Expanding Remote Student Learning-Internet of Things Applications and Exercises

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***Abstract*—The availability of inexpensive sensor, communication, and computing devices continue to drive a rapid proliferation of Internet of Things (IoT) applications. This has resulted in an increase in the importance of the inclusion of IoT related content in education programs. A project underway at Texas A&M University-Kingsville seeks to support teaching IoT concepts to remote learners through the design and deployment of IoT learning toolkits. A series of exercises have been developed to assist remote learners in becoming familiar with the toolkits and to introduce basic IoT concepts. The learning kits are to be deployed in two senior level capstone project courses to teach IoT related concepts and encourage students to consider how IoT technology might be beneficial for and integrated into their project designs.**

Keywords—Remote student learning, Internet of Things.

I. Introduction

Advances in sensor, computing, and communication technologies have continued to fuel the rapid proliferation of Internet of Things (IoT) applications [1, 10, 23]. As these applications have been deployed across an ever expanding variety of sectors, the importance of teaching IoT concepts and technologies has been recognized by educators, professional societies, and industry experts [16]. Various approaches have been suggested on how to best integrate and cover IoT related content in existing curricular material [2, 11, 18, 19, 28, 31]. The inclusion of hands-on project work has been suggested as an important way to increase student interest and engagement with the material [3, 22]. Many education researchers have proposed the development of an IoT toolkit as a means to conveniently proivde students with the materials needed to conduct projects involving IoT components and devices [12, 13, 17, 22, 24, 26, 29, 32, 33].

The IoT toolkits that have been proposed and developed vary along different dimensions. Some kits have been designed for use by younger students such as those attending K-12 schools while others are targeted at university level students [32]. Even among IoT toolkits intended for use by university students variations are found in the expected student background and level of technical knowledge. Some expect students to already be familiar with basic components and how to connect them while others intentionally shield underlying complexities to enable their use by less experienced students, e.g., non STEM students working within a university Maker Space facility [9]. The intended programming language and programming environment also differs among IoT kits. Some kits are limited to the use of a specific specialized language, such as block structured languages while others allow students to code in Python, C, or another general purpose language [9, 24].

An NSF sponsored project has been underway at Texas A&M University-Kingsville (TAMUK), a Hispanic Serving Institution, to support remote student learning of important IoT concepts and technologies. The project began during the COVID 19 pandemic, motivated by the needs of students taking laboratory courses to gain access to lab equipment in order to complete experiments and exercises. Another important motivation has been to accommodate students, especially non-traditional students, that due to work and/or family commitments prefer learning remotely at a time and place that matches their schedule [15, 27].

A basic IoT learning toolkit has been designed that includes sufficient components for students to learn about and gain hands-on experience with basic IoT concepts. Influenced by the type of target student described above, the kit is designed to be utilized by university level students familiar with basic components and how to connect them and can support projects in which a general-purpose programming language is used, especially Python or C. Remotely learning students are each allowed to check out a learning toolkit for the duration of the semester that they can utilize in their own workspace to complete exercises and assignments. The central component of the toolkit is a basic processor board (Raspberry Pi). The kit also includes primitive sensors to support the acquisition of input for an IoT application as well as devices that can be controlled to demonstrate potential outputs of an IoT application. A series of exercises have been developed to accompany the learning toolkit and introduce students to basic IoT concepts. Though sufficient for introducing students to basic IoT concepts, the current IoT learning kit is not able to support teaching more advanced aspects of IoT technology.

The next phase of the project is focused on accommodating the needs of students learning remotely that are working on more advanced IoT related topics. A more extensive IoT platform will be provided to students that is capable of supporting a wider variety of more sophisticated applications. Similar to the basic IoT kit the more extensive one is intended to be utilized by university level students familiar with basic components and how to connect them and that are utilizing Python or C for their projects. A new set of exercises will be developed to teach students how to utilize a wider array of sensors and communication capabilities in completing their exercises and assignments and the opportunities for exploiting these technologies in their class projects, especially capstone design projects.

