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Editorial Review Board Members

Development of a Novel Embedded Systems Design Kit with Modular Interchangeable Hardware Architecture

Gang Sun, Northern Kentucky University; Paul Simmons, Northern Kentucky University

Abstract

The rapid advancement of computer, sensor, wired and wireless communications, data storage, and integrated circuit technologies has had a tremendous impact on embedded systems design in many different types of industries. To integrate these new devices and technologies into current embedded systems learning and design processes, numerous engineering schools have expressed an urgent need for new development kits for their microcontroller-related courses. The primary objective of this current research project was to develop and test a new, low-cost embedded systems design kit with modular interchangeable microcontroller layers. The new kit encompassed the most useful analog, digital, and new wired and wireless devices, but its cost and size were reduced remarkably. Additionally, a novel modular, interchangeable hardware architecture was created to facilitate several popular microcontrollers (TI, Atmel, Microchip, etc.) being interfaced to the same main board. This novel hardware architecture would make it possible for students to learn different microcontroller models using the same on-board devices and peripherals. In this paper, the authors discuss in greater detail the kit development process, including schematic and printed circuit board (PCB) design, capabilities evaluation, and overall system requirements.

Introduction

Over the past decade, the rapid advancement of computer, sensor, wired and wireless communications, data storage, and integrated circuit (IC) technologies has had a tremendous impact on embedded systems design in many different types of industries (Roshan & Moallem, 2011). Integrating these new devices and technologies into current embedded systems development processes can facilitate product design, enhance the competitiveness of products, and help companies gain a more competitive position in the global market place.

Thus, numerous universities have expressed an urgent need for new embedded systems development tools for undergraduate engineering education. The new development tools are expected to be used from entry-level microcontroller courses at the sophomore level to final capstone/senior design projects. Also, such new development tools could support not only embedded systems design classes, but have the ability to be used in other courses, such as instrumentation, communications, and process control.

With the support of TI (Texas Instruments) and NASA, Sun, Morgan, Porter, and Yim (2015) developed a Modular Integrated Stackable Layer—Analog System Environment (MISL-ASE) platform (see Figure 1) for learning and designing embedded systems. This MISL-ASE platform is able to provide a comprehensive hardware development environment as well as fully support the rigorous demands of harsh operational environments found in fields such as aerospace, automotive, oil and gas, medical, or communications systems prototyping. The MISL-ASE platforms have been successfully used as main lab equipment for five electronics engineering technology courses at Texas A&M University and Northern Kentucky University over the past five years (12 semesters). A few universities, their students, and product development engineers have shown great interest in this MISL-ASE platform. Unfortunately, they could not afford it because of the price (each platform costs over $1000). Therefore, there was a need to design a new embedded systems development kit, as well as markedly reducing its cost and size. It was also expected that the new development kit would still encompasses the most useful analog, digital, and new wired and wireless devices that the MISL-ASE platform had.

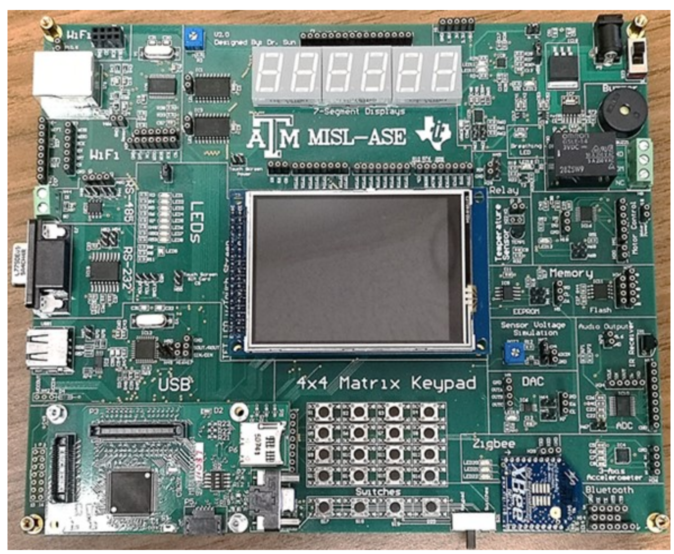


Figure 1. The MISL-ASE platform.

It should be pointed out that different engineering schools teach with different brands of microcontrollers (e.g., TI-MSP430, ATMEL-AVR, Microchip-PIC32, NXP, Silicon-8051, ARM, etc.). A review of the literature (Choi, 2008; Hsiung, Ritz, & Eiland, 2008; Sarik & Kymissis, 2010; Kramer & Anderson, 2011; Hass & Sun, 2012; Hsiung, Jao, Xu, & Issapour, 2018) indicated that all of the existing development boards were designed for a specific microcontroller model. If students are interested in learning multiple microcontroller families/brands, they have to purchase different types of development tools, which significantly increases their financial burden. In this current study, the authors also wanted to create a novel modular interchangeable hardware architecture that could facilitate several popular microcontrollers being interfaced to the same main board and make it possible for students to learn different microcontroller models using the same on-board devices and peripherals.

Overall Functional Block Diagram (FBD) Design

Figure 2 shows that the overall functional block diagram of the new development kit was divided into four major sections: 1) the modular interchangeable microcontroller layer architecture containing three boards (Texas Instruments-MSP430F5438A, Atmel-ATMEGA2560V, and Microchip-PIC32MX795F512L microcontroller layers); 2) a GPIOs (General Purpose Outputs/Inputs) section; 3) a signal conversion section; and, 4) a communications section.

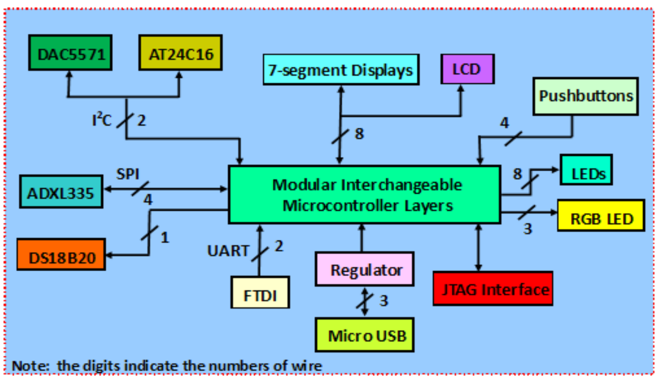


Figure 2. The overall functional block diagram of the new development kit.

Embedded Systems Development Kit: Schematic Design

Modular Interchangeable Microcontroller Layer Architecture

In this project, the modular interchangeable hardware architecture with three microcontroller (MSP430F5438A, ATMEGA2560V, and PIC32MX795F512L) layers were constructed. Each modular microcontroller layer only contained a microcontroller chip whose pins were pulled out to four male connectors. Those four male connectors were plugged into the corresponding female connections on the main development board so that the microcontroller layer was able to control all of the on-board features. This type of hardware architecture would allow for different brands of microcontrollers to be directly interfaced to the main board to share the same devices and peripherals. In other words, students could use this new development kit to study multiple microcontroller models and their peripherals without spending extra money on different embedded systems development tools. Figure 3 depicts the TI-MSP430F5438A microcontroller layer architecture and the location of the 100-pin data bus/connectors. All schematic diagrams were drawn using Eagle CAD software (Autodesk-Eagle PCB layout design, 2020).

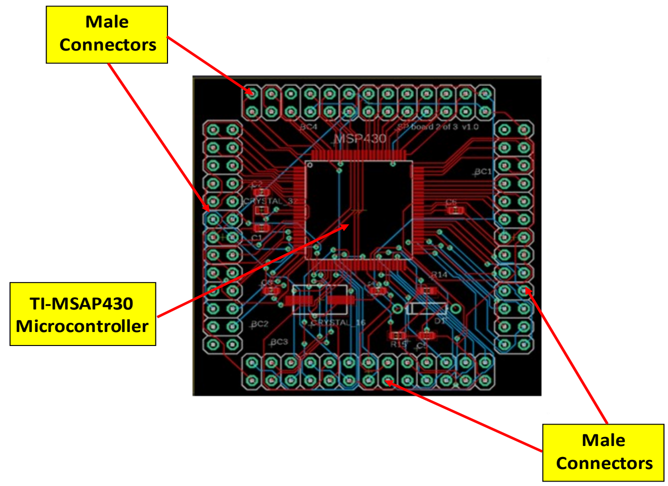


Figure 3. The modular interchangeable microcontroller layer architecture (TI-MSP430 layer).

General Purpose Inputs/Outputs (GPIOs) Section

GPIOs are one of the most valuable resources in embedded systems, providing the ability to communicate with the external world through digital lines configured to operate as either inputs or outputs. For GPIO outputs, GPIOs can control the binary status of external devices by setting an external voltage level to either a logic high or logical low. Typical external devices include LEDs, 7-segment displays, buzzers, LCDs, and relays. Figure 4 shows an example of the main board with eight red LEDs, one tri-color LED, and four common-cathode 7-segment displays that were used to indicate on/off status and display numerical digitals and characters. Due to the limits of the GPIOs' drive strength, two octal D-type latches (74HC573) were used. One latch drove a ~ dp segments (i.e., what to display) and the other latch selected which display to use. Both of the latches were controlled through the latch enable (LE) pins in order to prevent the latches from overriding each other. In addition, an external LCD (1602) was interfaced to one of the GPIO ports to illustrate images and information on the screen. For the GPIO-inputs, four independent mechanical pushbuttons were connected to the GPIOs of the microcontroller as a typical GPIO input example.

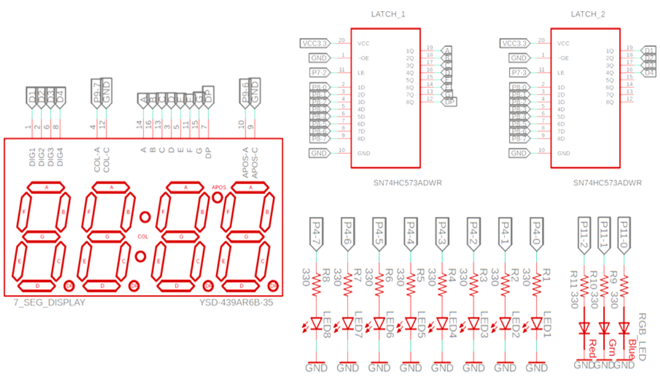


Figure 4. The schematic diagram of the GPIO-output section.

Signal Conversion Section

The most common task for embedded systems is to measure analog signals (e.g., temperature, pressure, flow rate, level, density, etc.) from the outside world and convert them into digital signals that microcontrollers can understand. Conversely, digital signals must also be converted to analog signals. Figure 5 shows the signal conversion section that included the following.

1. A potentiometer, used to simulate a varying analog input voltage to be fed into one of the internal 12-bit analog-to-digital (A/D) converters so that students could learn and practice A/D converter programming
2. A 3-axis MEMS acceleration measurement system (ADXL362) for measuring both dynamic acceleration resulting from motion or shock and static acceleration, a device widely used for home healthcare devices, hearing aids, motion-enabled metering devices, etc. The ADXL362 communicates with the microcontroller over an SPI (Serial Peripheral Interface) interface and operates at extremely low power consumption levels. The built-in digital logic enables autonomous operation for sleep and wake-up operation that can run as low as 270 nA and at a low measurement rate of 6 Hz.
3. The 8-bit digital-to-analog (D/A) converter (DAC5571) was a low-power, single-channel, 8-bit buffered voltage output DAC. The DAC5571 utilizes an I^2C (Inter-Integrated Circuit bus) interface that operates at clock rates up to 3.4 Mbps to convert digital signals to an analog output voltage. The output voltage was changed from 0V to Vcc (power supply) in order to alter the LED density. Furthermore, some PCB terminal blocks were reserved on the main board for connecting with several typical analog sensors (e.g., temperature/humidity, pressure, and flow-rate sensors) so that their outputs could be converted into digital signals via A/D converters inside the microcontroller.

Communications Section

Figure 6 shows the latest communication interfaces and protocols available for this development kit, including: a) four-wire communication networks—SPI (3-axis accelerometer ADXL362); b) two-wire communication networks—UART (USB/RS-232 FTDI); c) two-wire communication networks—I^2C (EEPROM 24C16, D/A converter DAC5571); and, d) 1-wire communication networks—DS18B20.

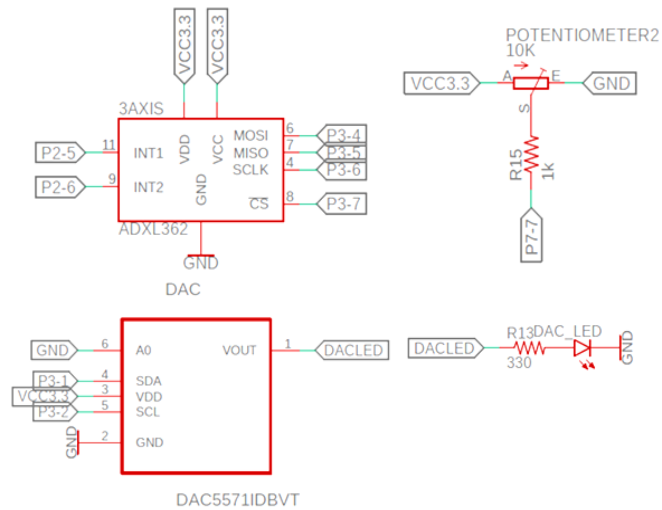


Figure 5. The schematic diagram of the signal conversion section.

