Internet of Things (IoT)-based Learning Framework to Facilitate STEM Undergraduate Education

Jing (Selena) He[1], Shouling Ji[2], and Patrick Otoo Bobbie[1]
[1]Department of Computer Science, Kennesaw State University, Marietta, Georgia, 30060, USA
[2]College of Computer Science and Technology, Zhejiang University, Hangzhou, Zhejiang, 310058, China
Email: jhe4@kennesaw.edu, sji@zju.edu.cn, pbobbie@kennesaw.edu.

ABSTRACT

Internet of Things (IoT) is rapidly emerging as the next generation of communication infrastructure, where myriad of multi-scale sensors and devices are seamlessly blended for ubiquitous computing and communication. The rapid growth of IoT applications has increased the demand for experienced professionals in the area. Since few, if any, dedicated IoT courses are currently offered, most Science, Technology, Engineering, and Mathematics (STEM) students will have limited or no exposure to IoT development until after graduation, and inadequately prepared in IoT development to enter into the workforce. Therefore, we have implemented an IoT-based learning framework to facilitate STEM undergraduate education. The design challenges of the novel learning framework are discussed in the paper. Subsequently, we established effective learning approaches to address the challenges. Specifically, we have introduced a lab development kit composed of Raspberry™ Pi/Arduino™ boards and sets of sensors with Zigbee™ supporting to provide wireless communication.

CCS CONCEPTS

• **Computer systems organization** → **Embedded systems**; *Redundancy*; • **Networks** → Network reliability

KEYWORDS

Internet-of-Things (IoT), lab-based learning framework, Arduino board, Raspberry Pi, lab development kit, STEM undergraduate education

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1 INTRODUCTION

Internet-of-Things (IoT) has emerged as a new network paradigm, which allows physical entities (such as chairs, lamps, and briefcases) and/or physical phenomenon (such as temperature, heart rate, and moving action) to communicate with each other. Eventually, the collected data and fused information are connected to the Internet to provide opportunities to build smart/intelligent systems and applications. Additionally, many modern technologies and devices such as Radio-Frequency Identification (RFID), Near Field Communication (NFC) (*e.g.*, Zigbee and Bluetooth), Wireless Sensor Network (WSN), cloud computing, social networks, universal mobile accessibility advanced technologies (*e.g.*, Wi-Fi hotspots, and cellular network), and big data analytics support IoT for establishing the next generation network infrastructure [1].

The ubiquity of IoT has expanded greatly in the last two years, and a June 2015 McKinsey Global Institute report estimates a 3.9 − 11.1 trillion-dollar economic impact across just nine sectors of industry by 2025 [2]. These industries correlate closely with current rapidly growing sectors for software developers in such areas as health care, manufacturing, retail, and urban planning. The McKinsey report also notes that IoT development will lead to “a rising demand for vertical expertise to help companies in specific industries that incorporate IoT technology”. Higher demand in these areas infers an increased need for qualified software developers, but current STEM undergraduate curricula offer little exposure to IoT concepts and practices.

IoT has not yet become part of Computer Science (CS) or Engineering curricula, and certainly not in the broader STEM fields. Due to the lack of STEM curricula in IoT and because there is little room for adding additional courses into existing STEM curricula, we propose to transform STEM curricula by integrating IoT-based learning framework into the various courses with lab projects - using a new learning framework as a campus-wide shared resource. The goal is that students can understand IoT fundamentals and gain hands-on programming experience in a variety of technology-driven courses.

This paper presents our initial effort on dealing with the challenges about the learning approach and method of designing and building the IoT-based learning framework. In this paper, we also describe the experience gained in integrating a well-designed pilot project into a distributed computing course. A majority of students provided positive feedback and enjoyed the IoT-based learning framework.

The rest of this paper is organized as follows: In Section II, we discuss the challenges of designing the learning framework and the approaches for integrating IoT-based projects into the framework to foster IoT-based education. In Section III, we introduce the technologies involved in implementing the IoT-based learning framework. Finally, the paper is concluded in Section IV.

2 IOT-BASED LEARNING RAMEWORK

In this section, we first summarize the challenges of designing the IoT-based learning framework and then propose effective learning approaches to overcome the challenges.