This paper reports on the most recent activities of the project. The basic IoT learning kit is described first along with a look at some of the exercises that have been developed to introduce IoT concepts and technologies to students learning remotely. A description of the more extensive IoT learning platform is provided next along with information on the exercises being developed to teach more advanced IoT concepts to remotely learning students. A deployment strategy for utilizing the IoT learning platforms to support remote learners is described next. The following section provides a brief description of an assessment process that will be utilized for the project and is followed by a conclusion.

II. A Basic IoT Learning Toolkit

The central component of the basic IoT learning toolkit is a simple processor board. While a variety of boards are available to use for this purpose the current project utilizes the Raspberry Pi board. Along with the processor board the kits contain sensors for gathering inputs and various components to represent potential outputs of an IoT application. The specific sensors and output devices included in the kit can be adjusted as necessary to support the teaching of specific IoT concepts. To support the initial exercises that have been developed for this project the kits include a simple digital IR sensor, LEDs, jumper wires, resistors, a motor, a motor controller, a battery, and a small breadboard to facilitate the connection of components.

Five exercises have been developed to support students learning about IoT concepts and technology remotely utilizing the basic IoT toolkit. Detailed descriptions of each of the exercises can be found in [24, 25] and also in [4-8]. The specific topics of the exercises are:

- Exercise 1: Introduction and running a simple program on a Raspberry Pi board
- Exercise 2: Connecting to the Internet with a Raspberry Pi board
- Exercise 3: Collecting IR sensor data readings using a Raspberry Pi board
- Exercise 4: Sending data to the cloud and plotting the data
- Exercise 5: Controlling a motor based on sensor readings

At each stage in the series of exercises students are provided with instructions on how to physically connect the necessary components required to accomplish the task of the exercise. They are also provided with an overview of how to write the code required to complete the exercise. Remotely learning students are also informed of how to seek assistance for any questions or issues they may have by communicating with their instructor or teaching assistant through email or attending a scheduled virtual office hours session via Zoom.

The topics of the exercises range in complexity starting with a basic introduction to the processor board in the first exercise. In this exercise students first learn about how to connect the Raspberry Pi board to a display, mouse, and keyboard. They are then instructed on how to power on the board and start a basic Python programming environment. They are also instructed about the order in which to connect components to avoid damage to the processor board. Students are provided with an overview of an IoT oriented version of the classic HelloWorld program to enter. Coding and running the program and observing its correct output ensures the student that the Raspberry Pi board is set up and functioning correctly.

Each exercise in the series builds on the results of previous ones by incrementally adding IoT related functionality and techniques. The second exercise focuses on establishing and testing network communications. The following exercise guides students in the connection of an IR sensor to the processor board and the collection of data readings from the sensor. Communicating the data readings to a centralized repository is the focus of the next exercise.

The topic of the last exercise in the series involves the control of a motor. Students are instructed on how to connect a motor and motor controller to the processor board to demonstrate output capabilities. The motor is to be turned off when an IR sensor detects an object (obstacle) in front of it and turned on when no object is detected. The exercise description explains to students how this task corresponds to the basic capabilities needed to control a robot's motors. Figure 1 illustrates the connected components required to complete the last exercise.

Students are instructed to use Python for writing the code required to complete the exercises. Throughout the exercises they learn how to access connected IoT sensors and devices from within their code via the integration of appropriate software libraries. They are also instructed on how to configure and utilize the general-purpose input/output pins of the processor board to collect sensor readings and communicate with output devices such as sending signals to the motor controller in response to the readings collected from the IR sensor.

As noted earlier the basic IoT learning toolkit is limited in the variety and complexity of applications it can support. However, the simplicity of the kit does provide advantages for students, especially those that are new to IoT technologies. Compared to a more comprehensive IoT learning platform, the basic toolkit is more self-contained in that students can use the supplied processor board to complete all tasks associated with the IoT exercises. The same simple processor board serves as a platform to physically connect IoT components, as a programming environment to write the required code, and as a deployment environment to run, test, and debug the IoT application. This simplification enables students to focus primarily on the IoT concepts of the exercises by avoiding the complexities often associated with development on a more comprehensive platform.