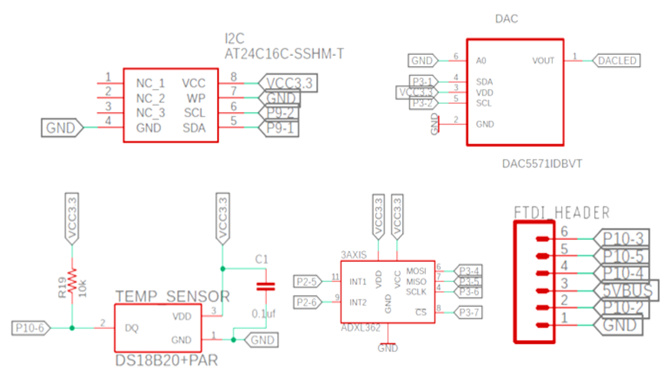


Figure 6. The schematic of diagram of the wired and wireless communications sections.

a) <u>The Serial Peripheral Interface (SPI)</u>
The SPI was a synchronous serial bus standard with full-duplex capability to support communications between a master (e.g., microcontroller) and one or more peripheral slave devices. On the main board, the 3-axis accelerometer ADXL362 was able to communicate with the microcontroller via SPI to measure dynamic and static acceleration. Also, on-board SPI headers were used to connect to external Wi-Fi modules (e.g., nRF24L01 and TI-CC3000). With this design, many different devices and equipment can be remotely accessed, monitored, and controlled through internet and Wi-Fi, such as web-based home automation, remote environmental monitoring, etc.

b) Universal Asynchronous Receiver/ Transmitter (UART)
The UART is a very useful feature of microcontrollers for communicating serial data (text, numbers, etc.) to computers or devices. A 6-pin FTDI header was created on the board to convert RS-232 or TTL serial transmissions to USB signals so that the microcontroller could communicate with other computer systems via UART interfaces. The GSM modules (e.g., SIM900) were connected to the UART for cellular network communications. However, the greatest disadvantage of GSM is that data transmission may encounter interference, if multiple users are simultaneously using the same bandwidth of the networks (e.g., 1900 MHz). Additionally, GSM cellular networks store user information on removable SIM cards. Any person with the qualifications to access to the GSM module can easily swap networks by putting in another SIM card. As such, GSM security needs to be considered to protect data transmissions.

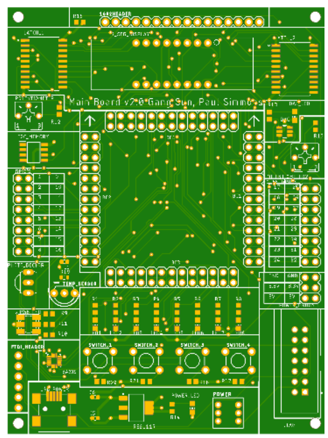
c) Inter-Integrated Circuit Bus (I^2C)
The I^2C is a synchronous serial communication protocol to support on-board interconnection of integrated-circuit devices. On the main board, the I^2C used two lines (SDA and SCL) to establish a half-duplex communication bus between the master (microcontroller) and two slave devices: 16K EEPROM (24C16) and D/A converter (DAC5571).

d) One-wire Communications
A digital thermometer (DS18B20) was employed to develop distributed temperature monitoring systems through a one-wire communication bus in lieu of the traditional measuring method using temperature sensors, signal conditioning circuits, and A/D converters.

Embedded Systems Development Kit: PCB Layout Design

The printed circuit board (PCB) layout of this development board had four layers—top, bottom, power, and ground—designed using Eagle CAD software. Eagle CAD was used to translate the schematic capture and all circuit connections into a file that could be laid out to accommodate the best design. Throughout the board layout, a number of design rules needed to be generated such that a design rule checker could be run on the layout to ensure that the design could be manufactured by the board house. The output of the board layout software was a set of Gerber files that were checked by the software's design rule checker and then submitted for verification by the board manufacturers design software. Figure 7 shows the overview of the entire main board PCB layout (version 2.0) and all four layers of traces. As can be seen in Figure 7, there are many different isolated circuits on the main board. These include LEDs, LCDs, push buttons, a 7-segment display, a one-wire temperature sensor, I^2C memory, IR, a 3-axis accelerometer, DAC, JTAG, and more. To power the board, a USB mini-B port was installed on the board.

Once the power button was turned on, the 5 volts from the USB port went to the voltage regulator (REG1117), which reduced the 5 volts down to 3.3 volts. The 3.3 volts was used to power all of the components on all of the boards and layers. Connected to the voltage regulator were two capacitors for filtering out the noise and helping to improve the power output. The last component in the power section was an LED to indicate the power on/off status. To the right of the power components was the JTAG header. This was used for programming and debugging the microcontroller that was plugged into the board. To the left of the power components is the FTDI header. This six-pin header converts the USB signal to serial communication (RS232). Above the FTDI header is a RGB LED with three colors (red, green, and blue).


a) PCB layout.

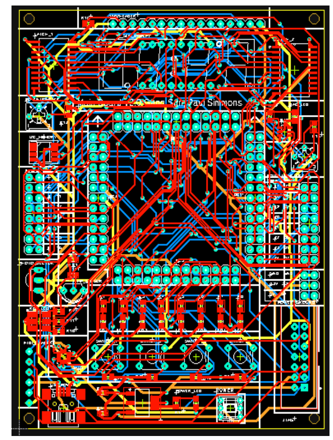
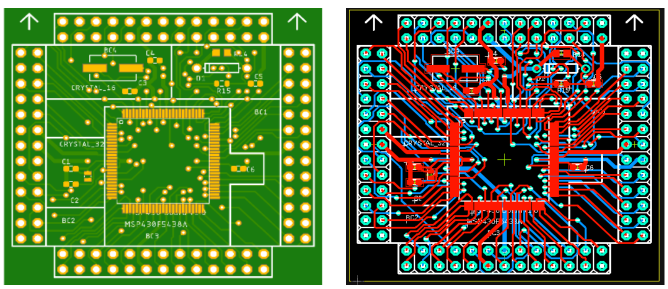

b) All four layers of traces.

Figure 7. Overview of version 2.0 main board.

The infrared sensor used on this board could detect any infrared radiation in the surrounding area. The one-wire temperature sensor could determine the temperature of the area. This one-wire temperature sensor circuit made for this project provided students with an opportunity to learn and practice new communication protocol and digital devices. To the right of those sensors is a row of four push buttons. Each push button was connected to one GPIO pin and each had a pull-up resistor attached to it. Above the four pushbuttons is a row eight red LEDs. Each LED was connected to one GPIO pin with a current-limiting resistor in-between. To the right of the eight LEDs is the three-axis chip. This is an accelerometer that can determine what angle the board is at. In the center of the board are four, twenty-six-pin connectors. These connects the main board to a modular interchangeable microcontroller layer. On the right side of the microcontroller layer is an 18-pin GPIO port. Seventeen of the pins were used as GPIO pins, with the eighteenth pin being used as a ground pin. Also on this side of the board is a potentiometer and a DAC. The 3.3 volts was sent to the potentiometer—there was a specific voltage drop for whatever resistance the potentiometer was set at.

The microcontroller, when so programmed, could read the amount of voltage across the potentiometer and display that voltage on the 7-segment display or an LCD. Continuing up the board is the DAC and its LED. This chip can convert a digital signal to an analog signal. On the right side of the microcontroller layer connectors are several other components. The first of these components is a fourteen-pin GPIO header. This is a two-column header with the right column being connected to one entire GPIO port and the left side being connected to another entire GPIO port. Above that header is the I^2C EEPROM chip. The final component on the left side of the microcontroller layer connectors is a second potentiometer that varied the contrast of the LCD screen. On the top of the main board are four components: a 7-segment display, a one-row, sixteen-pin header to connect an LCD screen to the board, and two D-type latches. The D-type latches were used so that the 7-segment display could be used by one GPIO port instead of having to use multiple GPIO ports. The first latch stored what number was to be displayed and the second latch stored the signal for which one of the four spots the number was displayed on. Figure 8 shows the PCB layout of the modular interchangeable hardware architecture—the MSP430F5438A layer and all of the traces on both the top and bottom layers.



a) MSP430 layer. b) Traces on both top and bottom layers.

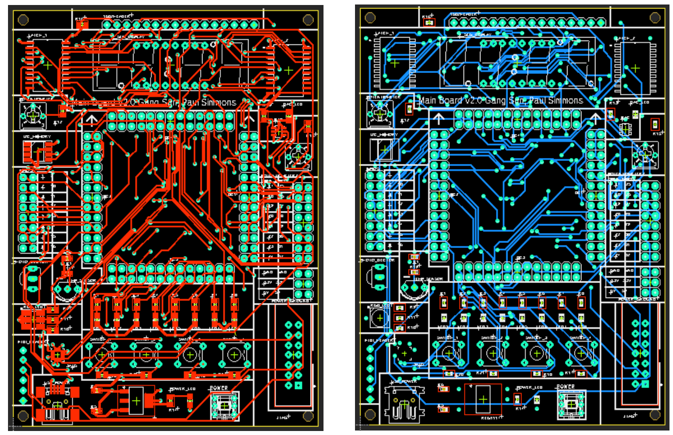
Figure 8. The PCB layout of the modular interchangeable hardware architecture.

Signal Layers

Figure 9 shows two signal layers: top and bottom. To potentially minimize costs of the board and make for a simplistic design, all components and silkscreen were placed on the top layer of the board. The bottom layer was used for routing of connections that could not be accomplished on the top layer or through the internal planes.

Embedded Systems Development Kit: Debugging and Evaluation

Two versions of the development kit were made. The version 2.0 design corrected a few errors from the version 1.0 main board and the microcontroller layers. Those errors were mainly related to the board layout and component placement. The biggest error related to the connections between the main board and the microcontroller layer. For version 1.0, when plugging the microcontroller layer into the main board, the male pins only went about halfway into the female socket, which did not make a great connection. Thus, for version 2.0, two headers on the main board and the microcontroller layer were moved outward one space.



a) Top layer. b) Bottom layer.

Figure 9. The PCB layout of the signal layers.

Also, there were other errors that were made on the main board. The JTAG header made a 180° rotation so that the notch on the header was facing outward. This let the user connect the cable without the cable being in the way. The four female headers in the middle of the main board along with the LEDs, switches, and all of the connecting resistors were moved down so that the 7-segment displays had more room. A new power switch pad was used for a smaller power switch. Figure 10 shows the circuit board pictures of the MSP430F5438A layer. The TI-MSP430F5438A is an ultralow-power microcontroller that features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. It has three 16-bit timers, high-performance 12-bit analog-to-digital (A/D) converters, up to four universal serial communication interfaces (USCI), hardware multiplier, DMA, real-time clock module with alarm capabilities, and up to 87 general-purpose I/O pins. On the MSP430F5438A layer, two external 32.768K and 16M crystals were connected with the oscillators XT1 and XT2 pins to generate clock signals for the microcontroller. A reset circuit included a 47k-ohm pull-up resistor, a 2.2 nF capacitor to ground, and a 1N4007 diode.

Figure 10 illustrates the main board along with the top, front, and bottom views of the modular TI-MSP430F5438A microcontroller layer. The final dimensions for version 2.0 of the main board came out to be 101.6 mm x 76.6 mm, while the dimensions of the modular microcontroller layer were 42.9 mm x 45.8 mm. The microcontroller layer was about sixty percent as wide as the main board and only forty-two percent as long.