2.1 Design Challenges

A new paradigm of learning in Science, Technology, Engineering, and Mathematics (STEM) is *learning by doing*. Responding to President Obama's call for a nationwide Computer Science for All Initiative [3], we propose to establish a laboratory-based learning framework to educate the next generation of students who are equipped with technological skills. The long-term goal of this project is to provide a campus-wide technology infrastructure or framework that supports teaching STEM-related course, and transform the way we teach these course using emerging computing technologies to 21st Century undergraduates. The framework is an environment for teaching computing concepts and theories using hands-on, problem solving, and pedagogy which prepare and enhance student learning experience. Some of the challenges in establishing such a framework include:

1) How to accommodate emerging computing technologies into this framework?

The purpose of this framework is to prepare students for the 21st Century industry. Hence, seamlessly integrating emerging computing technologies into this framework is important. However, ensuring that these technologies are sufficiently enabling and support different STEM course curricula could be daunting.

2) How to develop supplementary teaching materials in various applied STEM fields in a complementary manner to foster interdisciplinary group project implementation?

It is known that there is little room in all disciplinary areas for adding additional courses into existing curriculum. Hence, the challenge is to supplement teaching materials without adding new courses in another challenge.

3) How to improving students' hand-on experience and increase the opportunities to collaborate among STEM related fields?

One goal of this study was to prepare our undergraduates with technological skill, and their readiness for the workforce. Moreover, industries often have goals and requirements that may differ or different but are closely related to be interwoven with each other. Hence, the challenge is designing a good framework that accommodates the different but complementary requirements to prepare students for these challenges.

4) How to promote undergraduate students in research through applying this framework?

Kennesaw State University (KSU) became a Carnegie *Comprehensive University* in August 2013 [4] and was classified as an "R3" institution — a doctoral research institution with moderate research activity, in February, 2016 [5]. Consequently, undergraduate research is an important component in educating next generation students.

5) How to cultivate student interest in learning and keep student retention in STEM related field?

Several students often choose STEM related fields in early on when they enter college, but finally switch to non-STEM programs before graduation [7]. How to improve student self-efficacy and retention is a critical challenge that needs to be addressed through practical, a non-threatening environment.

6) How to broaden participation in STEM related fields?

Ethnic and gender inequities and under-representation in STEM related fields, and, more so in computing field, in the national workforce is profound [6], [7]. Addressing this inequity problem is challenging, but a fun-filled, hands-on approach could broaden participation for all groups of students, when given the opportunity [7].

2.2 Proposed Framework and Learning Approaches

To address these challenges, we propose to set up an instrumentation laboratory to support the new learning framework. The features of this novel learning framework are summarized as follows:

1) Integrating Internet-of-Things (IoT) to establish the learning framework:

The IoT-based learning framework is a collection of communicative, integrated computing devices, which have been assembled into an infrastructure for experimenting and mapping abstract concepts and theories taught in classrooms, or while teaching, into practical, hands-on experiential knowledge.

The Internet, as a massive telecommunication infrastructure, currently supports a plethora of computing and sensory devices capable of signaling or communicating with each other. When properly programmed, these devices can be used to test and validate theories and abstract concepts. The logical behaviors and data which such devices communicate with, or share, could be used to validate correctness of the underlying course concepts, models, or theories. Because of this capability, we've adopted IoT technology to accommodate as the learning framework. In sum, the integration of latest hardware and software allows students to learn this emerging technology, and to be well-trained to meet the current and future workforce and industrial needs.

2) Integrate the learning framework into different STEM- related courses by adopting a modular-based design approach:

Each course module will have multiple learning levels. The modular design gives instructors the flexibility to adopt the full course or to integrate selected modules, *e.g.*, course related projects based on their specific needs. Each module will include lecture notes, tutorials, review questions, hands-on laboratory practices, and assignments. All learning materials will be available online.

3) Developing a series of interdisciplinary hands-on projects associated with each module:

The importance of Experience-based/Hands-on learning has been surveyed and discussed in the learning theory literature [8]. By design, each module has hands-on materials specifically for the module learning objectives. Since the targets of this learning framework are STEM-related courses, interdisciplinary projects should be designed by working with STEM-faculty across campus. In addition, to make the learning more effective, all hands-on practices are implemented in an IoT-based lab development kit, which is composed of low-powered electronic devices: Raspberry Pi/Arduino boards, integrated with a set of sensor nodes and Zigbee to provide wireless communication capability. The low cost and high portable properties make the lab development kit possible to offer lab intensive courses in resource limited institutions even where there is a limited faculty expertise, limited budget, or limited lab maintenance support personnel. Moreover, the lab development kit provides Graphical User Interface (GUI)-based Integrated Development Environment (IDE) and online tutorials/forums, which shorten student learning curve and facilitate project development, debugging and testing.