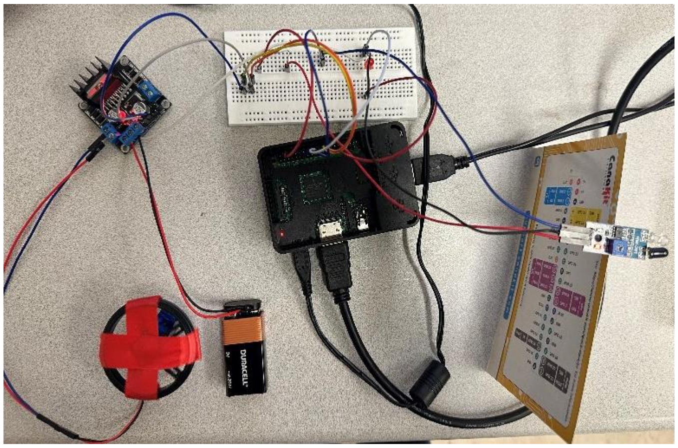

Fig. 1. Connected components required to complete Exercise 5.

III. AN ADVANCED IOT LEARNING PLATFORM

The more extensive IoT platform being utilized in this project is the Keysight U3810A advanced IoT teaching solution. The U3810A includes a basic processor board (BeagleBone Green) that is connected to a larger board that integrates a wide variety of sensors and other IoT related components [21]. Among the included components are a digital pressure sensor, both an analog and a digital temperature sensor, a variety of transceivers, buttons, and an LCD display. The U3810A includes bus structures that provide connectivity between the processor board and the various IoT related components it contains. The U3810A IoT learning platform is pictured in Figure 2.

The wide variety of sensors available enables the U3810A to readily accommodate more extensive IoT related projects. Having input sensors and output devices directly connected to the bus structure of the U3810A enables students to avoid the requirements to manually connect components when creating an IoT application. When writing code for their application (in the C language) students simply need to include the appropriate header files and be aware of memory mapped address locations in order to gain access to the devices they wish to include in an application. This readily facilitates experimentation with alternative component choices when designing an IoT solution.

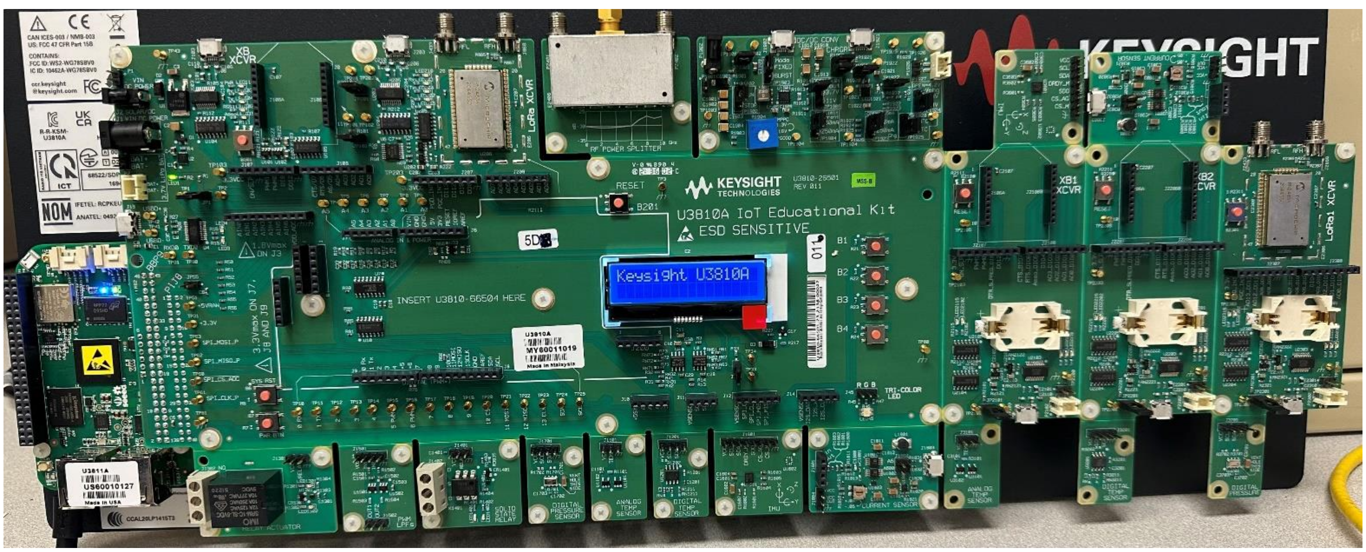

Fig 2. The U3810A IoT learning platform.