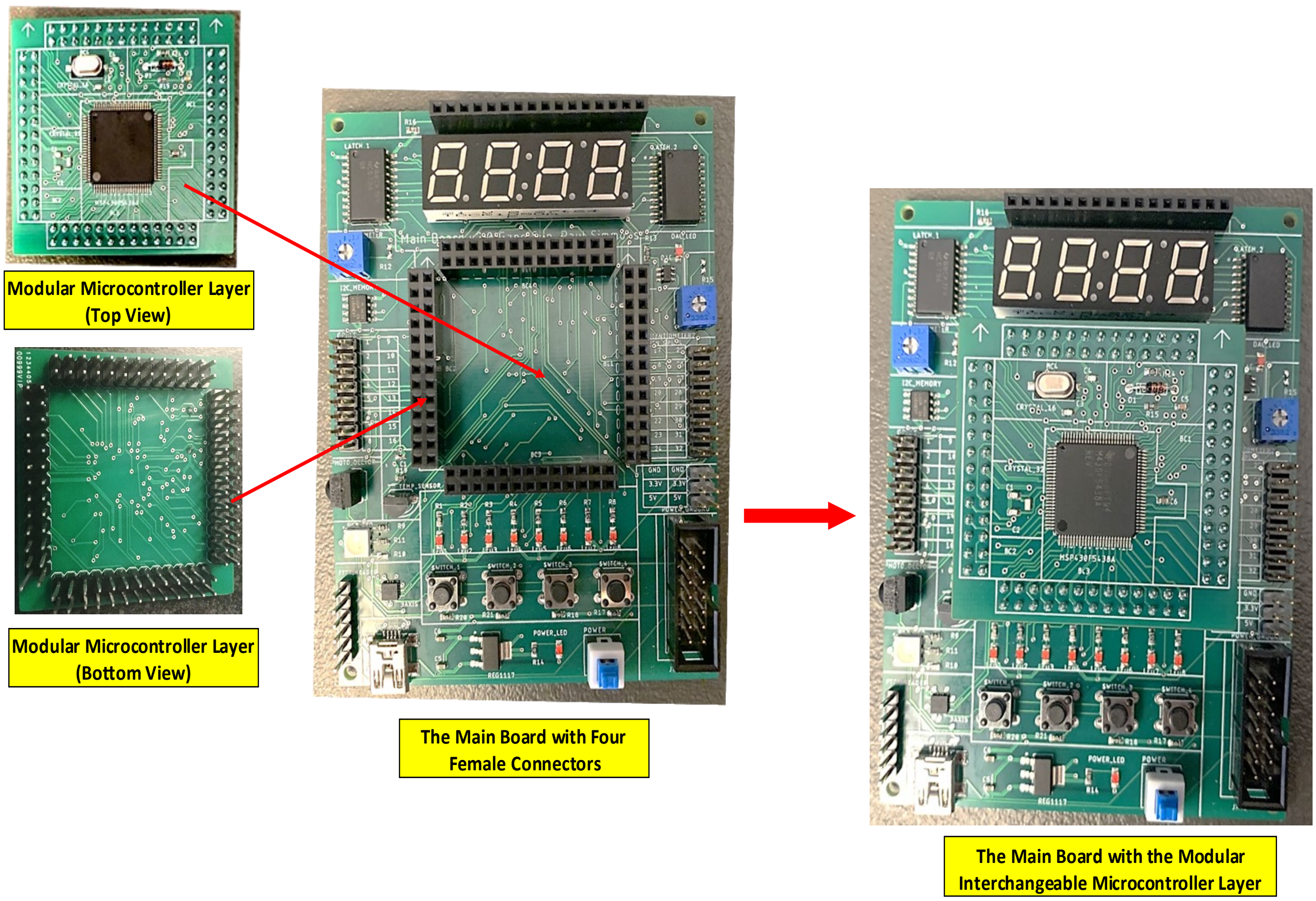


Figure 10. The version 2.0 modular MSP430F5438A microcontroller layer and main board.

With most of the components pushed out to the edge of the main board, the microcontroller layer did not block any of the components. For the layout of the microcontroller layer, there was a two-row, twenty-six-pin male header on each of the four edges (bottom view). For the layout of the main board, the four, two-row, twenty-six-pin female headers were placed in the middle of the board to connect the main board with the microcontroller layer. Each circuit unit was tested and a series of laboratory assignments were designed using this new hardware developed environment. The cost for the main board of the version 2.0 development kit was $372.28, along with $169.84 for the microcontroller layer, totaling $542.12. This $542.12 was paid for the manufacturer to produce 5 PCBs for the main board, 10 PCBs for the microcontroller layer, provide all of the components necessary to complete one of each board, and solder all of the components onto the appropriate board. Having the manufacturer (SEEED FUSION) solder all of the components was the most expensive part. If 50 development kits are procured and populated at a time, the price of each development kit would drop to $55.

Conclusions

In this paper, the authors presented the overall design of a new, embedded systems design kit with modular interchangeable microcontroller layers. The new kit encompassed useful analog, digital, and new wired and wireless devices, but its cost and size were reduced remarkably. The modular interchangeable microcontroller layers contained different brands of microcontrollers (e.g., TI-MSP430F5438A and Atmel-AT-MEGA2560V), which could be directly interfaced to the main board. This novel design allowed students to use the same devices and peripherals within various microcontroller development environments simply by changing the modular microcontroller layer (e.g., inserting the MSP430F5438A layer). It was expected that the new embedded systems development kit would provide an affordable hardware environment for students to learn, design, and test embedded systems using advanced microcontroller technology and a wide range of new communication protocols and devices.

Acknowledgments

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Biographies

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A LASER TRACKING SYSTEM USING ARDUINO AND MATLAB

Hamid Tahery, University of Northern Iowa; Jin Zhu, University of Northern Iowa

Abstract

Laser-tracking systems are used for detecting and tracking targets with specified characteristics, such as the shape and color of an object. It can have many applications in various areas. A laser-tracking system can be used in laser-cutting tools in industry or at crime scenes to look for specific blood stains, which are invisible to the human eye. In this paper, a laser-tracking system using an Arduino UNO board and MATLAB software was implemented. Image processing was done on the object using the MATLAB image-processing toolbox. An Arduino board was used to control a laser and make it follow the center of the object with the help of a high-resolution camera. The results showed that the method was effective in tracking objects with different colors and shapes.

Introduction

The word laser stands for Light Amplification by Stimulated Emission of Radiation. Lasers produce a very narrow beam of light and are useful for a variety of technologies and instruments, including medical use (Boulnois, 1986), machining processes in industry (Dubey & Yadava, 2008), cutting of different materials (Sharma & Yadava, 2018), and laser-tracking systems (Umetsu, Furutnani, Osawa, Takatsuji, & Kurosawa, 2005). Laser-tracking systems have been used widely in different areas. For example, Ramesh, Mannan, and Poo (2005) used laser tracking to improve the performance of servo systems in CNC machines. Also, laser tracking can be used in gesture recognition (Perrin, Cassinelli, & Ishikawa, 2004) and for computer gaming (Uchiyama & Saito, 2007). Consider playing a video game without using a mouse. A laser can track the hand position and the computer mouse can move based on the order accordingly, which makes the games more enjoyable, especially in large displays (Ionescu, Suse, Gadea, Solomon, Ionescu, & Islam, 2013; Shim & Kim, 2016).

In this paper, the authors discuss the design and implementation of a laser-tracking tool using the Arduino UNO platform and MATLAB software. Arduino is an open-source physical computing platform with a simple micro-controller board (Boulnois, 1986). Also, as this platform is open source, it can be used for study and research purposes. The name Arduino comes from a bar in Ivrea, Italy (Nayyar & Puri, 2016). It was originally developed for designers and artists to test electronic prototypes (Galadima, 2014) to share their ideas and to promote innovations. However, it has been used in many other projects. For example, Desai and Patel (2015) tested the use of Arduino on an industrial CNC machine as a control unit to make the design simpler and easier.

The MATLAB image-processing toolbox was used in this current study. The MATLAB tool box has been widely used in many studies, from applications in medicine and biology, to detecting road-pavement surface cracks and measuring tomato qualities (Gastélum-Barrios, Bórquez-López, Rico-García, Toledano-Ayala, & Soto-Zarazúa, 2011; Khan, Hassan, Malik, Islam, Ansari, & Gilani, 2014; Oliveira & Correia, 2014). The color and shape of an object can be defined within MATLAB's image-processing program. Considering different dimensions of an object, the laser would try to track the center of the object. Figure 1 shows an example of an Arduino, which is able to understand and specify different objects with different colors using color sensors such as the TCS3200, a common Arduino color sensor. However, this sensor can only determine a limited number of colors at a very short distance. The shape of the object is also important. Therefore, a color sensor was not suitable for this current project.

Figure 1. TCS3200, a common Arduino color sensor.

The first shortfall of this sensor is that it can only be used at very short distances (please refer to the TCS3200 datasheet). It can distinguish the colors of red, blue, and green, but not the shapes. As a solution to these problems and for the purposes of this project, the use of another software package, MATLAB, was necessary. MATLAB image processing is a very powerful, tool but it needs high computing power and an Arduino UNO board cannot be used. Note that it is possible to use the Arduino's microprocessor for image processing but, for the purpose of this project, it was not powerful and reliable enough. Instead, a Windows computer with Core i5, 3.5 GHz CPU and 8GB RAM memory was used for image processing.

The purpose of this project was to track objects with special, predefined colors, and considering the shape of the object using a laser-tracking system built by Arduino UNO. A Windows laptop computer with MATLAB and Arduino installed was used. With a high-resolution camera, real-time videos of each item were recorded and sent to the MATLAB software for real-time image processing. After MATLAB finished processing the images in real time, if the object's color matched the predefined color in MATLAB, then the position of the laser and its distance was calculated. The computer did most of the processing work and had the supervisory role. MATLAB considered the size specification and pointed a laser at the center of the object, and a closed-loop control system in MATLAB was used to keep the laser in the center. Figure 2 shows a simple diagram of the closed-loop control system for this program. MATLAB calculated the position of each image pixel and found the middle of the image, based on the average distance.

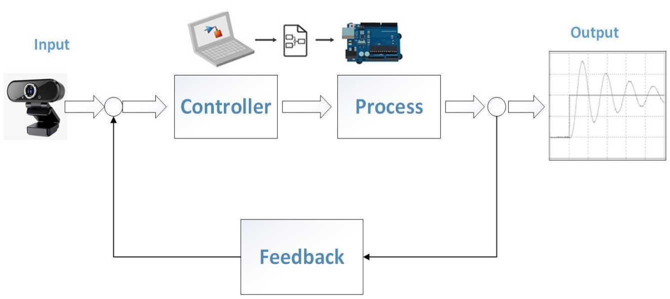

Figure 2. A simple diagram of the closed-loop control system for the proposed method.

The laser position was determined using a closed control-loop system in MATLAB. The webcam could be moved in any direction. Figure 3 shows how the two servo motors were connected together with special servo mounts, in which one of them could move the laser horizontally and the other vertically. These two servo motors were connected to an Arduino UNO board and the Arduino board itself was connected to a computer. The webcam was connected to the computer and the pictures were processed in MATLAB. Based on the results of the image processing, the directional information was sent to the Arduino board. In this project, the program was still able to point the laser in the center of the object, when both the object and the webcam changed their positions. This means that it could be used for applications involving a moving camera and/or a moving object.

Using a high-resolution camera, many images were taken each second. The photo format was RGB, which has the best quality for image processing. Each item had a different shape. In image processing, the computer finds the center of each item based on the Euclidean distance formulation. If laser position and central object position are denoted as (X_{LP}, Y_{LP}) and (X_{OC}, Y_{OC}), respectively, then the error is defined as the distance between laser position and object position. The error can then be calculated using Equations 1-4:

$$\Delta x = x_{LP} - x_{OC} \tag{1}$$

$$\Delta y = xy - y_{OC} \tag{2}$$

$$dist(x, y) - \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \tag{3}$$

$$error = dist(\Delta x, \Delta y) \tag{4}$$

where, x and y are two points in Euclidean n-space and x_i and y_i are the Euclidean vectors.

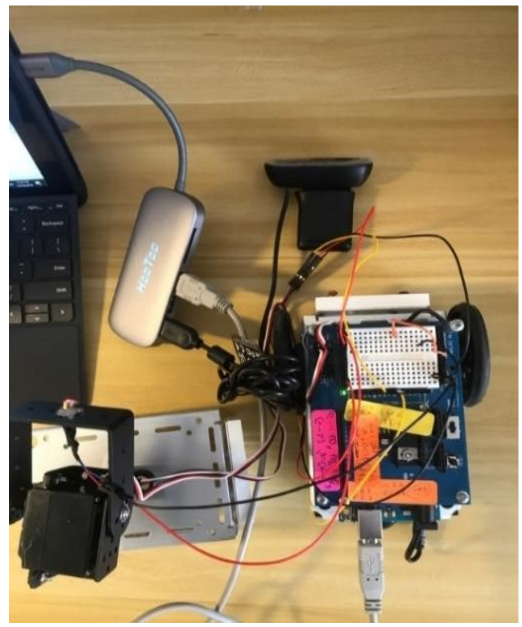

Figure 3. Servo motors connection to Arduino and USB connection for Arduino and webcam.

Figure 4 shows how the program calculates distances between each two points of interconnecting diagonals and the borders of shape, and based on which decides where the center of the object is. In another step, the image-processing program locates the red laser on the screen. The positions of the laser and the object at any moment are calculated based on their positions in the image in time. Figure 5 shows how the Euclidean theorem is used to calculate the error. If the error is less than a predefined error, it means the laser is close enough to the object center in which case the laser point would stay at its current position.

