Agilent Technologies), has developed new measurement equipment to address more accurate and sensitive current draw of circuits to assist with power-frugal designs for long battery life. They have also developed a programmable board along with several experiments geared towards IoT applications [2].

Last summer a small group of graduate students, with the guidance of a senior faculty member, used the IoT board to assess its efficacy for less experienced engineering students. The board and the associated experiments were found to be very useful and a good addition to the program. The experiments are also valuable for continuing education purposes for developing specific skills in the development of IoT systems. The team created an updated and tailored user's manual [3] to better serve the needs of the engineering students and to alleviate the initial frustration associated with setting up the system.

Many institutions have already offered and are offering courses in the IoT field [4 – 7]. This is not only because IoT is a rapidly growing field but also because it affects myriad of industries and fields; as examples, please refer to [8 – 11] among many others. However, most of the courses approach the IoT subject as a sensor and wireless access projects mostly based on development kits; for example refer to [4 – 7] among many others. Although this approach is very necessary and helpful to students, but it misses to provide students with more analytical and basic design skills so they would develop a holistic view and capability to design an end-to-end system based on solid engineering best practices. In this light, we embarked on the approach of a two-course program, mentioned earlier. The first course covering more fundamental topics that an engineer might confront in designing a IoT system, while the second course covers more experiential techniques, providing students with several lab experiments covering various hands-on aspects of the IoT ecosystem.

In this paper, we will present the experiences of the pilot program and the key points that present the enhancements of technical manual for a teaching environment. We will present the value that the IoT board and its experiments bring to the students in order to enhance their experience when learning about the IoT ecosystem.

The First Course

IoT, in general, is deployed for many different applications and in myriad of environments needing different levels of service quality, bandwidth, latency, etc. Therefore, an IoT design engineer may face issues at various layers of an end-to-end system from physical to application layers, from local networks to the cloud, up and downloading using various application services. This course was designed to introduce a wide range of design issues and techniques to prepare students for as many design challenges at different layers as possible in an end-to-end IoT system. In Table 1 below, we list the main topics covered. Since our program is ABET accredited along with each topic we have also included the most applicable ABET "a" through "k" Student Outcomes [12].

Topic Covered (Topic's relevant ABET a-k outcomes)	**Topic Benefits to Students**
High level introduction to physical layer, MAC layer, networking layer, etc. as pertinent to IoT	Bring students from various backgrounds (e.g., electrical, computer engineering,

(ABET: e)	computer science, etc.) basic preliminary knowledge to par
Modulation and multiplexing techniques used in most IoT applications (ABET: a, c, e)	Provides basic knowledge of IoT physical layer issues, techniques and capabilities. Students learn the limits of each technology as they choose them or as imposed on them due to legacy reasons. How to aggregate data flows across multiple virtual channels if one channel is not enough, etc. High level detail of the differences between QAM (single tone), CDMA and OFDM technologies covered providing students with pros and cons of each technology when applied to specific issues
Basic RF planning over wireless channels most pertinent to IoT (ABET: a, c, e)	Teaches students what power levels based on required error rates are required to plan for a successful wireless IoT sensor network deployment
Required capacity estimation (ABET: a, c, e, k)	Teaches students how to estimate what bandwidth (raw bit rate) is required on a channel when multiple sensors' data and their communication technologies (e.g., RTP, UDP, TCP, IP, codec rates, modulation techniques, etc.) are provided
High level graph theory techniques, such as Dijkstra algorithm, minimum spanning tree, min-cut max flow, network topologies, etc. (ABET: a, b, c, e)	Teaches various options available in deploying a network of IoT sensors, find bottlenecks when traffic increases, best paths for broadcasting to sensors, etc. Along with other topics covered this item covered network layer issues as well
Intermediate details on many wireless access techniques appropriate for IoT applications, including: WiFi, IrDA, Bluetooth, Bluetooth Low Energy (BLE), IEEE 802.15.4, ZigBee, Z-Wave, UWB, LoRa, DSRC, DASH-7, SigFox, Narrow-Band IoT (NB-IoT), LTE Class 0 (ABET: a, b, c, e)	Teaches students about various wireless technologies available and their capabilities based on range, bit rate, performance, etc. This lets students find a few technologies best matching their application and down select based on other factors such as price, availability, security, etc. Along with other topics mentioned above this item provides a solid base for students for the physical and link layer issues
Higher layer IoT related protocols, such as CoAP, MQTT, AMQP as well as more comprehensive standards, ETSI and 3Gpp as pertinent to IoT (ABET: a, c, e)	Provided students with the differences between the protocols, especially as data packets are transferred within a local area sensor network, between a local area gateway and the cloud application server or between application servers. This covers the higher