As expected with a more extensive IoT learning platform the student experience differs from that of the basic IoT kit. Although making manual connections between the processor board, sensors and the other components needed for an IoT application is not required (as described above), additional steps are involved in the writing, compiling, and deploying of the code required for the application.

Students interact with the U3810A platform through the use of a USB connected laptop or desktop device utilizing programs such as PuTTY and WinSCP. PuTTY is an SSH client program that enables a command tool connection to be established to the processor board of the U3810A [30]. WinSCP is an open-source ftp client program with a graphical user interface that facilitates file transfer between computers [34]. In this case WinSCP provides a convenient way to move files to and from the U3810A platform.

Students are able to write software for their U3810A IoT applications in the C programming language using an editor or IDE of their choice running on a connected laptop or desktop device. They can then compile their code utilizing a cross compiler with the BeagleBone Green as the target deployment processor. Alternatively they can use WinSCP to copy their source code to the BeagleBone Green processor board and compile it natively through the use of an available C compiler.

The necessary compilation commands can be entered through the PuTTY command shell connection. Once compiled the IoT program can be started on the U3810A platform by again utilizing the PuTTY command shell connection.

Five exercises are being developed to support students learning remotely utilizing the advanced IoT platform. For each of the exercises students will be given information on which header files need to be included in their programs and what the relevant addresses are for memory mapped components of the U3810A platform. They will also be provided with an overview of how to design the code required to complete the exercise. The specific topics of the exercises are:

- Exercise 1: HelloWorld “IoT style”
- Exercise 2: Monitoring the status of buttons on the U3810A
- Exercise 3: Collecting temperature readings
- Exercise 4: Outputting information to the U3810A LCD display
- Exercise 5: Pushing data to a cloud based IoT service for analysis and visualization

In the first exercise students are tasked to display a message on both a PuTTY command window and the U3810A LCD display. It is intended as an IoT version of the classic HelloWorld exercise in which students complete a basic task in order to become familiar with how to compile and run programs in a new environment. When completed successfully the specified message will appear in both the PuTTY command window (Fig. 3-a) and the LCD display (Fig. 3-b).

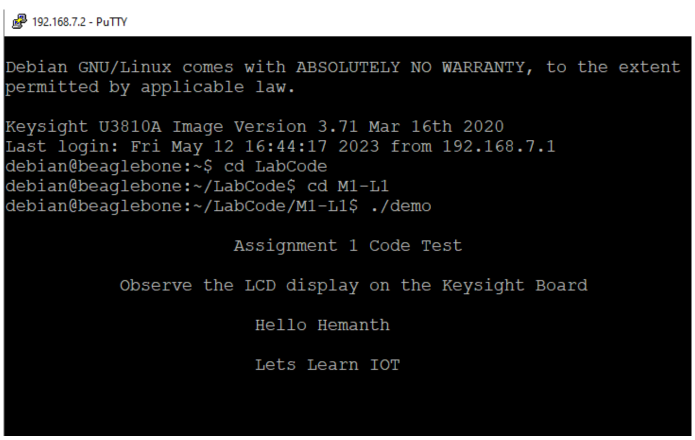

Fig. 3-a. A message displayed in a PuTTY window.

