The Integration of IoT Devices for STEM Outreach

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Abstract

The Engineering Technology & Industrial Distribution (ETID) department of Texas A&M is actively working to develop young students’ interest in careers in Science, Technology, Engineering, and Mathematics (STEM) fields. To this end, the department has a need for a prototype demonstration system that integrates mechanical, electronics, computer, and control systems concepts into a small form factor Internet of Things (IoT) environment. This system will be used in workshops targeting 4th grade to 12th grade students. In addition, the system must be low cost so units can be left with the K-12 grade schools for extended evaluation.

EnTronics Systems, an undergraduate Capstone team, has been tasked with the development of this new system known internally as the “Engineering Learning Kit” (ELK). This kit will consist of Nodes with distributed sensors (temperature, humidity, light, and motion) packaged in custom 3D printed enclosures that will sense the environment and transfer captured data wirelessly to a Graphical User Interface (GUI) for viewing and analysis. A programming environment for the sensors will also be developed that is usable by students with varying programming backgrounds. This paper presents the rational for the Engineering Learning Kit, its use in STEM outreach and recruiting, as well as the engineering design and implementation of the system.

* This paper will be presented by an undergraduate student Capstone group from the Electronic Systems Engineering Technology program at Texas A&M University with the faculty advisor being Dr. Jay Porter.
Introduction

The Electronics System Engineering Technology (ESET) program of Texas A&M University is a part of the Engineering Technology & Industrial Distribution (ETID) department. ESET focuses on providing students with a knowledgebase of electronics, communications, testing, instrumentation, embedded, and control systems to prepare students to meet the needs of the private and public sectors. Prior to graduating, students in ESET are expected to complete a two-semester Capstone project. These projects must encompass the knowledge that is taught to students throughout the program and allows for the implementation of these topics in a single integrated environment. To this end, the students must find an idea for an electronic intelligence-based product and develop a professional, functional prototype.

The Capstone experience is broken down in two parts and completed over the course of two semesters, or approximately nine months. The first semester focuses on finding an idea for a product, developing a preliminary design, and planning the implementation. This introduces students to valuable project management skills that are commonly needed in industry as well as prepares them for the Certified Associate in Project Management (CAPM) exam. While the CAPM exam is not a requirement for Capstone, it allows students to further differentiate and distinguish themselves amongst their peers when looking for employment. Some topics covered through the first semester include determining the scope of a project through a Work Breakdown Structure (WBS), separating and assigning members responsibilities through a Responsibility Assignment Matrix (RAM), determining the length of said project graphically with a Network Logic Diagram (NLD), and defining the cost and scope of a project through a Gantt chart.

For the second semester of Capstone, students take action on the planning that was done in the previous semester. During this semester Capstone teams develop Alpha, Beta, and Final Board schematics and layouts, as well as Alpha, Beta, and Final Code for the project. Throughout the semester, students are also expected to have weekly Technical Assistance Team (TAT) meetings with their sponsor utilizing a “SPRINT” approach, where each three weeks there is a live demo of the progress of the project. The intention of these meetings is to keep the sponsor up to date on the progress of the project, as well as hold students accountable to the timelines they set during the planning phases of the project.

In short, all students in Capstone must:

- Form three- to four-person teams to take on the persona of a small startup company. This includes creating and developing a company name, logo, website, and assigning individual members specific roles, such as Hardware Engineer, Software Engineer, Systems Integration, and Project Manager.
- Find a real customer with a need for the design of a product encompassing embedded technology. The customer can either be a sponsoring company or faculty advisor but must be available to participate throughout the entire Capstone experience.
- Plan, design, and develop the required product. This includes developing a project management plan, creating preliminary designs, and implementing a fully-functional prototype.

EnTronics Systems is a current Capstone team comprised of Jonathan Cramer (Project Manager), Oscar Joya (Systems Integrations), Carlos Bocanegra (Software Engineer), and Sean Walters
(Hardware Engineer). This paper uses EnTronics Systems as a demonstration of the rigors of the ESET program. The paper will discuss the product requirements and design process or their Capstone Project as well as summarize the lessons that this process has taught them.