	layer issues as related to the IoT ecosystem below application layer
Cloud applications useful in IoT ecosystems; e.g., Amazon's AWS, Microsoft Azure, IBM Cloud (formerly named IBM Bluemix [13]), Kaa, Google Cloud IoT and Google Android Things (ABET: c, e, k)	Students were familiarized with the top IoT cloud service applications, finding out the types of services they provide, how to get services from them, etc. This section provided valuable application layer services introduction.
Simple group project (ABET: b, c, d, e, g, i, k)	Students in several groups performed simple projects uploading their smartphone accelerometer and/or other sensor data to the cloud (mostly IBM Cloud (formerly Bluemix)) and observe them in real-time. This provided students with hands-on practice to perform a simple end-to-end sensor to cloud task and appreciate the details in between

Table 1: Topics and benefits covered in the first course

The physical and link layer issues took more time than other topics did over the semester. This was expected as students need more time to grasp this topic mostly due to the relatively complex nature of it. Other topics were introduced in high or medium level of detail. Students were encouraged to read more on their own as each topic has many details to go through over the course of one semester. In addition, exposure to find out where and how to get such pertinent information is more important than going over their mundane details (such as details of standard information, etc.) that will be soon forgotten and needed only when the need arises in practice. A question in the final exam assured that students did actually read more detail on their own.

Since the topics in the course were varied and needed special attention due to their depths we made sure that students stay current with the topics as the course was progressing by giving quizzes every two to three weeks. This way we made sure students learned each subject in time and did not procrastinate to midterm and final times. The quizzes accounted for 20% of the final grade. There also was one midterm and one final for 35% weight toward the final grade as well. The remaining 10% of the weight toward the final grade was dedicated to a project. The students formed groups of one to three students to do their respective projects depending on the complexity of the project they chose. To get the highest grades in the project, we encouraged students to do projects involved with data collection from sensor(s), communicated wirelessly to the cloud and pulled from the cloud. In this manner, students experienced an end-to-end IoT ecosystem endeavor.

Some of the projects the students performed are as follows:

- The mobile-phone accelerometer data was uploaded to IBM Blue Mix and downloaded and presented in real-time
- TI tags' data was stored in the cloud (IBM IoT Watson)
- Used Arduino Uno to store data from a MyoWare ™ muscle sensor and a DHTII temperature sensor in IBM Quickstart

- Used Metro Mini and Arduino to store temperature sensor in the cloud
- Used Amazon's AWS as a platform and send email alarms to the user when certain cost, data usage, or other threshold exceeded
- A platform developed where the home's thermometer data was stored in the cloud and analyses and actions were performed to adjust the thermostat
- Stored the smart-phone's gyroscope, WiFi signal strength and luminosity in IBM Blue Mix

The class had 21 students and at the end of the semester an anonymous feedback questionnaire about the course was given to students to find out about the efficacy of the course to help improve it further if need be. Eight of the questions were designed to have five answers from strongly disagree with a weight of zero to strongly agree with a weight of four. These questions are listed below:

1 – The course taught me new topics valuable for my current/future career
2 – The course matched my expectations by exposing me to a burgeoning field
3 – The contents of the course were wide and covered most aspects of the IoT ecosystem
4 – I believe I am a better engineer as a result of taking this course
5 – I will recommend this course to my colleagues/classmates
6 – I will recommend and/or possibly take a follow on dedicated hands-on IoT course
7 – The topics covered were wide and deep enough at this level
8 – Overall, I liked this course

Six write-in questions were also included so students could explain what topics they would like to see in more or less detail and provide other suggestions.