Sending Moving Orders to Servo Motors using the MATLAB-Arduino Interface

Let (M, N) be the position of the laser with an image quality of 680x480 pixels. For finding the center of the image, M needs to be deducted from 340 and N needs to be deducted from 240 (which are the center of the image and changes based on the image resolutions). Then, based on the calculated distance, the program sends orders to the servos to move to specific positions such that the distance error decreases each time (closed-loop control system). For this purpose, MATLAB sends signals to the Arduino board via a predefined MATLAB-Arduino interface (Ayi, Ganti, Adimulam, & Karthik, 2017). Two MATLAB add-on Explorer packages need to be installed, which is explained in the study by Ayi et al. (2017).

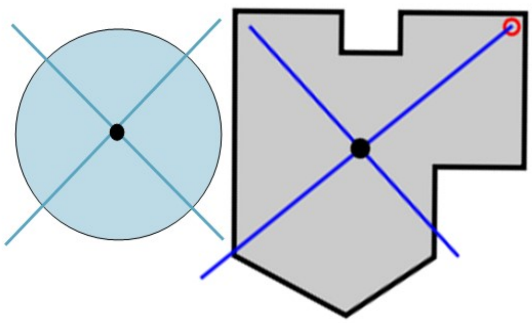

Figure 4. A simple method for finding the center of an object.

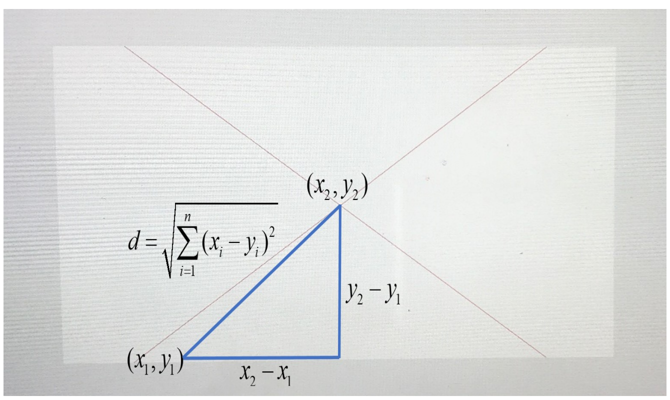

Figure 5. Error calculation using Euclidean theorem formulation.

Receiving Moving Orders by Arduino UNO and Transferring to Servo Motors

A laser was connected and navigated by the Arduino board with the help of two servo motors. When a data stream from the computer is received by the Arduino UNO to navigate the laser in order to track the object with the special color, the Arduino would translate those instructions and adjust the servo motors so that the laser would point to the center of the object. A program was written for Arduino to receive and translate the MATLAB output signals, recognize the servo motor pins, and send data to the servo motors. Figure 5 shows a flowchart of the program.

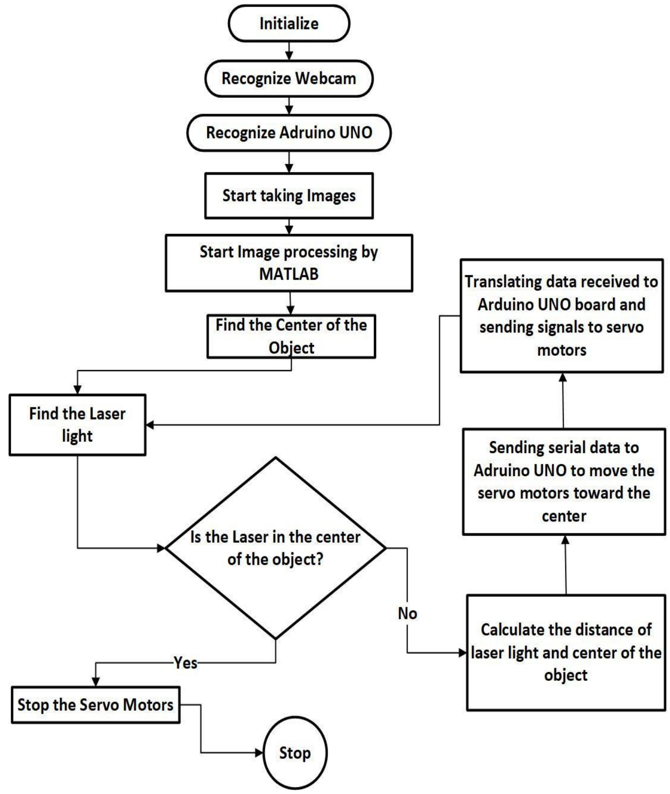

Figure 6. Simple flowchart of the proposed algorithm.

Results

To test the system, two scenarios were considered. The first was for the case where the object was stationary but the camera was moving. The second was for the case where the object was moving. In these operations, the computer played the role of manager and controlled the robot with MATLAB. First, a picture was taken and then processed in MATLAB. The center of the image was then calculated and, with the consideration of the laser position, MATLAB sent a controlling order to the servo motors to move the laser position to the center of the image. This process was performed in a fraction of second and a stream of images was taken by the camera and sent to MATLAB for image processing. This closed-control loop calculated the laser's position and took it to the center of the image in a reasonable amount of time. The results showed in both of these scenarios that the robot acted accurately and fast enough to be able to follow the center of the object. Also, different objects with different colors and shapes were tested and the results showed that the program worked accurately and very fast.

Conclusions

A laser-tracking system algorithm using MATLAB software and Arduino UNO was tested. The algorithm was able to identify objects with different colors as well as objects with different shapes with predefined colors and track the object's center with the laser. As most of the processing was done with MATLAB, the results showed that using a good tracking algorithm, accompanied by a powerful processor, notably accelerated the tracking processes. The results also showed that the proposed program could identify the center of different objects and that it worked better for round and rectangular objects. As a future study suggestion, a more detailed image-processing code that is able to identify different shapes would be suggested. Also, using artificial intelligence (AI) might help to increase the accuracy and speed of the program.

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Implementation of a Raspberry-pi Temperature Sensor and Smart Mirror-based, Display-unit Integration using Open Source Tools: A Capstone Project

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Abstract

Gathering biological data and displaying it in a user-friendly manner is always of interest and gaining more popularity these days due to the recent COVID-19 pandemic. In this capstone study project, a prototype model for sensing human body temperature using a Raspberry-pi microcontroller system and displaying it in a cost-effective and user-friendly manner was explored. The construction of the display unit was inspired by the "smart mirror" concept in which people simply stand in front of the mirror and their biometrics will be displayed on the screen. In this project, the authors focused on demonstrating a biometric display for screening purposes, along with various display options for business information, such as menu items in restaurants, schedules in business firms, the weather, or any other piece of information that a business would want to display. Another major highlight of this study was the integration of Raspberry-pi and the temperature sensor, which, combined with several other free online tools/resources such as GitHub, dataplicity, and freeboard, led to online access, communication, data handling, and the display of the project output. In this paper, the authors present in-depth technical aspects of the system.

Introduction

Measuring biometric information of the human body, such as heartbeat and body temperature, and displaying them using a smart-mirror concept has been explored in detail in several recent published studies (Miotto, Danieletto, Scelza, Kidd, & Dudley, 2018; Colantonio et al., 2015; Park, Lee, Seo, & Billinghurst, 2020). Monitoring different vital signs is critical in maintaining the health and wellness of human beings. The widespread Coronavirus (COVID-19) pandemic has impacted the daily lives of people all over the world in one way or another. Businesses, workplaces, and schools have started to screen people using their body temperatures to maintain health and safety.

In this paper, the authors describe the capstone project that focused on designing and creating a touch-free, human-body temperature sensor and display unit using a Raspberry-pi microcontroller-based system. The concept of implementing an affordable mirror display unit capable of displaying biometrics along with any other needed business information was also built and tested as part of this project. Various open source and free online tools were used for the successful completion of this project. These are also described in detail in this article.

Measuring Biometrics with a Microcontroller

Studies show that microcontrollers such as Raspberry-pi and Arduino Uno can be connected with a heartbeat sensor and/or a body temperature sensor and used to read a person's vital signs. In a recent study, a group of scientists describe how their research team accurately read heart rate and precisely measured temperature, and how they also took the project one step further by designing the system to transmit the data wirelessly to a laptop computer (Sollu, Alamsyah, Bachtiar, & Bontong, 2018). The data were then stored on a server and could be retrieved at any time with a specific code so that patient data would be accessible if needed at later times. This work with the Raspberry-pi microcontroller demonstrated that the unit can be used to create systems to measure a person's vital signs. Because of the Raspberry-pi's small form factor and low power consumption, it can be used in any number of ways to read and display critical information about a person's heart rate and temperature. While their research and design showed that microcontrollers are capable of measuring biometrics, it is important to investigate how this is being implemented in real-world scenarios.

In another study, the idea of monitoring a patient's body temperature, respiration rate, heartbeat, and body movement using a Raspberry-pi board was explored (Kumar & Rajasekaran, 2016). However, equipment that allows doctors to continually monitor their patients' condition is usually expensive and not always available to those in developing countries. Another group of researchers proved that the same microcontrollers that Sollu et al. (2018) used can be implemented in such a way as to track the vitals of patients over a long period of time (Purohit, Jadhao & Bhavarkar, 2018). The data collected by their microcontrollers were transmitted through common networking methods to the patients, their families, and to medical professionals at a very low cost. For their study, the Raspberry-pi 3 model was chosen as the main board of the project because of its small size and its incredible ability to read and transmit data. With 40 I/O pins, a 1.2 GHz processor on board, and an 802.11 Wireless LAN and Bluetooth chip, the Raspberry-pi 3 has more than enough power to read data from different sensors and transmit them via an internet connection. They chose the DHT11 temperature sensor, a digital temperature sensor that is known for its reliability in measuring temperature within one to two degrees of the actual value. Purohit et al. (2018) showed that, with the power of the Raspberry-pi and Arduino microcontrollers, a temperature sensor, heart-rate sensor, and a blood pressure cuff sensor can be connected and programmed to constantly read all the vitals of a patient.

DS18B20 Temperature Sensor

Based on the literature support from the aforementioned articles, Raspberry-pi was selected as the microcontroller to be used in this current capstone project. Choosing an appropriate temperature sensor for the project was the next critical step. The DS18B20 is a very small digital thermometer that only has three pins for data, power, and ground. (https://datasheets.maximintegrated.com/en/ds/DS18B20.pdf). It is affordable and can be used to accurately measure temperatures in a variety of situations. These features make the DS18B20 a very popular choice when it comes to taking temperature readings. It is compatible with a variety of controller units, including the Raspberry-pi and Arduino. In a study by Chen, Zhang, and Wang (2008), a DS18B20 temperature sensor was used to design a body-temperature monitoring system. The article described how they were able to use the DS18B20 sensor with a microcontroller to successfully create a body-temperature measurement system. The programming and data acquisition of the design seemed a bit more complicated, however, due to the use of the AT89S51 microcontroller. A more user-friendly controller like the Raspberry-pi was chosen for use in this current project, as it was considered the better option than the DS18B20 temperature sensor.

The DS18B20 sensor is a three-pin device—ground, data, and power pins. There are two main ways of connecting the sensor for reading temperature. The difference in the connection methods is mainly in how the sensor is powered. One of the methods is called parasite power in which the voltage to power the device is taken from the data line. This method can be used when a power supply may not be available. This is a less-popular method for connecting the DS18B20 sensor, as it adds some complexity and extra conversions into the final temperature output. The other, and more popular method is to provide a direct VCC voltage to pin 3. This takes away the extra work of connecting the power and data together through the parasite power method (Chen et al., 2008). Figure 1 shows the connection diagram for the DS18B20 sensor with +5V VCC as the power source. Accuracy is important when taking a body temperature measurement. Based on the findings by Chen et al. (2008), the DS18B20 is a very accurate piece of electronic equipment. While the sensor can read temperatures anywhere from -55 degrees Celsius to 125 degrees Celsius, it operates best between -10 degrees Celsius and 85 degrees Celsius with an accuracy of approximately +/-0.5 degrees. Based on the aforementioned reasons, the DS18B20 was selected as the temperature sensor to be used in this capstone project.

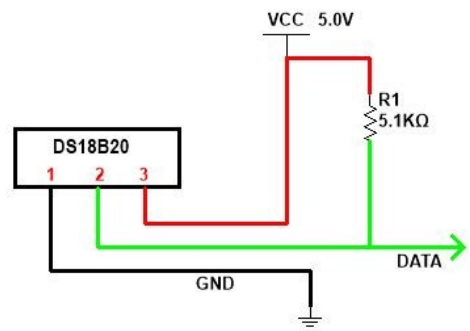

Figure 1. The DS18B20 sensor connection diagram showing the direct VCC connection to pin 3.

The Idea for a Smart Mirror

Once the temperature is derived from the sensor, the focus needs to be shifted to displaying the readings in a user-friendly fashion. The most popular method is to use a simple pixel-based LCD display. These are inexpensive and easy to implement with all kinds of sensors and microcontrollers. While the basic LCD display can be used, different GUI-based designs can be encoded to make the temperature reading more presentable. Again, this is where the use of more traditional microcontrollers such as the Raspberry-pi is extremely useful.