4) The framework is scalable and capability of problem-solving activities in STEM research:

Through the well-designed problem-solving activities in each course module, students can become familiar with the process of conducting research, which includes developing a research project; conducting a literature review; investigating appropriate methods and tools to implement the research project; making oral presentation of the application of the research project; and writing reports or manuscript that document the techniques used in and findings about their research.

5) Course modules are augmented with project-oriented technology-driven contents from STEM related fields:

Each module is designed with a series of programming projects associated with the specific technology applicable to the discipline. This learning-by-doing pedagogy will promote students' life-time learning skills. It will allow students not only to practice in pre-designed hands-on labs, but also have opportunities to design and invent their own applications.

6) The framework adopts team-based approach. Various modules are augmented with real life applications from STEM related fields:

Studies have found that students in computing sciences (CS) typically prefer to learn new concepts when they are augmented with real-life applications. Varma [9] also found that students desire relevance from their studies. Moreover, students, especially women, look for creativity in their studies [10] of which CS is not perceived to have much [11]. Other factors dissuading more women from studying CS consist of the negative image of CS. Females want to work with people, are opposed to sitting behind a computer all day, and think they dislike programming despite never trying it [6].

Hence, a team-based approach, which let students work together, could be effective. Moreover, real-world projects provide students with the opportunity to apply the knowledge and skills acquired in their courses to a specific practical problem; extend their academic experience into working with new ideas and learning new advanced technologies; demonstrate their proficiency in written and oral communication skills; extend and refine their knowledge and skill in the realization of their personal and professional goals.

3 IOT-BASED LEARNING FRAMEWORK OVERVIEW

In this section, the technologies used to develop the new learning framework are summarized first. Subsequently, we describe the proposed framework architecture.

3.1 IoT Technologies Overview

3.1.1 Internet of Things

Internet of Things (IoT) has emerged as a new network paradigm, which allows various physical entities in the world to connect with each other. The observed or generated in- formation of these entities have a great potential to provide useful knowledge across different service domains, such as building management, energy-saving systems, surveillance services, smart homes, and smart cities. [1]. One foundational technology of IoT is the Radio-Frequency IDentification (RFID) technology, which allows microchips to transmit the identification number of objects to a reader through wireless communication. Through RFID technology, physical objects can be identified, tracked, and monitored automatically. Nowadays, RFID technology has been widely adopted in logistics, pharmaceutical production, retailing, and supply chain management [12], [13]. Another foundational technology of IoT is Wireless Sensor Networks (WSNs), which adopt interconnected intelligent sensors to periodically sense the monitored environment and send the information to the sink (or base station), at which the gathered/collected information can be further processed for end-user queries [14]. The applications of WSNs include disaster control, environment and habitat monitoring, battlefield surveillance, traffic control, and health care applications [15]. Additionally, many other technologies and devices such as Near Field Communication (NFC) [16], short-range wireless communication (*i.e.*, ZigBee [17] and Bluetooth [18]), universal mobile accessibility (*i.e.*, Wi-Fi hotspots [19], cellular networks [20]), social networking [21] and cloud computing [22] support Internet of Things paradigm for defining network infrastructure.

3.1.2 Raspberry Pi/Arduino Boards

Arduino is an incredibly flexible open micro-controller and development environment which is easy to use. Arduino was first launched in 2005, which is based on a board with a single micro-controller, and input/output pins for communications and control of physical objects and the environment. The functionality to connect and control physical objects directly relates to Internet of Things. Hence Arduino gained popularity in a short time because of the simplicity to use and low costs in configuring a basic model. Different boards with various capabilities have been developed since 2005, such as the UNO™, Mega™, Leonardo™, Minim Due™, and Yun™ [23].

Raspberry Pi is a series of credit-card-sized single board computers developed in the United Kingdom by the Raspberry Pi Foundation with the intent to promote the teaching of basic computer science in schools and developing countries. All models feature a Broadcom system on a chip (SOC), which includes an ARM compatible CPU and an on-chip graphics processing unit GPU [24].