The results of the questionnaire were very positive and indicated that the course matched its intended goals. Figure 1below shows the results

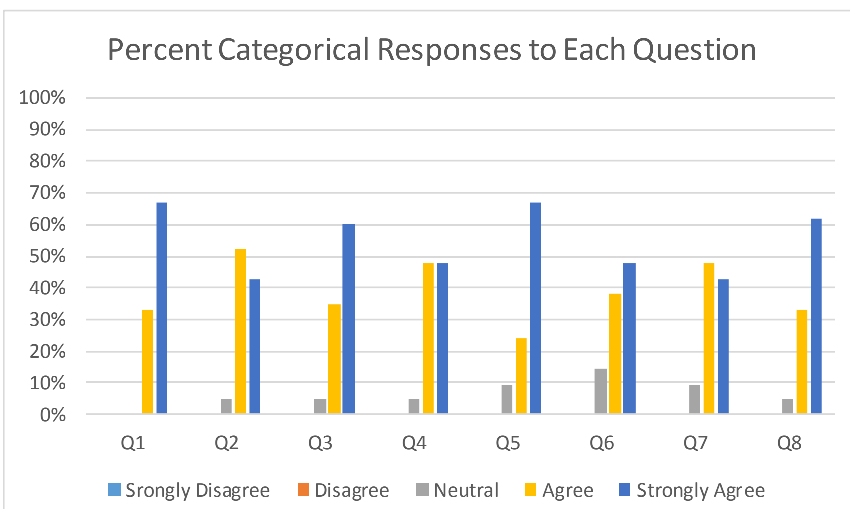

Figure 1: Percentage of categories (Strongly Disagree to Strongly Agree) of responses to the eight questions

Figure 2 below shows the weighted response to each question, that is for each question each answer is multiplied by its weight (0 for strongly disagree to 4 for strongly agree) and then averaged. In addition Figure 2 also shows the 95% confidence interval based on the number of students (21) responding if these results were to represent a larger body of students.

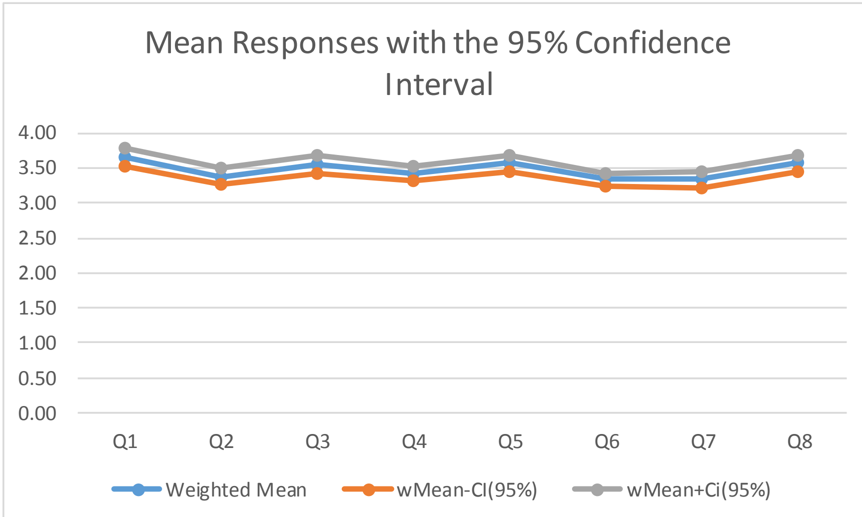

Figure 2: Weighted mean response to each question along with 95% confidence interval

Note in Figure 2 that the lowest weighted average for any of the questions is 3.333, which means between Agree and Strongly Agree responses. This attests to the success of the pilot course. It is noteworthy to mention that the grand weighted-average of all questions was 3.654 (out of 4) or over 91%, further corroborating the success of the course.