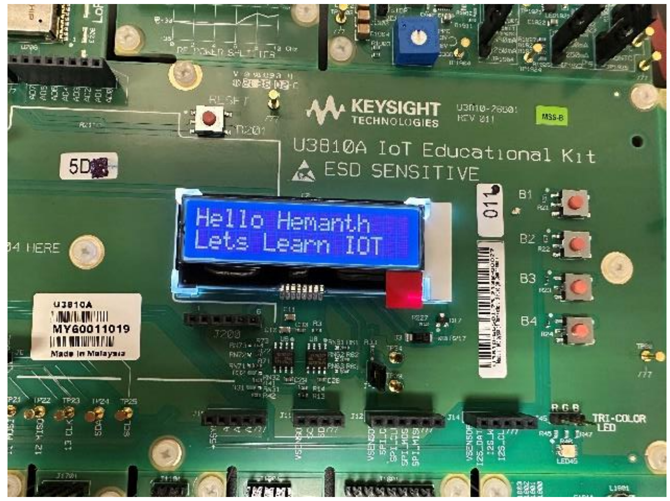

Fig. 3-b. A message displayed on LCD panel.

The second exercise involves monitoring and tracking the status of four input buttons on the U3810A. When one of the input buttons is pressed a message is to be output to both the U3810A LCD display and a PuTTY command window indicating which button was pressed. The application should then pause for a brief (1 second) interval to enable the message to be observed, and then resume monitoring the status of the buttons. As additional button presses are detected the outputs to the U3810A LCD display (Fig. 4-a) and the PuTTY command window (Fig. 4-b) should be updated accordingly.

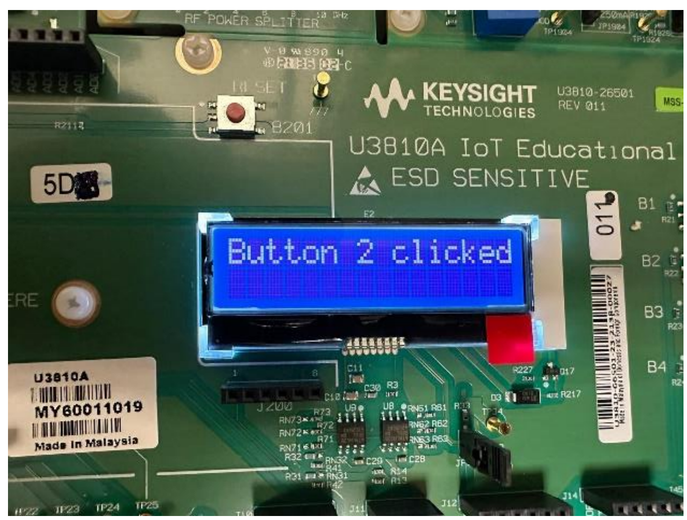

Fig. 4-a. Button status information output to LCD panel.

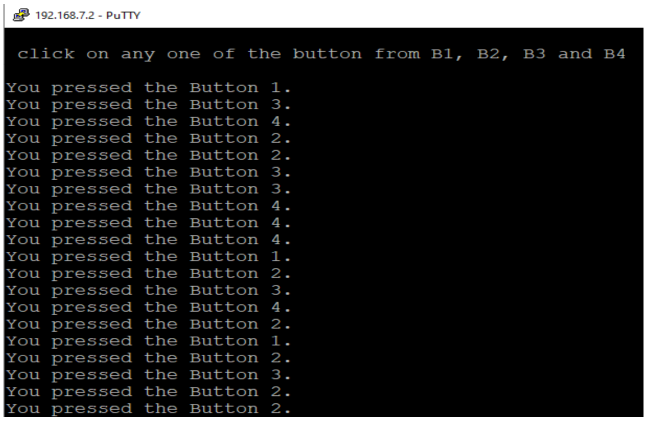

Fig. 4-b. Button status information output to PuTTY window.