With the rise of smart devices such as Amazon Alexa, Google Home, and Apple Home pod, designers and consumers alike are looking for ways to implement more smart devices in their daily lives. One such approach is the use of smart mirrors for health monitoring and general wellness. In a study by Colantonio et al. (2015), they discussed the design and implementation of a smart mirror, cleverly named Wize Mirror, which was meant to detect certain health risks in humans and encourage them to alter habits to live a healthier life. The Wize Mirror was designed to combat the risks of obesity and heart disease and help people make choices that can positively affect their health. The authors outfitted the Wize mirror with numerous pieces of technology to make monitoring health an easy daily task with the use of components such as a breath-analysis device and an IR thermometer. Users can breathe into the analyzer while their temperature is being read by the sensor in order to get a good idea of their overall health. Statistics and suggestions are then shown to the user to encourage a better lifestyle.

Colantonio et al. (2015) further discussed an application of the Wize mirror in their article, which was to connect the device onto a network and then share the critical health data to a health provider to ensure that a patient at home is in good condition and is taking needed steps towards better health. Several similar studies focused on the concept of smart mirrors have been published since then. These studies targeted a wide range of areas including the healthcare industry, home security, and personal training. A Do-It-Yourself smart-mirror concept was proposed by Kulovic and Ramic-Brkic (2018). A detailed explanation of the construction and a cost analysis of the system is mentioned in their paper. In a similar study by Miotto et al. (2018), the authors discuss various aspects of the use of smart-mirror technology in biomedical applications. They also laid out the pros and cons of the use of these technologies in the healthcare industry along with related challenges in using these smart-mirror technologies in the healthcare field.

Expanding the applications of smart-mirror technology to home security, Nadafa, Hatturea, Bonala, and Naikb (2020) proposed the use of this technology for an intruder-detection application. In a study by Park et al. (2020), the authors explained the application of the smart mirror in personalized training, another diverse application of the technology. In another study by Uddin, Dey, Parvez, Mukta, and Acharjee (2021), the authors proposed the use of artificial intelligence and smart-mirror technology for facial-recognition systems; they also explore the use of Internet of Things (IoT) in their article. This current capstone project was inspired by the "smart mirror" concept and the various methods used for displaying data using internet-based technologies. For this project, a mirror-based display unit that houses some form of technology behind it was designed and constructed using cost-effective approaches. Along with this concept, several different online-based, free tools were used for network communication and data display.

Display Unit

As discussed, a cost-effective, mirror-like display unit was chosen for this current capstone project. The outer casing of the smart mirror was constructed using lumber, paint, clear acrylic, one-way mirror film, and a monitor mount. The goal was to create a case that simulates a mirror and, when the monitor is powered on, the user can see the display as well as the reflection from the mirror film. One-way -mirror film was chosen, due to its low cost when compared to purchasing an actual one-way mirror. The clear acrylic was cut to size so that it would fit onto the door of the case then the mirror film was applied. One-way mirror film is a popular choice for many homeowners to reflect sunlight and increase privacy during the day. One-way mirror film is easily applied to smooth surfaces, such as acrylic or glass, by wetting the surface and smoothing it out until dry. A vesa (Video Electronics Standards Association, https://vesa.org) mount was put inside the case and a 24-inch monitor was installed.

The monitor was then connected to a Raspberry-pi micro-controller to be used for the rest of the smart-mirror design. The result was a perfect reflection when the light outside the case was greater than inside, and the image displayed on the monitor could be clearly seen. Figures 2 and 3 show the images of the case. Figure 2 shows the scenario when there is not enough light, and the display shows nothing. Figure 3 shows the situation with good lighting and, hence, a nice reflection and the display is visible. Figure 4 shows the data display on which a weather map is displayed.

Figure 2. Display case construction showing not enough lighting and, hence, not a good reflection. (The hand symbol helps to see the case border.)

Figure 3. Display case showing good lighting and, hence, a good reflection.

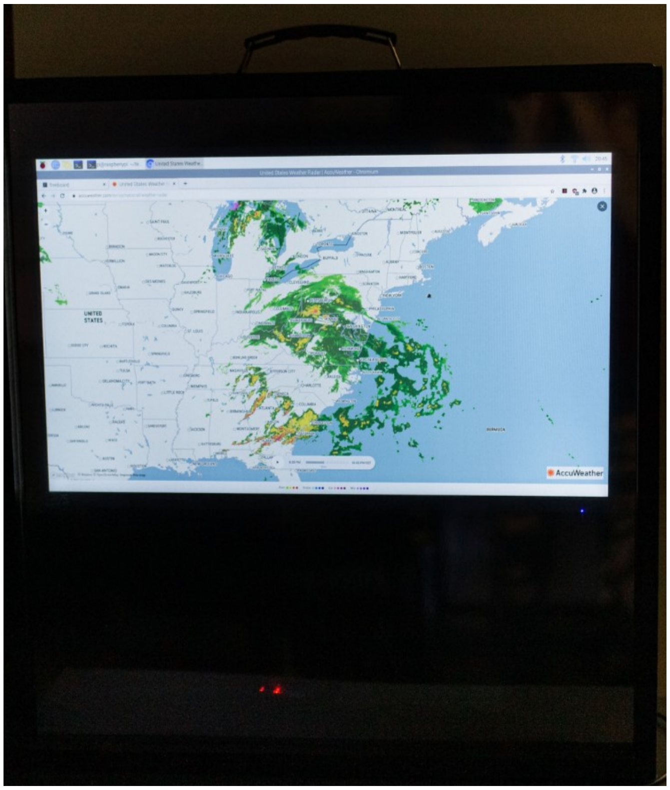

Figure 4. Mirror showing the weather map displayed on the monitor.

Raspberry-pi and Implementation of the DS18B20 Sensor

To turn this normal display mirror into a handy smart device, the Raspberry-pi microcontroller was integrated into the system. As discussed earlier, the Raspberry-pi is an open source microcontroller that operates like a miniature computer. It is based on the Linux operating system and supports several programming languages, including Python and Java. The model chosen for this capstone project was a Raspberry-pi 4 loaded with 8 GB of memory and a 256 GB SD card for storage. With 40 I/O pins, 4 USB ports, wireless card, LAN port, and micro HDMI, the Raspberry-pi can handle several inputs and outputs and be used for any number of applications. It is a popular choice among electronic enthusiasts and was a perfect fit for this current project.

One of the most difficult parts of creating a temperature-sensor system with the Raspberry-pi microcontroller is selecting a compatible sensor. Choosing a sensor that can take advantage of the onboard I/O and be integrated into a program is the key. Based on the literature reviews discussed in the previous sections, the DS18B20 digital temperature sensor was chosen as the perfect device for measuring temperature. It can be easily integrated with the Raspberry-pi microcontroller.

Once the Raspberry-pi and the DS18B20 temperature sensor were chosen for the smart mirror, the next step was to get everything connected to the Raspberry-pi through several of the 40 I/O pins. Since the DS18B20 sensor is a three-wire electronic device, only three I/O pins were needed on the Raspberry-pi. Pins 2, 7, and 9 were used for power, data, and ground, respectively. An external bread board was used to make these connections, so everything could easily be connected and disconnected without constantly touching the board of the Raspberry-pi. The pins from the breadboard were then connected to their respective pins on the Raspberry-pi for temperature measurement.

Operating system and Interfacing

After completing all of the hardware connections, the next step was to work on the operating system and ensure that data could be read from the DS18B20 temperature sensor. The Raspberry-pi is capable of imaging with many different operating systems, such as the consumer systems of Windows and Mac OS. These operating systems can be used for all sorts of electronics projects and allow the user to program the Raspberry-pi with ease. For this current project, the popular Linux operating system for Raspberry-pi, called Raspbian, was chosen. Raspbian OS is a Linux-based operating system that was easily downloaded from the internet and flashed onto the Raspberry-pi using the micro SD card, which was also used for system storage. Once the operating system was loaded, the Raspberry-pi could be run and powered on and off just like a computer. The 8 GB of memory was helpful, as it allowed for a quick boot time and could easily handle many open windows and programs running at the same time.

The next step was to start the configuration and programming of the DS18B20 temperature sensor. To interface the temperature sensors and download the necessary programs for the Raspberry-pi, Windows Terminal was used. Windows Terminal (WT) is a command line interface on which nearly everything for the microcontroller can be controlled. To access WT, an SSH connection was used through PuTTy. PuTTy is an open source tool used to access and emulate WT for computers and servers. To use PuTTy, the SSH feature of the Raspberry-pi had to be turned ON in the settings. Once this was complete, PuTTy would run on any other computer on the same network to access the WT interface of the Raspberry-pi. To make the connection, the IP address of the Raspberry-pi (192.168.1.252) was entered. Figure 5 shows the WT commands, including the Raspberry-pi IP address. To ensure that full access to the Raspberry-pi was available, an account called a Superuser was used. A Superuser is a special account on a Linux operating system that has full administrative access to the machine. This account, named “pi”, was used to ensure that the session was elevated to the proper permissions, and to create and change directories as needed.

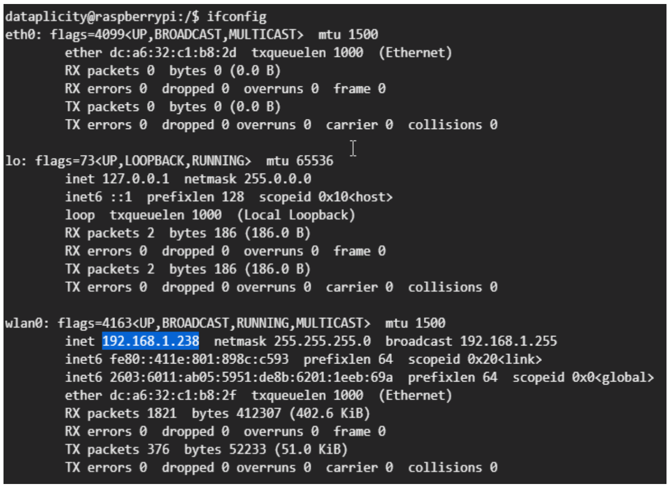

Figure 5. ifconfig command running in Windows Terminal to show the IP address of the Raspberry-pi.

After establishing the connection between the Raspberry-pi and the temperature sensor and made it accessible through PuTTy, the next step was to assemble the entire unit inside the smart-mirror case and connect it to the monitor, where it would remain for the duration of the project. While PuTTy is useful for accessing the Raspberry-pi on a device connected to the same network, the next problem to resolve was to ensure the device's accessibility for users from other networks. To resolve this, an online tool called "dataplicity" was used. By creating a free account with dataplicity and installing their free client on the Raspberry-pi through a WT command, the Raspberry-pi WT interface became available anywhere through dataplicity's online portal. While the project was mostly completed with all devices connected to the same network, this was an amazing feature to control the system, if it were deployed at a different location.

Programming

The DS18B20 needs a small amount of coding to read and display temperature. For this current project, a program from the open source site of GitHub was used. GitHub is an online site hosted by Microsoft where software developers and enthusiasts can collaborate and share their projects. To use this program, the correct directories and permissions were needed to be set up on the Raspberry-pi. The directory "projects" was created using the command *mkdir ~/*projects. Once inside this directory, the program was cloned onto the directory using the URL https://github.com/timfernando/temperature-serve-pi.git. The user can then change to the directory in which the program will run "*temperature-serve-pi*" which was created from the imported program files from GitHub. The next process was to install the necessary requirements to run a webserver named gunicorn. This is a very light webserver that does not use many resources. To finally run the program and get a temperature reading from the Raspberry-pi, the command *sudo gunicorn temperature:app -b 0.0.0.0:80* was used (see Figure 6).

This command runs the program as the webserver through internet port 80 of the Raspberry-pi, which dataplicity uses to communicate with. Once the command was successful, the user would see the system time with the words "request received." This was part of the Python program used to display "request received" when a valid temperature reading is being taken by the DS18B20 temperature sensor.

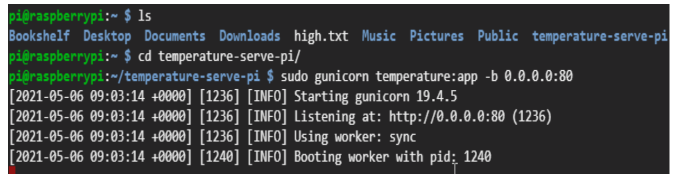

Figure 6. Windows Terminal command to run the program for a temperature reading of the DS18B20 temperature sensor.