The Second Course

In preparation for the second course of the series, we chose the IoT tutorial platform from [our industry partner] and improved it to better assist students with in-depth practical experiments.

It is important to note that the second course has not been offered yet. This course will be piloted in Fall of 2018. As a result, detailed student feedback is not available currently. However, we formed a small group of students to enhance the [industry partner] set of detailed IoT experiments for presentation in the second course, which is exclusively experiential in nature.

In this section, we will present the experiences of the experiential pilot program and the key points that present the enhancements of technical manual for a teaching environment. We will present the value that the IoT board and its experiments bring to the students in the IoT ecosystem.

Evaluation of the IoT Tools - Experimenting with the Keysight Technologies platform:

Last summer a small group of graduate students, with the guidance of a senior faculty member, used the IoT board to assess its efficacy for less experienced engineering students. The main theme of the activity was to use IoT tools to see how to monitor the moisture level in the soil in a garden. There were five steps to reach the final goal as follows:

Activity 1:
The first lab activity helps in getting used to the board by introducing users to various scripting procedures that can be used to program and simulate different scenarios. Various languages we introduced in this initial task were Shell Scripts, C/C++, Java, Python, etc. The next step was interfacing the board to a Sensor Tag (CC2650 in this case) and subsequently collecting data through sensors. Our example uses an analog temperature sensor that collects data, for interpretation in various subsequent use cases.

Activity 2:
This activity walks the user through understanding Bluetooth Low Energy (BLE) and ZigBee protocols, as well as how to connect sensor nodes with gateway devices. The follow on tasks include such activities as connecting sensor tag with Intel Edison, automating data collection utilizing python scripts, in turn using C/C++ programs to call the python script and connecting the ZigBee kit with gateway.

Activity 3:
This activity walks the user through a major step in an IoT environment, which is storing the collected data in the cloud/storage media. All the technologies that we implemented in the form of sensors and communication techniques were used to gather data, which were interpreted for various purposes later.

The steps that assists a user in understanding these concepts are: (a) getting used to HTML/JavaScript to consume third party services, (b) using Google's App Script for creating a cloud and (c) using AMP stack to expose our data collection. Once we collected this data we performed operations such as linear regression, anomaly detection etc., as data interpretation examples.

Activity 4:
This activity explains the benefits of the MQTT protocol used for communication between end devices and the components of our development kit. MQTT is a Client Server publish/subscribe messaging transport protocol. It is lightweight, open, simple, and designed to be easy to implement. These characteristics make it ideal for use in many situations, including constrained environments such as communication in IoT contexts where a small code footprint is required and/or network bandwidth is often constrained.

We deployed our own MQTT broker in the cloud. Once we deployed the protocol in the cloud, we proceeded to subscribe to its services by subscribing to "topics". A topic is a UTF-8 string, used by the broker to filter messages for each connected client. A topic consists of one or more topic levels. Each topic level is separated by a forward slash (topic level separator).

In our application, we used Python scripting to subscribe to the MQTT broker by developing an MQTT client to subscribe to a topic. The same code, deployed on the board, can enable communications with the gateway via MQTT.

Activity 5:
This activity combined our learnings from all previous activities to develop a comprehensive application to monitor the soil moisture level in a garden. We interfaced the sensor tags to the development kit using the locally developed cloud application and utilizing the MQTT protocol developed in activity 4. Using all the experience gathered, we tested the temperature, humidity and moisture levels in the soil. This final task resulted in the successful creation of a multi-faceted experiment that shows the various tasks involved in an end-to-end IoT system deployment to students in an orderly fashion. This involved breaking various disparate technology implementations into separate activities and then integrating the results of the activities in the final task to exhibit the end-to-end IoT data collection, communication and interpretation.