**Problem Statement**

The ETID department of Texas A&M University has a need to increase the flow of students into the Science, Technology, Engineering, and Mathematics (STEM) fields. At the same time, the ETID department has a need for a prototype device that can be used in a proposal for the National Science Foundation (NSF). This prototype must allow for the integration of mechanical, electronics, computer, and control systems into a demonstration environment that can be used in a K through 12 education environment. EnTronics Systems plans to meet the needs of the ETID department, represented by Dr. Joseph Morgan, through the creation of a small form factor Internet of Things (IoT) system known internally as the “Engineering Learning Kit” (ELK).

The ELK will consist of three subsystems: Base Station, Node, and Sensor Module. The Base Station will be comprised of a Windows based PC with a wireless (XBee) USB dongle. The main subsystem, the Node, will be a small form factor IoT device with two internal sensors – temperature and 3-axis accelerometer – that will be able to communicate with the Base Station wirelessly using the IEEE 802.15.4 protocol. Finally, the Sensor Module will be a proof-of-concept expansion to the Node that will add humidity, light, and motion sensing capabilities to the system.

Ultimately, the ELK will be used by students ranging from the 4th grade to the 12th grade levels. Therefore, the ELK must be easy to use and understand. A typical use case for the ELK would be:

- Faculty-student teams teach workshops for regional teachers from 4th to 12th grade that introduce the Engineering Learning Kit and how it can be used as a demonstration environment to teach essential math and science concepts.
- As part of a workshop, teachers work with faculty and students to develop experiments that leverage the ELK and 3D printing that can be used in their classroom.
- Teachers from the workshop are given an ELK and an inexpensive 3D printer to use in their classroom. They are given ongoing support through a web portal and faculty/student teams as they implement their customized experiments in their own classroom.

The goal is to develop a sustainable methodology for teachers to excite and motivate their students to consider careers in STEM fields that might otherwise been seen as out of reach. The ETID department hopes to be able to commercialize the ELK and utilize it as an outreach and recruiting tool.
Research

Currently many schools in the United States focus on the science and math sections of the STEM curriculum rather than technology and engineering. Both the ETID department and EnTronics Systems are striving to add focus on the technology and engineering aspects of STEM. To accomplish this endeavor, EnTronics Systems is developing an IoT-based system as an interesting and exciting way to introduce students to these missing areas. IoT allows objects to be sensed and controlled remotely across networks, typically through wireless connections. This is accomplished by the remote devices collecting data through sensors and transmitting the data to a collection point.

In the case of the ELK, the IoT device will be the Node. The Node will collect data through specific sensors on the board. Through these sensors, the students will have real data that they can interpret and analyze. This will help merge the engineering sector and the technology sector seamlessly. In order for this merge to happen, EnTronics Systems did research into different communication protocols, microcontrollers, and various sensors for the ELK.

When choosing a communication protocol for the ELK, there were three main factors considered: wireless capabilities, low power consumption, and have the ability for mesh networking. In the end, the DigiMesh 2.4 (Digi, Eden Prairie, Minnesota) module was selected. This module utilizes a slightly modified ZigBee protocol and falls under the IEEE 802.15.4 standard.

The DigiMesh protocol will be used for Node-to-Node communications as well as for Base Station-to-Node communication. Using this module, the ELK will allow up to thirty-two nodes to be simultaneously connected to one Base Station. This is easily accomplished through the DigiMesh protocol which allows for a theoretical maximum of over 60,000 nodes. DigiMesh accomplishes this by operating at 2.4 GHz on up to sixteen separate transmit channels, allowing for minimization of interference with other networks operating at the same frequency.

The three main advantages of using the DigiMesh protocol include stem from the following capabilities: the network can self-heal, dynamically creating routing between the end node and the gateway, and can “sleep” to conserve power. For mesh networks, each Node will act as a ‘Router Node’ and the Base Station will act as the ‘Gateway’ as seen in Figure 1.
The self-healing aspect of DigiMesh allows any node to go into or out of the system without affecting the functionality of the network as a whole. The route discovery of DigiMesh allows for continuous routing updates to happen when transmitting data. The sleep mode capabilities allow for each of the Nodes to go into a sleep state to conserve battery power.

Next, a microcontroller was selected based on two TI recommended MSP430 families - the MSP430F24XX and the MSP430F54XX. Given that the microcontroller and other peripherals on the Node will be low cost and battery powered, active power consumption, standby current, and cost were important factors when selecting a microcontroller. Also, possessing UART and I2C capabilities for the XBee module and various sensors were considered deciding factors. These specifications ultimately led to the selection of the MSP430F54XX and specifically the MSP430F5418A (Texas Instruments, Dallas, TX) microcontroller.