The final step in the process was to display the results in a better fashion than that given in a WT window. A benefit of having dataplicity running on the Raspberry-pi is that it creates a wormhole, a type of URL link that can be used by other programs and devices to access data from the Raspberry-pi. The website freeboard.io is one such program that the combination of the Raspberry-pi and dataplicity can take advantage of. Freeboard.io is a web-based platform for creating a dashboard of data. Figure 7 shows the wormhole, mentioned earlier, that dataplicity creates that can be imported into freeboard.io in order to display the temperatures read by the DS18B20 sensor in a nicely represented graphical gauge. This display option was used as an example for showing that a variety of options are available for the users when it comes to displaying data. The settings can be altered to display temperatures in both degrees Fahrenheit and degrees Celsius. Other items can be displayed as well, such as maps and the weather. It is a good platform for organizing and displaying statistical information and can be explored well beyond the scope of this capstone project.

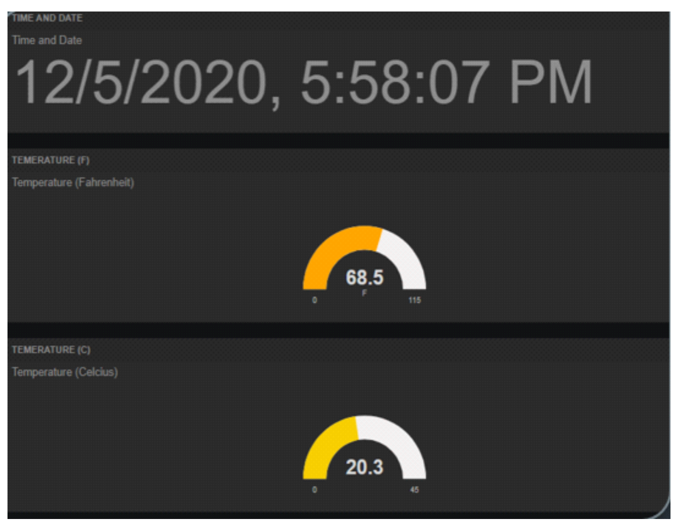

Figure7. Example of output captured in freeboard.io showing the temperature as a graphical gauge display.

Study Results and Validation Tests

With the sensor connected to the Raspberry-pi and the entire unit connected to the desired network through dataplicity, validation tests were conducted to ensure that the entire arrangement was capable of measuring the temperatures correctly. These tests also ensured that the data were displayed properly by communicating through the various interfaces involved. Several scenarios were used to ensure that the system could function as designed under various situations. The following list provides the test scenarios and their corresponding temperatures used for measurements.

Test Scenarios and Data Used

1. Room air temperature with thermostat reading 67°F
2. Room air temperature with thermostat reading 74°F
3. Water at room temperature with thermometer reading 66°F
4. Water left in fridge set to 38°F
5. Water with large amount of ice. Expected to be just above 32°F
6. Water just after boiling. Expected to be between 180°F to 220°F
7. Personal Body Temperature (Measured orally with a regular store-bought thermometer)

A total of seven validation tests were performed. Table 1 shows the outcomes of the test results obtained. As can be seen, the actual test results were very close to the expected values, with error percentages closer to 1%, except for test case scenarios #3 and #5. For #4, a 1.3% error was obtained. These differences could be due to the inaccuracy with the thermometers used, but the readings were still close to one another. Since one of the main aspects of this project was to measure human biometrics, the most important reading in this list is the body-temperature measurement. Since the DS18B20 is a waterproof sensor, it has no issues being submerged in water or measured orally by a user just like a regular thermometer.

Body temperature was measured three times periodically throughout the day. Normal body temperature ranges from 96.5-98.6°F. The three readings recorded by the DS18B20 were 97.7°F, 97.4°F, and 97.5°F. All of these values matched well with the then-measured body temperature of the first author using a digital thermometer that was purchased from a drugstore. The DS18B20 reading and the drugstore thermometer were always within +/- 0.1°F. Please note that the % error can vary depending on the accuracy of the digital thermometers used for testing. In this project, the drug store-bought thermometer had very good accuracy and, hence, resulted in a very low percent error. Figure 7 shows that all of the readings were displayed properly in the display mirror and were accessible anytime and from anywhere when the display mirror was operating.

Table1.Validation test results.

Test Scenarios	Expected Temperature (ET)	Measured Temperature Displayed (MT)	%Error [(MT–ET) / MT] *100%
1. Room temp. #1	67°F	66.9°F	-0.15%
2. Room temp. #2	74°F	73.9°F	-0.14%
3. Water at room temp.	68°F	66°F	-3.03%
4. Water in fridge	38°F	38.5°F	+1.3%
5. Ice water	32°F	32.7°F	+2.14%
6. Boiling water	180-220°F	181-190°F	N/A
7. Body temp.	97.55°F (average)	97.53°F (average)	-0.02%

Conclusions

From the tests conducted in this study, it was clear that the DS18B20 sensor integrated with a Raspberry-pi could create an accurate temperature-measurement system with an inexpensive but attractive display unit. The use of PuTTy, dataplicity, and freeboard.io rounded out the project to show results in a beautiful way on the display inside of the mirror case. An improvement on this system would be to use a contactless temperature-measuring device to read body temperature instead of a sensor that has to be used orally to get an accurate reading. Another enhancement would be to add even more display items to the freeboard.io dashboard, such as weather details of the day, menu items for restaurants, and events in a hotel or resort.

Acknowledgments

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Adapting Legacy Robotic Machinery to Industry 4.0: A Cloud-Based IoT Experiment

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Abstract

In this paper, the author presents an experimental adaptation of a non-collaborative robotic arm to collaborate with the environment, as one step towards adapting legacy robotic machinery to fit in industry 4.0 requirements. A cloud-based internet of things (CIoT) service was employed to connect, supervise, and control a robotic arm's motion using the added wireless sensing devices to the environment. A programmable automation controller (PAC) unit, connected to the robotic arm received the most recent changes and updated the motion of the robotic arm. The experimental results showed that the inexpensive service was tractable and adaptable to a higher level for machine-to-machine collaboration. The proposed approach has industrial and educational applications. In this approach, the CIoT technology is added as a technology interface between the sensors to the environment and the robotic arm. The proposed approach is versatile and fits a variety of applications in order to meet the flexible requirements of industry 4.0. The approach was implemented in an experiment using a MECA 500 robotic arm, an AMAX 5580 programmable automation controller, and an ultrasonic proximity wireless sensor.

Introduction

The market penetration of industry 4.0 has increased in the recent years; however, many factories that have a large amounts of working legacy automation manufacturing equipment, such as robotic arms and assembly machines, cannot afford to replace their entire systems. The financial problem caused by a slowing economy has turned it into a bigger dilemma. Adapting the existing legacy programmable automation machinery to industry 4.0 by adding the required connectivity to industrial internet of things (IIoT) would be one inexpensive solution to the above requirement. Similar needs also have been reported as a push towards adapting the legacy systems in a transitional model (Rosendahl, Schmidt, Luder, & Ryashentseva, 2015). Guidelines for adapting the legacy devices to industry 4.0 during the transition phase have been offered in the literature (Illa & Pandhi, 2018).

In this current paper, the author presents the experimental results of a study using cloud-based IoT between programmable legacy automation machinery and the environment that, in a more general form, could be extended to interaction between manufacturing machines such as robots and supervisory and control systems. Programmable logic controllers (PLC) have been the workhorse for industrial automation for decades (Chivilikhin, Patil, Chukharev, Cordonnier, & Vyatkin, 2020); however, their legacy programming language is not necessarily adaptable to a variety of robotic machines without a custom-designed hardware interface. Programmable automation controllers (PAC), with their versatility, computing power, and networking options, are one suitable replacement for PLCs in supervisory, control, and networking of robotic machinery. Even though employing a PAC instead of PLC, a regular PC provides much more flexibility; however, collaboration with the environment can be confusing, as it does not provide a clear model to facilitate actual implementation of the legacy devices in an industry 4.0 network. A model for transition of the legacy automation devices to industry 4.0 by using cloud-based internet of things (CIoT) was described by Delsing (2017). In a larger context, the development of an interface between enterprise and control systems has been discussed in ISA-95 (Williams, 1994).

It is worth mentioning that connecting the legacy devices using CIoT opens them up to their cyber-physical shortcomings (Pessoa, Pisching, Yao, Junqueira, Miyagi, & Benatallah, 2018). Cloud security is just one of these issues, though solutions have been proposed for this shortcoming (Hamilton & Alasti, 2017; Li, Cao, Hu, Xu, & Buyya, 2019; Sanislav, Zeadally & Mois, 2017; Tian & Jing, 2019). To ensure security in a wireless local area network (WLAN), WiFi Alliance and IEEE, in June of 2018, released WiFi protected access rev. 3 (WPA3) that allows customized security for IoT applications (Kwon & Choi, 2020). Big-data attributes, such as variety, velocity, and veracity, need to be discussed. Accordingly, a big-data gathering framework must be carefully defined, case-by-case, for smart factory management (Bellavista et al., 2019). For instance, in the collection of data from different sensors for quantities such as distance, speed, dust, angle, touch, moisture, pressure, light intensity, and gas density on a manufacturing site, besides their number, the speed and the quality of collection are also important. Accordingly, the problem of promoting a legacy robotic site can be an important big-data problem (Xian, 2020; Martins, Costelha & Neves, 2019).

An experimental integration of wireless sensing and CIoT to allow a non-collaborative robotic arm to collaborate with the environment was explored in this current study. The integration results showed that employing a PAC and cloud-based service provided the capability to make the robotic arm collaborate with the environment. In a broader view, this integration may allow robotic arms to collaborate with each other and the environment, which would result in higher productivity, a safer production environment, better products, and less capital expenses. In this study, an ultrasonic proximity sensor was used to monitor the distance of the approaching object in order to control the speed of the robotic arm. The proximity sensor sent its observation of the distance to the running CIoT service. The PAC read the update of the sensor observation and controlled the speed of the robotic arm in order to reduce the risk of incident with the approaching object. The results of this study have applications in industry and education. For instance, several companies use or produce products for cloud-based IoT, for example: the system that MAN uses for tracking engine faults in trucks and buses; smart factories automated by Siemens using industrial cloud-based IoT; and ABB considers sensors inside their robots for maintenance and repair of their products. For educational applications, students in their curricula become involved in robotic concepts and take courses in cloud computing and IoT. The proposed experience from this current study is a good merger between these three fields and allows students to become familiar with an area that is becoming a need in industry. Figure 1 illustrates a big-picture approach to the idea.

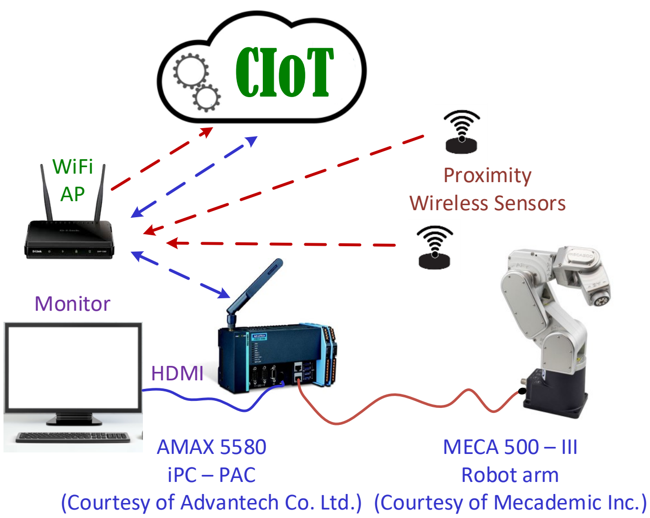

Figure 1. The programmable automation controller (PAC) is attached to the MECA 500 robotic arm to control its motion, based on the environmental data that it reads from the CIoT.

The proposed approach in this paper has no conflict with open source robot operating system (ROS) and eventually can be linked to extend the application domains of ROS. Similar to ROS (Guizzo & Ackerman, 2017), which allows users to shift their software stacks to fit their robot and application areas, this current approach allows the user to add their own code for interface, protocol, etc.

Problem Statement

To adapt legacy robotic machinery with industry 4.0 requirements, a pilot project was conducted. Wireless sensors, such as ultrasonic proximity sensors, shared their collected data from the environment to the robotic control unit. Traditionally, the control unit is a custom design-fed robotic controller that usually has insufficient capability for communicating with the environment or other brands of robots. The objective of this current project was to add sensors to the environment to allow the robot to collaborate with the environment and, specifically, to control its speed proportional to the distance of the approaching object, or completely stop the robotic arm. In the pilot project, a MECA 500-III robotic arm (MECA-500, 2018) and an AMAX 5580 (AMAX-5580, 2019) were used, which were non-collaborative a mini robotic arm and an APC unit, respectively.

The Proposed Solution

As mentioned, the MECA 500 robotic arm was controlled using a PC. This robotic arm was programmable either using a web interface that was accessible in a browser or independently using a high-level programming language such as Python. The robotic arm had no sensor or camera to get information from the environment or any other working machines. In the proposed solution, a modular PAC and sensor unit were considered that would allow the robot to receive real-time information from the environment. In the proposed solution, the PC was replaced with an AMAX 5580. This unit was an inexpensive modular, industrial personal computer (iPC) with PAC features. The iPC had several ports—USB, RJ45, EtherCat, RS232, RS485, HDMI, etc. The modular feature of this new iPC allowed for the addition of additional ports in order to control several devices simultaneously.