In the third exercise readings are to be taken from the onboard Lm75 digital temperature sensor of the U3810A. Students will be informed of the memory mapped address for the temperature sensor and the way in which temperature values can be sampled from it. Their program should take sample readings continuously at a specified time interval (1 second) and then display the values in a PuTTY command window. A code listing for a solution to the exercise is illustrated in Fig. 5-a and temperature values being output to a PuTTY window are shown in Fig. 5-b.

```
#include "mraa_beaglebone_pinmap.h"
#define Sensor_LM75A_I2C_ADDR        0x48
int main(int argc, char** argv)
{
    float temperature = 0;
    int raw_value = 0;
    char bus[2] = {0, 0};
    mraa_init();
    mraa_i2c_context SensorBus_I2cs;
    SensorBus_I2cs= mraa_i2c_init_raw (I2CS_BUS);
    mraa_i2c_frequency (SensorBus_I2cs, MRAA_I2C_STD);
    mraa_i2c_address(SensorBus_I2cs,Sensor_LM75A_I2C_ADDR);
    while (1)
    {
    // Read temperature value
    mraa_i2c_read(SensorBus_I2cs, bus, 2);
    // Convert temperature value from raw data to Celsius
    raw_value = (bus[0] << 8) | bus[1];
    raw_value = (raw_value & 0x7FFF) >> 7;
    temperature = raw_value / 2.0;
    char sign = (bus[0] & 0x80) ? '-' : '+';
    // Print temperature value with sign
    printf("%c%.1f degC\n", sign, temperature);
    // Wait for 1 second before next iteration
    sleep(1);
    }
}
```

Fig. 5-a. Example exercise solution code listing.

Fig. 5-b. Temperature values output to PuTTY window.

The fourth exercise builds directly on the third exercise by instructing students to output temperature readings to the U3810A LCD display as well as the PuTTY command window. The code illustrated in Figure 5-a can be augmented so that temperature readings are also output to the LCD display as illustrated in Figure 6.

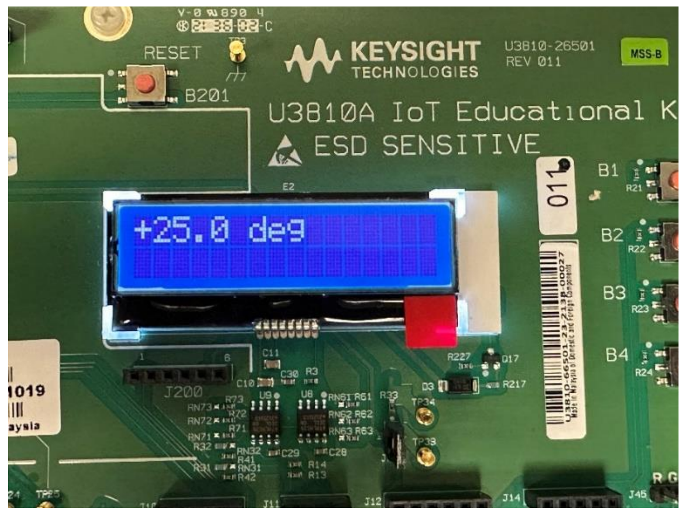

Fig. 6. Temperature readings output to the U3810A LCD display.

The fifth exercise will integrate the use of a cloud based IoT service to analyze and visualize collected data. Students will be instructed to utilize the ThingSpeak IoT analytics platform to create a visualization of a live data stream [20]. To do so students will be instructed to augment their solution for Exercise 4 to also send the collected temperature readings to a ThingSpeak channel. Students will be tasked to configure the ThingSpeak channel so that it will display the current temperature reading as well as a graph visualizing recent temperature readings over time on a laptop device connected to the U3810A. Example windows providing the expected outputs are illustrated in Figure 7-a and Figure 7-b.

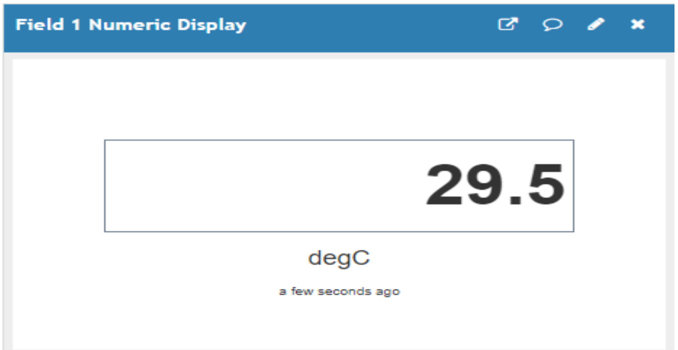

Figure 7-a. Display of current temperature reading.