Finally, in order to simplify the project as a whole, sensors utilizing the same communication interface were sought after. Due to its single master-multiple slave properties, the preferred communication interface was chosen to be I2C (Inter Integrated Circuit). Amongst sensors utilizing the I2C protocol, power consumption and size were taken into consideration; power consumption in order to maximize battery life and size to keep the overall system in a small form factor. Through these guidelines, a 3-axis accelerometer, temperature, humidity, motion, and light sensor were chosen.

Through research of wireless communication protocols, circuit to circuit communication interfaces, and microcontroller selection, appropriate components were chosen to be used in the ELK. EnTronics Systems hopes to successfully design and implement circuitry around the selected components in the creation of a comprehensive teaching device.

**Design**

Upon completion of research, the project moved to the preliminary design stage by creating a conceptual block diagram to represent the solution at a high level and demonstrate to the customer an understanding of the problem at hand. From the conceptual block design, a more technically detailed diagram was created in the form of functional block diagram.
Conceptual Block Diagram

By using the ELK’s three subsystems – Base Station, Node, and Sensor Module - and a LabVIEW based Graphical User Interface (GUI), students will be able to collect and analyze sensor data. Students will also have the ability to 3D-print enclosures for the Node and the Sensor Module given EnTronics’ provided designs. An overall conceptual design of the Engineering Learning Kit can be seen Figure 2. Upon request by a user on the Base Station’s GUI, one or more of the various sensors, some internal to the Node and some on an external sensor module, are to gather data on the environment. This data is then transmitted to the MSP430 microcontroller on the Node, who will process and transfer said data to the XBee module. From here, the XBee module will transmit the data to a USB dongle on the Base Station using DigiMesh. Once received, a user can analyze, store, and manipulate the data as they see fit.

Figure 2: Conceptual Block Diagram

Though the Conceptual Block Diagram shows only one Node and Sensor Module, the ultimate goal is to have a system capable of supporting up to 32 Nodes. The finished system will comprise of multiple Nodes, scattered throughout a classroom environment, communicating to a centralized Base Station in near real time. Given that the Sensor Module provided serves as a
proof of concept, more external modules can later be created to meet the user’s needs. Unused pins on the DB15 could also be taken advantage of when creating new Sensor Modules to allow for expanded sensor capabilities giving the students a gateway to experience all parts of STEM.

**Functional Block Diagram**

The functional block diagram illustrates and describes the internal connections of the ELK. This kit will be implemented using two different boards - a Node and Sensor Module - and a Base Station consisting of a USB dongle with a GUI a user can access on a computer. The overall system and each subsection can be seen in Figure 3.

The flow of the overall functional block diagram starts at the Base Station, located at the top of the diagram, followed by the transmission of instructions to the Node, shown on the center of the diagram. Communication between these two sections is made through the XBee module using the DigiMesh protocol. Requests of sensor data will be generated by the user at the Base Station’s LabVIEW based GUI. Requests shall then be transmitted to the MSP430F5418A microcontroller for data acquisition.

Power to the system will come from two different sources. For the Base Station, power shall come from the outlet the computer is plugged into and for the Node and Sensor Module, power shall come from rechargeable batteries. Voltage coming from the batteries will be boosted through the use of a voltage regulator to an operational 3.3 V which will allow the Node and Sensor Module to function properly. The regulator has a low battery detection as well, which will be used to alert microcontroller replacement batteries may be needed. This information can also allow the microcontroller to initiate a battery save mode in order to prevent the rechargeable batteries voltage from dropping its too low and damaging the batteries. From the power limitations previously stated, the MSP430F5418A, a low power consumption microcontroller, was selected. This microcontroller has a low active power consumption of 1.095 mW at the 3.3V the Node will operate at. The MSP430 will also allow for various communications interfaces including UART, SPI, and I2C. Thus all the internal and external components selected will be able to communicate with this microcontroller. Though an 80 pin and 100 pin package of the MSP430 are available, only 49 pins are required for this design. Therefore, the 80 pin package was selected as it is less expensive and has a smaller footprint. All unused pins can later be used for expandability by the user.

For ease of use purposes, the Node will make use of a visual user interface in the form of status LEDs; one LED for power, two for internal sensors, and up to three for external sensors. The sensor LEDs will visually reflect the magnitude of the sensed parameter through changing colors. For instance, the temperature LED will emit a blue light when the temperature is in a cold range and change to a red light when in the warm range, where the range is software programmed. The sensor LEDs will also blink when transmitting data to the Base Station.