In this project, a Python code was developed to program, control, and monitor the robotic arm on the AMAX-5580 platform. The code controlled the speed of the robotic arm and, once an object approached the robotic arm, one or two of the ultrasonic proximity sensors would send the distance of the approaching object to the CIoT site. The iPC frequently and periodically checked for the most recent distance of the approaching object from the recorded sensor data over the CIoT and adapted the speed of the robot accordingly in order to avoid or reduce any potential damage from incident. In this scenario, the sensors would not communicate with each other. The collected data from the sensors were stored on CIoT and analyzed or refined by the running code over the cloud. The continuously running code on the PAC retrieved the refined data to use for environment awareness and controlling the speed of the robotic arm.

The proposed approach improved the safety of the work environments by adding awareness to the robotic arm control system. The robotic control system changed the speed of the moving arm, or completely stop it, as a moving object (a human being or another working robot) entered into neighborhood zones around the robotic arm. The original motivation for this research was a tragic event that happened in the Volkswagen factory in 2015, where a robot "in the setup process" killed a worker (Washington Post, 2015).

On the sensing side, one ultrasonic proximity sensor was attached to one ESP32 microcontroller board, where the WiFi, Bluetooth, and LoRaWAN connectivity allowed it to send observations from the sensor to the remote CIoT. The application of LoRaWAN for industrial IoT was previously investigated (Sisinni, Ferrari, Carvalho, Rinaldi, Marco, Flammini, & Depari, 2020). This wireless technology, which is unlicensed, due to its low power transmissions at low data rates, is becoming more popular for industrial applications, where the data volume is small. WiFi wireless connectivity is also an excellent option, specifically for short-range indoor applications. Due to the indoor location of the robotic arm in this current project, WiFi was used for access to the internet.

Based on the conducted measurements, the accuracy of the wireless sensors was around 1 cm, and the wireless sensor assembly could measure the distance up to around 5m. This accuracy and also the defense range were proper for reaction in medium-to-low-motion speeds in indoor manufacturing sites. In a general scenario, several wireless sensors at different angles could be placed around the robotic arm. The simultaneous monitoring of the robotic arm's surroundings would also allow the iPC to detect the direction of approach of the moving object, which could be another moving robot at the manufacturing site. Figure 2 illustrates this scenario in the development of a smart, invisible defense for the robotic arm.

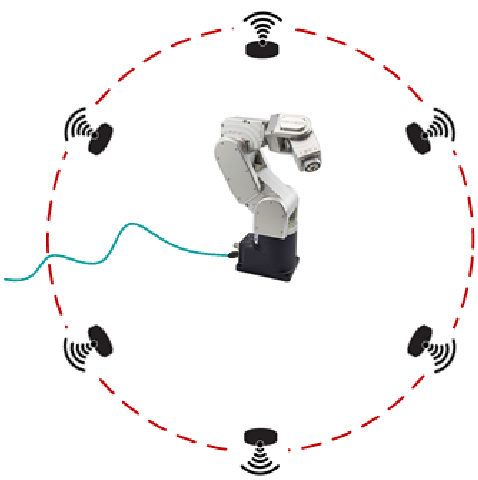

Figure 2. Using several wireless sensors to make a smart, invisible fence around the robotic arm.

The general steps of the algorithm to the proposed solution are shown below, and include the step where the iPC continuously watches for any new updates in the data log for any possible approaching objects in order to properly change the speed of the robotic arm based on its distance and zones. Design of the Python code on the iPC is extremely important, as it needs to use interrupts or multi-tread programming to make sure that the robotic arm reacts in time.

1. Wireless proximity sensors sense the distance of the approaching object.
2. The presence of the approaching object is reported via WiFi to the running service over the cloud (CIoT).
3. The reported distance of each sensor is stored in a database over the cloud and presented in graph versus time.
4. The PAC collects each update from the CIoT database.
5. The speed of the robotic arm is controlled proportionally, if the object's motion and the robotic arm are in risk of collision.
6. Repeat the process from step 1.

Experimental Implementation

This project was implemented in four phases: i) search for suitable sensors and communication devices, as well as approaches for implementation of environmental sensing; ii) find a cost-efficient implementation system for access to CIoT services; iii) purchase an affordable PAC as a replacement for PLC and PC to work in industrial environments; iv) search for a capable programming language that has potential networking capability in order to retrieve the stored data on the CIoT database and can be used to program the robotic arm. In the first phase of the project, several breakout microcontroller boards with wireless communication capabilities were considered as candidates; in the end, an ESP32 microcontroller was selected, due to its several wireless communication ports. Also, among a large number of sensors, an ultrasonic proximity sensor was selected, due to its simplicity and low cost. For the first implementation phase of the project, only one wireless ultrasonic proximity sensor was attached to one ESP32 microcontroller board.

In the second phase of the project, the provisioning requirements of the CIoT services were reviewed, such as leasing web space, creating online database, programming for online visualization of the data, and security for private access to the stored data. Against the development of the above items, there was another approach for use of the available CIoT services. After preparing a list of the CIoT service providers, and considering factors such as simplicity of work with the service, cost, security, visualization, the allowed access speed and custom design capabilities based on common programming languages, Thingspeak was selected. For this project, one IoT channel was created on Thingspeak, which was easy to build, inexpensive and had flexible options. Thingspeak is affiliated with MathWorks and allowed MATLAB modules and codes to be used for analysis of the collected data. The third phase of the project was selecting a versatile robotic controller unit with access capability to internet and online databases. After consulting with a number of industries and vendors, and getting no reasonable answer that met the available budget, an extensive search was conducted. In the end, the author purchased one unit of AMAX 5580 from Advantech Co. Ltd. At the time of purchase (August, 2020), less than 100 units of this PAC had been sold worldwide.

Figure 3 shows the assembly of the robotic arm, the AMAX 5580 PAC, and the wireless proximity sensor module. The PAC module was connected to the robotic arm via its RJ-45 jack and the CAT-5 Ethernet cable and served as master EtherCat module. The PAC module was connected to the internet via WiFi. The temporary assembly of the proximity wireless sensor node on the breadboard can be seen at the bottom of Figure 3. The wireless sensor sends its observations of the approaching object to one Thingspeak channel. Figure 4 illustrates a snapshot of some reported data on Thingspeak.

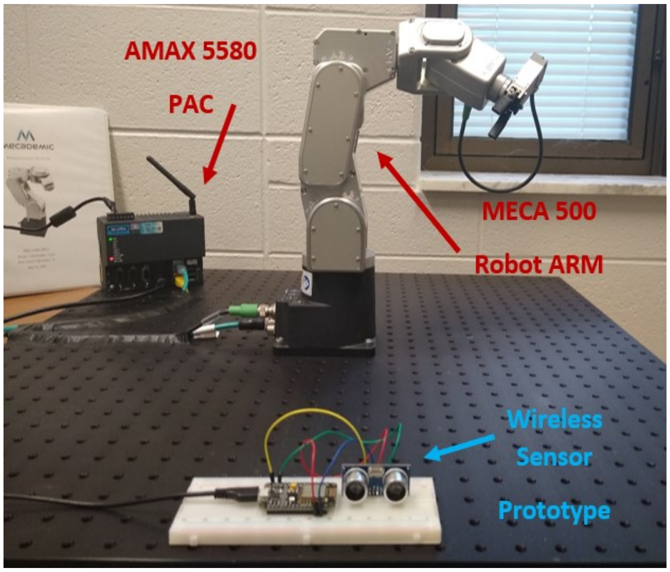

Figure 3. The first implementation of the CIoT-based legacy robot control system.

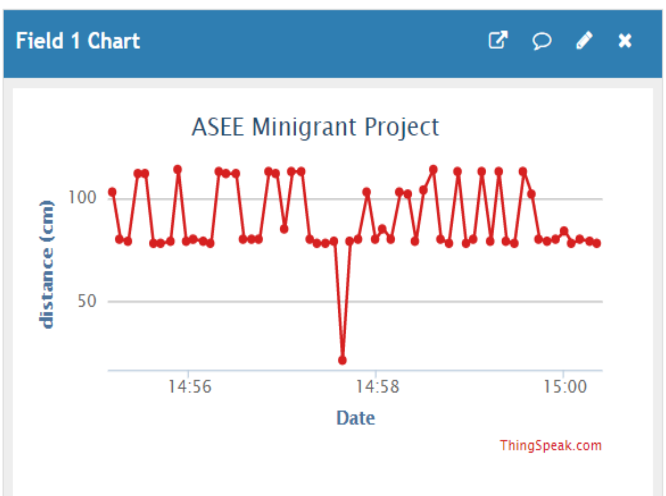

Figure 4. A snapshot of the uploaded distance of the approaching object to the robotic arm by one ultrasonic wireless sensor.

In the final implementation phase of the project, several programming languages were considered; Python was selected, due to its network programming capabilities, ease of programming, and available modules. The Python code running on iPC, periodically and frequently captured any updates on the related channel of Thingspeak and, proportional to the distance to the robotic arm, adjusted the speed of the robot's motion. In a real-life example and on a large scale, this control can avoid or at least reduce the risk of casualty in the work area.

Even though the MECA 500 is not a legacy device and it has limited use in industry, it is worth mentioning that the approach in this study could be extended to other forms of legacy robots, provided that two requirements are met. First, a connector interface between the legacy robot's connector to fit into the PAC input connector (if PAC does not have it). Second, a software interface is created that works as an interface between the PAC and the robot. In this current study, Python was used and the running Python code communicated with the robotic arm via the EtherCat cable. This proposed approach is comparable with preparing an open-source personal code for ROS.

Conclusions and Future Work

An experimental implementation to use cloud-based Internet of Things (CIoT) as a technology interface for adapting legacy automation devices to industry 4.0 was investigated and discussed. MECA 500, as a non-collaborative robotic arm, was adapted to collaborate with the environment by adding an AMAX-5580, a programmable automation controller (PAC), as the programming and control unit, along with a wireless sensor for observation of the environment. In the implementation of the experiment, one ultrasonic proximity sensor was added in order to monitor the surroundings of the robotic arm and collect distance information on approaching objects. The wireless sensor data were recorded on one channel of Thingspeak, as the CIoT service provider.

A Python code running on PAC collected the recorded information of the wireless sensors in real time in order to adjust the speed of the robotic arm. On a larger scale, this project could be implemented for collaboration between two or more robots or machines. According to this experiment, it is possible to adapt legacy robotic devices to industry 4.0 by adding wireless (or wired) sensors to the system or environment and using the collected information on CIoT to control the robots and machines. The proposed approach has industrial as well as educational applications.

In the next step of this project and as future work, the use of network of things (NoT) instead of CIoT is under investigation. Also, to improve the decision-making system, using machine learning algorithms in merger of the collected sensor's data will be considered. Another possible focus area of this research is the merger of the proposed approach with open source ROS. Latency in communication and decision-making is another aspect that could be evaluated by the use of 5G and next-generation networks.

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Biographies

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Designing a Smart Trailer System using Bluetooth 5 Beacons and a Mobile Application to Monitor a Semi-Truck Trailer's Conditions

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Abstract

Many automobile companies are using sensors to improve the safety and efficiency of their vehicles. The trucking industry is one of the last to adapt to these modern technologies. Fleet owners and drivers need a solution that monitors trailer safety systems with a user-friendly, driver-inspection tool. The purpose of the Smart Trailer is to improve safety, security, and cargo assurance for the trucking industry. The Smart Trailer will offer freight lines and distribution companies an efficient and reliable way to monitor the status of their trailers. The Smart Trailer will outfit a semi-truck trailer with various sensors that allow truck drivers/end-users to monitor the health of their trailer. In this study, the authors used a shock sensor to detect when the trailer was experiencing infrequent and potentially damaging vibrations, due to reckless driving or road conditions, and log the exact times of trailer movement to prevent falsifying records. A magnetic door sensor was implemented to check when the door was opened or closed for accountability and security. An interior light sensor was implemented to further promote security—this sensor detected light entering the trailer while the door was closed. An interior temperature sensor was implemented to ensure that temperature-sensitive cargo met proper threshold values. A Central Intelligence module collected and organized data from the sensors to send encrypted data to the mobile application. A mobile application provided an informational interface of the trailer's conditions, while prioritizing the most critical issues to the driver.