Keysight Technologies IoT Experiments Board

The lab exercises based on the Keysight board comprise four modules. The first two modules are covered in this paper. However, two final modules (modules 3 and 4) are being finalized to cover yet more relevant topics in the IoT field. The third module addresses various IoT applicable wireless technologies while the fourth module addresses sensor and power management issues. The latter is an important IoT topic, as many IoT sensor modules need to have multi-year battery life capability. As a result, techniques to characterize, evaluate and optimize current draw are an important part of a well-designed IoT system.

Table 2 below presents a summary of the lab exercises covered by the four modules mentioned above. Again, note that a select set of the experiments in modules 1 and 2, as described earlier by activities, will be delivered in the Fall 2018 semester. Experiments in modules 3 and 4, when finalized, will be integrated in the following semesters. At the time when the final two modules are ready, the faculty and industry partner team will reconvene to choose the experiments from among all four modules to fit in a semester and bring the most valuable experiences to the students. Subsequently, the results and experiences of the second course will be presented.

In Table 2, each module covers an important topic a student needs to cover. Within each module there are several lab experiments (labeled Lab#, where # stands for the lab experiment number) to be covered so students get a good understanding of each topic. Module 1intriduces the students to use the platform to connect to the cloud and download information from the cloud using various techniques mostly used in IoT world, such as MQTT, etc. Module 2 introduces students to connect the platform to various sensors via wireless air interfaces, and together with the experience from Module 1, cover the end-to-end data collection and uploading/downloading using various current techniques.

Modules 3 and 4 are in the final phases of development. Module 3 will cover various wireless technologies in more detail so students will understand the benefits and shortcomings of each technology as applied to various scenarios in detail. Module 4 will cover the very important power management measurement and techniques, as this is a very important subject for an economically successful IoT deployment.

Mod 1: IoT Fundamentals (Covered in this paper)	**Mod 2: IoT Systems Design** (Covered in this paper)	**Mod 3: IoT Wireless Communications** (In development)	**Mod 4: Sensors & Power Management** (In development)
• Lab1: IoT System Overview • Lab2: Exploring LAN/PAN Connectivity Protocols and Understanding the Purpose of an IoT Gateway • Lab3: Exploring the Web-based Cloud Services for IoT • Lab4: Exploring MQTT Messaging Protocol for IoT • Lab5: Exploring Data Visualization and Analytics • Lab6: Cloud-enabled IoT Application	• Lab1: Introduction to the IoT Development Kit • Lab2: Introduction to the Peripherals of the IoT Development Kit • Lab3: Interfacing to IoT Devices • Lab4: Digital Communication Protocols for IoT • Lab5: Wireless Sensor Networks for IoT • Lab6: Exploring Cloud Messaging Protocol • Lab7: Cloud-enabled IoT Operation	• Lab 1: Setting Up IoT Sensor Network with Multiple Wireless Technologies • Lab 2: Analyzing Bluetooth Low Energy Protocol for Low Power IoT Devices • Lab 3: Building Your ZigBee Mesh Network for Better Data Routing and Extended Range • Lab 4: Evaluating the IoT Data Link Protocols for Short Range Wireless Communications with Low Power Consumption • Lab 5: Evaluating and Improving Wireless Local Area Network (WLAN or WiFi) Signal Performance • Lab 6: Analyzing the Range and Coexistence of Low Power Long Range Communications (LoRa) • Lab 7: Validating the WiFi Devices Design and High Density	• Lab 1: Setting Up IoT Gateway and Connecting Sensor Network to the Cloud • Lab 2: Characterizing IoT Sensor Board (Device) Static and Dynamic Power Consumption • Lab 3: Evaluating the Impact of Dynamic Current Drain and Solar Energy Harvesting on IoT Battery Life • Lab 4: Optimizing Power Consumption and Efficiency Using Dynamic Power Management in Sensor Networks • Lab 5: Characterizing MEMS Accelerometer and Gyroscope Sensors and their Applications