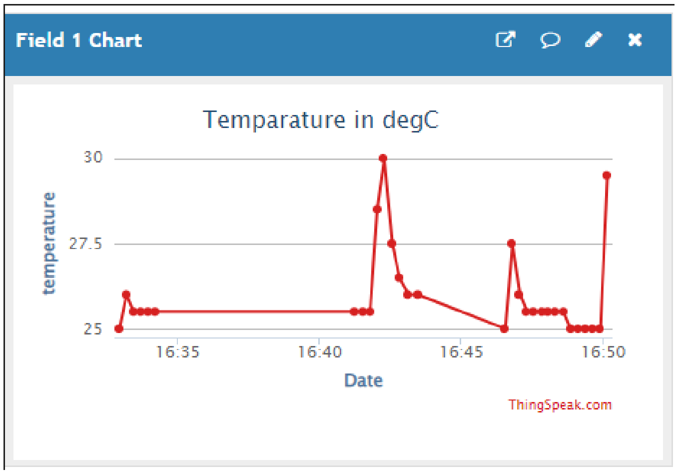

Figure 7-b. Visualization of recent temperature readings.

Remotely learning students utilizing the U3810A platform will also be informed of how to seek assistance for any questions or issues they may have by communicating with their instructor or teaching assistant through email or attending a scheduled virtual office hours session via Zoom.

It should be noted that the five initial exercises utilize only a small subset of the capabilities of the U3810A platform. However, after completing them students should have a basic familiarity with the U3810A platform and the general approach to be utilized in accessing its components through software, including how to establish network communications. Students will also have an understanding of how to write and compile code for their IoT applications and deploy it to the U3810A platform. Though, as described earlier, this process is more complex than that for the basic IoT kit and involves the use of additional tools including PuTTY and WinSCP, it is also probably more realistic and reflective of what will be encountered when working in the field.

IV. Deployment Strategy

A primary target for utilizing the IoT learning kits is in the senior level capstone project courses in engineering and computer science related disciplines. In particular, for the project described in this paper the electrical engineering and computer science capstone courses at TAMUK will utilize the learning kits to introduce students to IoT related concepts and encourage them to consider how IoT technology might provide benefits for and be integrated into their designs.

The choice of which IoT kit to utilize in a learning application will be influenced by various factors, especially the cost involved and the complexity of a project. The lower cost basic kit could feasibly be made available to all students in a capstone class (average class size of 25 students) in order to introduce IoT concepts and technology. Afterwards, students choosing to work on a capstone project that will incorporate a substantial amount of IoT technology could then be issued advanced learning kits for the duration of their projects.

Additional deployment targets include non-capstone courses on a curriculum that have a significant focus on IoT related concepts or technologies. An example could be an electrical engineering or mechanical engineering course focused on sensors and systems. Additionally, students participating in a directed independent study course with an IoT related emphasis could utilize one of the IoT learning kits.

V. Assessment Plan

The planned assessment method for the project is to utilize student perception surveys. The surveys will be administered both pre-participation, before a student takes a course utilizing the IoT learning kits, and post-participation, at the conclusion of the course. The survey questions will be designed to gauge students' perceived confidence and competence in their knowledge of basic IoT concepts. They will also measure student ability to recognize opportunities to exploit IoT technology and successfully integrate it into their designs where appropriate.

VI. Conclusion

A basic toolkit and series of exercises have been developed targeted to support remote students learning about IoT concepts and technology. Though limited in the variety and complexity of applications it can support, the basic IoT kit offers the advantages of simplicity and a self-contained nature to learners, especially those new to IoT technology. An advanced IoT platform has been selected to support students learning about and working with more extensive IoT applications. A series of exercises are being developed to introduce students to the advanced platform and its range of capabilities. Though the process of writing and compiling code for an IoT application is more complex utilizing the advanced IoT platform, it also more closely resembles what will likely be encountered when working in the field.

The IoT toolkits will be deployed in two senior level capstone courses at TAMUK. Pre- and post-participation student surveys will be used to assess the use of the IoT toolkits and their impact on students' perception of their confidence and competence with IoT concepts and technology and its utilization in their design projects.

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