Raspberry Pi/Arduino boards have been chosen to implement the lab development kit, because they are low-powered, low cost electronic devices and provides GUI-based IDE, and a large set of online tutorials/forums. In addition, Raspberry Pi/Arduino boards offer enough capacity and functionalities with its availability of myriad of third party components.

3.1.3 Web 2.0

Web 2.0 is a term used to describe the second generation of World Wide Web (WWW), which emphasizes the ability for people to collaborate and share information online [25]. Web 2.0 services include video hosting services, wikis, blogs, social networking, and resource sharing environments (such as Flickr).

Every system uses resources; in this case, these resources can be pictures, video files, Web pages, business information, or anything that can be represented as content data in a computer-based system.

A resource can consist of other resources. While designing a system, the first thing to do is identify the resources and determine how they are related to each other. Once we have identified the necessary resources of a domain, the next thing step is to find a way to represent these resources in our system. In Web 2.0, there are two formats to represent the resources, eXtensible Markup Language (XML) and JavaScript Object Notation (JSON). XML is a meta-language that can be used to define our communication language, while JSON is a lightweight alternative to XML format. JSON is a collection of key/value pairs, which belong to a subset of the object literal notation of JavaScript. Since these key/value pair structures can be adopted in any programming language, JSON is independent of the programming language used when exchanging data.

3.1.4 Google Cloud Web Services

Private cloud web service is needed to handle back-end requests from Raspberry Pi/Arduino boards and mobile application. Google App Engine has become a suitable component used to implement framework backend, which accept POST requests from the Raspberry Pi/Arduino boards and store the data in the cloud. The web service also provide GET requests, which return the sensing data in JSON format for display of retrieved data in the mobile application. In addition, for energy efficient design, we adopt *master-slave* communication architecture, in which the slave nodes only responsible for collecting data and send data to master nodes, while mater nodes take the responsibilities of calculation and storing data to the cloud server. The architecture and the flow of data of the cloud web service is illustrated in Fig. 1.

3.1.5 REST and RESTFul APIs

REpresentational State Transfer (REST) is an architectural style that specifies constraints, such as the uniform interface, for networked hyper-media applications. It is primarily used to build Web services that are lightweight, maintainable, and scalable. When Web services use REST architecture, they are called RESTful APIs (Application Programming Interfaces). REST is not dependent on any protocol, but almost every RESTful service uses Hypertext Transfer Protocol (HTTP) as its underlying protocol. In sum, RESTful systems typically, but not always, communicate over HTTP with the same HTTP verbs (GET, POST, PUT, DELETE, etc.) used by web browsers to retrieve web pages and send data to remote servers. The purpose of a service is to provide a window to its clients so that they can access these resources. REST does not put a restriction on the format for representing the content of a resource. Moreover, RESTFul API does not require the client to know anything about the structure of the API. Rather, the server needs to provide whatever information the client needs to interact with the service. For example, the server specifies the location of the resource, and the required fields. The browser doesn't need to know in advance where to submit the information, and it doesn't know in advance what information to submit. Both forms of information are entirely supplied by the server. Hence, RESTFul APIs is now popular in implementing web services and mobile Apps.

3.1.6 Other Technologies

Some other technologies, such as location-based services, big data analysis and visualization, social networking, robotics management are important components to implement the learning framework. Moreover, different STEM fields may have different technologies need to be integrated into the learning framework implementation.

3.2 Framework Architecture

To illustrate, we discuss a practical example based on an IoT-based laboratory development kit for designing an activity. In this scenario, the students participate in hands-on assignments in order to gain experiential knowledge, maintain their interest levels, and prepare for the STEM-workforce. As shown in Fig. 2, an RFID reader automatically reads each device's identification and passes the ID data to the Arduino ATmega32u4 microcontroller.

The integrated sensors continuously collect physical data. The students write a program to periodically cause the data to be sent to a Cloud server using, for example, an open- source ThingSpeak data platform. The program then passes the sensory data along with the timestamp to the Atheros R9331 microcontroller through a bridge (API) library [26]. Finally, the bridge library issues an HTTP POST request to the ThingSpeak API [27] along with the device-ID. ThingSpeak uses a concept of "channels", where each channel can be configured with different labels to hold different kinds of data.