		WiFi Networks for Optimum Coverage • Lab 8: Validating and Comparing the Bluetooth Low Energy and ZigBee Communications for Low Power Applications	• Lab 6: Characterizing MEMS Pressure and Temperature Sensors for Applications in Harsh Environment

Table 2: Lab exercises provided by [the industry partner]

Conclusion

In this paper, we present a two-course pilot program to introduce interested students to the IoT ecosystem. The first course covered all relevant technology concepts needed to design an end-to-end IoT ecosystem including various wireless access technologies, RF planning, networking concepts, cloud services, etc. The second course complements the first one by providing an experiential hands-on approach, utilizing our industry partner, Keysight Technologies' IoT board to implement an end-to-end data collection, uploading and interpretation. This was achieved by data collection, dissemination and interpretation in five separate activities, each concentrating on a fundamentally different task in a practical end-to-end IoT system.

The first course, already delivered to a class of twenty-one students, was very successful according to the results of an anonymous questionnaire filled out by students. The results of various questions are included in the paper. In short, the grand average of the results were 91% validating the value provided to the students. The second course will be offered in Fall 2018.

References

[1] J. Manyika, M. Chui, P. Bisson, J. Woetzel, R. Dobbs, J. Bughin, D. Aharon, "The Internet of Things: Mapping the Value Beyond the Hype", Executive Summary, McKinsey and Company, June 2015

[2] Keysight Technologies Data Sheet, "U3801A/02A IoT Fundamentals Applied Courseware,"; at https://literature.cdn.keysight.com/litweb/pdf/5992-2086EN.pdf?id=2829739

[3] B. Karimi, S. Mateti, L. Sharath, S. A. Sridharan, C. P. Teja, "An Independent Study on Advanced Embedded Systems & IoT", Internal Report, Taglieta College of Engineering, University of New Haven, Aug. 2017

[4] X. Zhong, Y. Liang, "Raspberry Pi: An Effective Vehicle in Teaching the Internet of Things in Computer Science and Engineering", Electronics 2016, 5, 56; doi:10.3390/electronics5030056; at http://www.mdpi.com/journal/electronics

[5] Gu-Min Jeong, et al, "Course design for Internet of Things using Lab of Things of Microsoft Research", INSPEC Accession Number: 16505169, Proceedings of IEEE Frontiers in Education Conference, 12 – 15 Oct. 2016, Erie, PA, USA

[6] Jai W. Kang, Qi Yu, Erik Golen, “Teaching IoT (Internet of Things) Analytics”, SIGITE ’17, Proceedings of the 18th Annual Conference on Information Technology Education, pages 135 – 140, Rochester, New York, USA — October 04 - 07, 2017

[7] Anna Forster, et al, “Teaching the Internet of Things”, GetMobile: Mobile Computing and Communications, Volume 20 Issue 3, July 2016

[8] L.A. Grieco, A. Rizzo, S. Colucci, S. Sicari, G. Piro, D. Di Paola, G. Boggia, "IoT-Aided Robotics Applications: Technological Implications Target Domains and Open Issues", *Computer Communications*, vol. 54, pp. 32-47, 2014

[9] S.M. Riazul Islam, D. Kwak, M. Humaun Kabir, M. Hossain, K.S. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey", *Access IEEE*, vol. 3, pp. 678-708, 2015

[10] D. X. Li, W. He, S. Li, "Internet of Things in Industries: A Survey", Industrial Informatics IEEE Transactions on, pp. 2233-2243, 2014

[11] S. Dhananjay, G. Tripathi, A. J. Jara, "A Survey of Internet-of-Things: Future Vision Architecture Challenges and Services", *Internet of Things (WF-IoT) 2014 IEEE World Forum on*, 2014

[12] http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf; Engineering Accreditation Commission, ABET, “Criteria for Accrediting Engineering Programs”, page 3, Nov. 1, 2014

[13] https://www.ibm.com/blogs/bluemix/2017/10/bluemix-is-now-ibm-cloud/; IBM Cloud Blog, Oct 31, 2017