Both of the internal sensors, temperature sensor and 3-axis accelerometer, communicate to the MSP430 microcontroller through the use of the B0 I2C bus, where the address of both sensors are static. In addition to the required I2C connections, the TMP102 temperature sensor will also make use of a digital output connection to alert the user when the maximum temperature limit have been reached. Similarly, the MMA8452Q accelerometer can also make use of two output interrupt lines which can be programmed to alert the microcontroller when certain movements
are detected. Both the digital output of the TMP102 and the interrupts of the MMA8452Q will be included as an available feature that users can implement in the future.

The remaining three sensors - motion, light, and humidity – are external to the Node and located on the Sensor Module. All of the external sensors are connected to, and powered by, the Node through the use of a Micro DB15 connector. Both the light and humidity sensors will communicate through the use of a digital I/O port. On the B1 I2C bus, the light sensor will have a software configurable address while the humidity sensor will have a preset address value. In addition to the required connections, the OPT3001 light sensor will make use of an interrupt pin on Port 2 of the MSP430 that can act as an expandable feature for the end-user to take advantage of if a quicker reaction to a change in light detection is desired. Though the external sensors will not make use of all the DB15 pins, the extra pins will be left for future expandability.

Figure 3: Overall Functional Block Diagram

In order to program the various aspects of the ELK, two coding languages will be used: Embedded C and LabVIEW. Embedded C will be used to program the MSP430 microcontroller and its connected sensors as well as the XBeet module. This will be done through the Code Composer Studio (CCS) Integrated Development Environment (IDE) to minimize communication problems, since the microcontroller and IDE are both produced by TI. For the GUI, National Instrument’s (NI) graphically oriented LabVIEW environment will be used. LabVIEW executable files will be created and given to the user to provide an easy to understand environment the user can take advantage of without needing to know the low level workings of the system. Given that the ELK will be used by users of varying coding experience, code will be written in functional tiers that each student can delve into when they feel comfortable.
Current Project Status

At this time, all project planning, component selection, board schematic and board layout along with basic design of software has been completed. By following crucial project management technique to identify project risk and manage time, our team will ensure the project is completed by May 5th 2016. By this time, EnTronics Systems will provide the ETID department with a system that can be used for STEM outreach and give students the ability to view and analysis data through our custom GUI interface.

Hardware Development

Currently, the preliminary design is done and the team is finalizing and then constructing the Alpha PCB. All five sensors of the board’s design are split into two different boards, the Node and Sensor Module. The Node contains the 3-axis accelerometer and temperature sensors. The connectable Sensor Module contains the light, motion, and humidity sensors. Based on the functional block diagrams in Figures 3, in which the pin levels are described, an alpha schematic was created. EnTronics Systems is currently reviewing the design with the team’s technical advisor and capstone design director. Once the review process is over, the team will order the boards and populate them personally. Testing and verification of components will be started upon the completion of board population. The boards will each have their own 3D printed enclosures that will be designed by EnTronics Systems to match and work with one another.

Software Development

EnTronics Systems has acquired the MSP430F5529 development board and the necessary sensor breakout boards. Using these development tools, EnTronics will be able to further code progress through code testing and debugging. By doing this ahead of time, before the board has been fully designed and ordered, the team will be able to make headway into the ELK’s progress. The GUI development has also seen a head start in the form of LabVIEW files. A simple mock-up GUI has been created and will be continuously improved throughout the continual development of the project.

Conclusion

Being on the cutting edge of new technology is what the ESET program and Capstone strive for. Though many complications can arise, with each new complication comes a learning experience that can only be taught by overcoming obstacles. Both Capstone and the Engineering Learning Kit are meant to teach students advanced problem solving skills, and those needed to adapt to the ever changing technological world. Through Capstone, students are able to learn how to interact with customers, create and live by a schedule, integrate and extrapolate their classroom knowledge, and apply it in a creative design environment.

The Engineering Learning Kit is meant to provide an exciting and motivating environment to teach 4th-12th grade students about STEM careers. Through hands on experimentation with sensors and other electronics, students will become knowledgeable in electronic concepts, data collection, and data analysis. Additionally, scalable code functionality levels will help develop student’s skills in embedded electronics software from the beginner to advanced levels. Overall, the Engineering Learning Kit will allow students to develop a better understanding of STEM concepts.
References