In Fig. 2 two channels are shown. The USER channel holds user information while the SCAN channel holds sensing data. For advanced IoT applications, an Android application can be developed to allow administrators, or other interested users, to monitor the collected data and view the results on a mobile device. The overview of the Android architecture is also illustrated in Fig. 2. Fig. 3

depicts a typical Arduino Yun lab development kit with RFID sensor and pressure sensor. These devices are inexpensive, yet they can offer incredible platforms for developing STEM-related projects as students are prepared for the workforce.

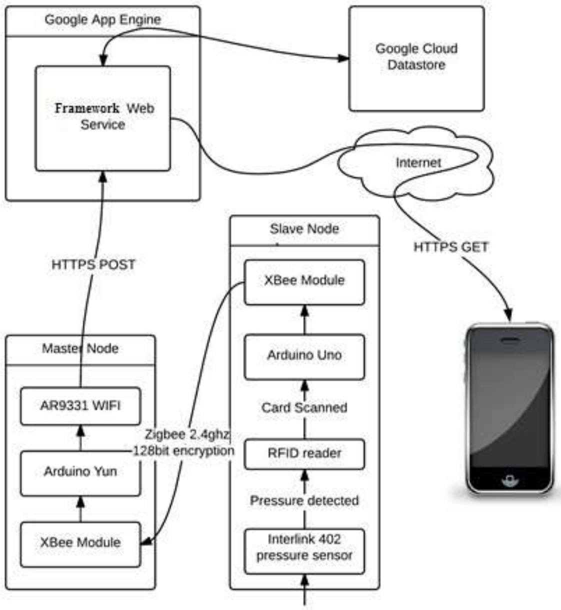

Fig.1: Google Cloud Web Service Architecture.

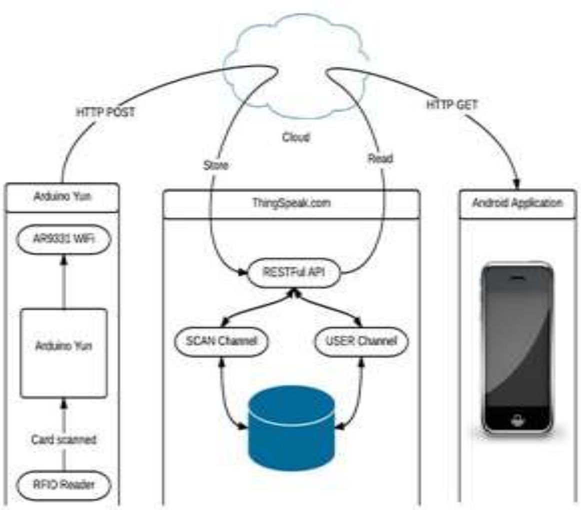

Fig. 2. IoT-based Learning Framework Architecture.

4 CONCLUSION

In this paper, we describe a learning framework, which integrates Internet-of-Things and hardware/software technologies, to create a new paradigm of learning. We believe that students learn better and knowledge is retained better using a hands-on and team-oriented learning approach. The authors are developing suites of inter-disciplinary projects, which are purposefully designed to solve problems that are drawn from concepts in STEM areas.

Incorporating IoT into existing STEM curriculum offers the opportunity to position undergraduates competitively with respect to: the ever-growing demands for this skill-set in the technology-focused marketplace; the need to augment existing coursework with projects to keep pace with emerging trends in industry; and the need to increase student interest and success in targeted courses that also broaden participation.

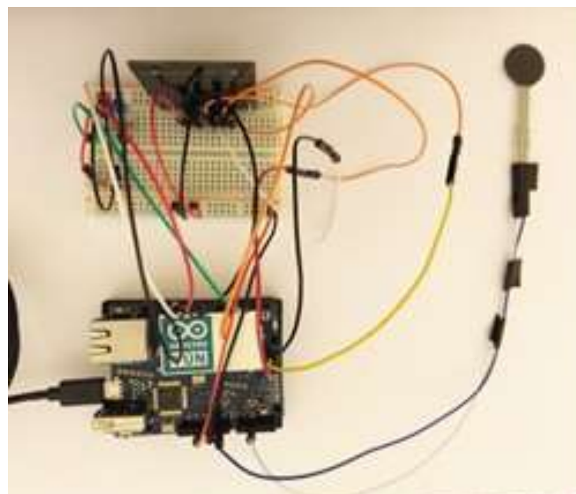

Fig. 3. Arduino Yun Lab Development Kit.

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