Related Works

Research related to Bluetooth Low Energy in the supply chain and trucking industry is limited, though one study (Tarn, Pang, Yen, & Chen, 2019) indicated strong support for Bluetooth technology for logistics and supply chain-related companies such as FedEx, UPS, and DHL. However, that study concentrated on the use of peripherals for drivers and delivery personnel to operate in a safer environment. In another study, the authors (Blasio, Quesada-Arencibia, Rodríguez-Rodríguez, & García, 2018) looked at Bluetooth Low-Energy beacons in a static environment, much like one of the trailer-use cases. In this research, the beacons were measured in free space and at varying orientations. Unlike the research conducted here, this team utilized the highest power setting of the beacon and came away with mixed results.

Ng, She, and Park (2017) researched the use of beacon density in a proximity-of-interest (PoI) system that applied to some degree to the research conducted in this current study. Proximity to a specific edge relay device within the trailer helps us know for sure that the pallet is loaded on the trailer, but this does not resolve to a high degree the location or the passage across the threshold. In research regarding indoor positioning using Bluetooth Low Energy, Zuo, Liu, Zhang, and Fang (2018) introduced a graph optimization-based method to help understand location based on inertia and pedestrian dead reckoning. This novel approach may also be interesting in comparison to the research conducted in this current study. Another smart phone-based research study was conducted by Shchekotov (2016) in which he studied the log-normal path loss of Bluetooth Low-Energy signals. His research was quite interesting in that it helps our understanding of the indoor multipath and signal variations observed in a semi-trailer.

One of the most interesting papers discovered was on the concept of "fingerprinting" locations within a space. Fingerprinting is a technique used to establish a known set of RF characteristics of sectors to create an expectation of those parameters when actual devices are within that area. Faragher and Harle (2015) compared Wi-Fi fingerprinting and Bluetooth Low-Energy fingerprinting, finding that Bluetooth Low-Energy fingerprinting provided a higher degree of location accuracy. This paper also illustrated the susceptibility of fast fading. Finally, Decker, Zoghi, and NG (2020) utilized Bluetooth Low Energy on a semi-trailer to detect the threshold of a trailer with a Bluetooth Low-Energy beacon device. In this current paper, the authors describe the use of a Bluetooth Low-Energy gateway as a means of getting data out of the trailer and to a hosted web server for use by others (e.g., maintenance and operation personnel).

Introduction

Semi-trucks and trailers make up the backbone of American commerce. Whether it's Amazon, Walmart, or other dealers and suppliers, transportation logistics are vital assets to these companies. With that in mind, fleet owners and drivers need a solution that monitors trailer safety systems with a user-friendly, driver-inspection tool. The purpose of the Smart Trailer is to improve safety, security, and cargo assurance for the trucking industry. The Smart Trailer would offer freight lines and distribution companies an efficient and reliable way to monitor the status of their trailers with a non-intrusive installation. The Smart Trailer would outfit a semi-truck trailer with various sensors that allow truck drivers to monitor the health of their trailers. Communication is currently limited to the driver, due to the absence of a cellular network. Future work might make it possible for fleet owners or a third party concerned with supply chain security and environments to have full access to the data. As such, the following devices and measurements were be integrated into the system.

- Shock Sensor: Detects when the trailer is experiencing infrequent and potentially damaging vibrations, due to reckless driving or road conditions. Also used to log the exact times of trailer movement to prevent falsifying records.
- Magnetic Door Sensor: Checks when the door is opened or closed for accountability and security.
- Interior Light Sensors: To further promote security, this sensor detects if light enters the trailer while the door is closed. The detection of light assists in monitoring haul breaches.
- Interior Temperature Thermometer: To ensure that temperature-sensitive cargo meets proper threshold values.
- Central Intelligence Module: Collects and organizes data from the sensors to send encrypted data to the mobile application.
- Mobile Application: Provides an informational interface of the trailer's conditions, while prioritizing the most critical issues to the driver.

Fleet owners and individual drivers would be targeted for use of the Smart Trailer system. With the multilayer diagnostic capabilities of the Smart Trailer, a trailer's health and functionality can be constantly monitored to provide reassurance to the user. With regards to functionality, the final product would provide real-time data through a reliable and secure connection. All data traffic would utilize Bluetooth 5 as a means of transmission. With consumers in mind, the Smart Trailer would include a user-friendly display of acquired information on a dedicated mobile application. Figure 1 displays the conceptual block diagram of the Smart Trailer system.

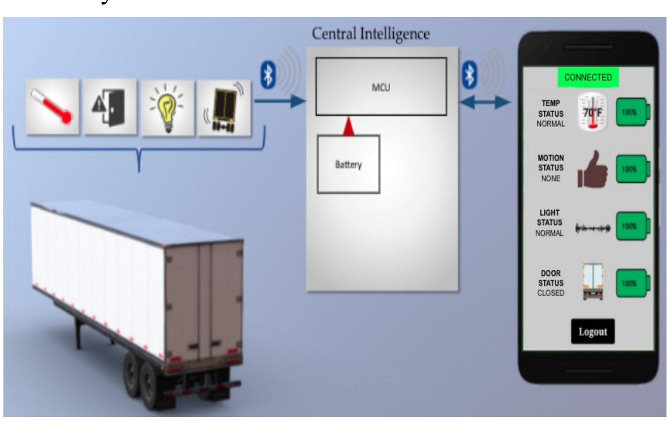

Figure 1. Smart trailer conceptual block diagram.

The Smart Trailer system consists of four integrated sensors, a data processing hub named Central Intelligence, and a user-friendly mobile application. The four icons above the trailer signify the four different types of sensors that would be placed throughout the trailer. The sensors monitor the trailer's internal temperature, door access, ambient light, and g-forces. The sensors then beacon data that the Central Intelligence module captures. The Central Intelligence module collects, analyzes, processes, and distributes the information to the mobile application. After the transmission, the data are displayed in an easy-to-view format, allowing users a glimpse into the conditions of their trailers.

Functional Design

The main function of the Smart Trailer project was to retrieve measurements from specific areas of a semi-truck trailer using sensors. Each sensor was equipped with an Arduino Nano 33 BLE for processing and transmitting data over Bluetooth 5 to the Central Intelligence module. The Central Intelligence module has the capability to organize the data from the sensors and communicate them to the user interface mobile application using Bluetooth 5. The mobile application displayed the information in a format that was easy to read and understand and had notifications enabled to alert the semi-truck driver of any issues that should be addressed. Bluetooth 5 communication protocol allowed for more channels of data and a longer transmission distance. The Central Intelligence module utilized two externally attached antennas to communicate from inside the trailer to the outside of the trailer. Software was needed to program the Central Intelligence module as well as the Arduino for each sensor. In addition to software for the embedded systems, the mobile application needed a separate software development platform.

Each sensor had its own separate power bank to supply energy to both the sensors themselves and their corresponding Arduino. Two AA alkaline batteries were tied in series to sufficiently power these devices as well as the Central Intelligence module. In addition, a voltage divider was used to differentiate the actual battery level in order to monitor the battery percentage of the sensors. The hardware required for the Smart Trailer project consisted of the various sensors previously mentioned, the Arduino to be integrated with each sensor, the microcontroller to serve as the Central Intelligence module, and two external antennas added to the Central Intelligence module. For the Central Intelligence module, the Nordic nRF52840 development kit was implemented. This device was chosen because it utilizes the Bluetooth Low-Energy 5 protocol, which is long-range and has the capability of operating on various channels. One of the external antennas placed on the outside of the trailer with a cable connected to the Central Intelligence module inside of the trailer to allow the Central Intelligence module to communicate outside of the trailer. The other antenna was placed on the inside of the trailer so that the Central Intelligence module did not lose communication with the sensors inside of the trailer. Both of the antennas were connected to the Central Intelligence module using a special PCB-mounted coaxial cable connector and a coaxial cable splitter.

To simplify the communications between the sensors and the Central Intelligence module, the Arduino Nano 33 BLE was integrated with each of the sensors, because it contained the same Nordic nRF52840 chip. Each of the sensors and their respective Arduino were integrated using a custom -printed circuit board that catered to the size and power requirements of each application. The accelerometer was located on the Arduino Nano 33 BLE, so the shock sensor system only required a custom PCB for power management. The door sensor was a Hall effect sensor integrated with the Arduino and magnet attachments and located near the door of the trailer. The ambient light sensor also integrated with the Arduino and located at the top of the trailer at locations more susceptible to breaches. The internal temperature sensor integrated with the Arduino and centrally located inside the trailer. The Central Intelligence module utilized two additional antennas connected by a coaxial cable splitter. One was used internally to capture the beacons from the sensors and the other was routed externally to allow the Central Intelligence module to communicate with the mobile application.

There were three separate programming platforms used to program the Central Intelligence module, sensors, and mobile application. All devices or applications had the ability to either establish a connection to their respective device or beacon necessary information using Bluetooth 5. Through these methods, data and notifications were transmitted and received. Further analysis of data as far as conversions and organizing was implemented onto the devices. Each sensor had the ability to receive measurements from its respective sensor and compute internal calculations to determine what specific value or notification to beacon as well as its remaining battery life. The Central Intelligence module properly scanned for all Bluetooth sensors and received their beaconed data. It would also be able to process and organize the received data to be transmitted to the mobile application using an established connection. The mobile application was able to establish a connection with the Central Intelligence module using Bluetooth 5 and continuously receive data that would be used to update the display on the mobile application's user interface. Depending on notifications received, the display would show different icons to assist the user with understanding the trailer's status.

The method of communication for this project in which the devices connect and relay data to one another was through the Bluetooth Low-Energy 5 protocol. Bluetooth was needed to beacon data from the multiple sensors located in various parts of the trailer and to establish a connection between the mobile application and the Central Intelligence module. These Bluetooth connections and methods were used to communicate data and alerts throughout the system.

The functional block diagram of Figure 2 shows the subsystems contained in the Smart Trailer that include: several sensors on a semi-truck trailer, a Central Intelligence unit for organizing and processing data for the user, and a mobile application for displaying the sensor information. The functional block diagram outlines each of the sensor systems, sending information over Bluetooth 5 to the Central Intelligence module, which then sends information over Bluetooth 5 to the mobile application.

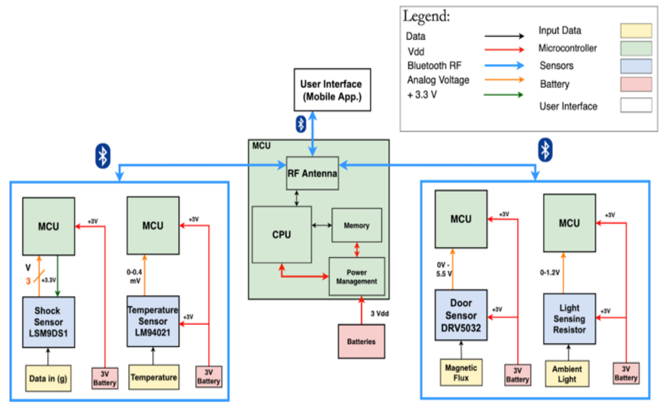

Figure 2. Smart trailer functional block diagram.

The functional block diagram of Figure 2 also outlines the power requirements and interfacing for each of the sensors as well as the Central Intelligence module. The accelerometer takes measurements of g-force, as input and output analog voltage values for 3-axis g-force measurements to the microcontroller. The temperature sensor reads the temperature inside of the trailer and sends the data to the microcontroller as a voltage value. Both the sensor and the microcontroller were powered using a 3V battery. The door sensor utilized a Hall effect sensor that was triggered by removing a magnetic force out of the range of the sensor. The sensor sent information to the microcontroller as voltage; when the magnet was out of the sensing range of the sensor, the switch was enabled and sent a voltage high to the microcontroller. When the magnet was returned into the sensing range of the sensor, the switch was deactivated and no voltage was passed to the microcontroller. The internal light sensor was a photo resistor that changed resistance with the light inside the trailer; the photo resistor was tied in series with a 10k ohm resistor, so together they acted as a voltage divider. The microcontroller read the divided voltage and classified changes in the value as changes in light.

Performance Specifications

Each of the subsystems for the Smart Trailer project had to meet the typical conditions of a semi-truck trailer. The specifications for the conditions are outlined in the following sections and include power, hardware, and software. Each subsystem was equipped to communicate over Bluetooth 5 with the Central Intelligence module, which communicated with the mobile phone, also using Bluetooth 5.

In addition, all of the subsystems had low power consumption to ensure a sufficient lifespan without requiring maintenance. Each sensor system also had to be small in size so as not to interfere with the normal operation of the trailer.

Hardware

The sensors and Central Intelligence module for the Smart Trailer each needed to be powered by an external power bank. The battery of choice was a standard alkaline AA battery with a nominal output voltage of 1.5 V. Two of these batteries were tied in series in order to provide the sensors with a maximum of 3V. These batteries also provided the sensors with a long life span. The battery life was reduced, due to developer issues with the Arduino Nano sleep libraries. The Arduino was not able to enter into idle mode and was constantly consuming full power. With this in mind, the sensors' current draw ranged from 21mA to 5mA. With an average current draw of 5mA, the AA batteries were expected to work up to six weeks before the voltage supplied was too low to power the sensors.

A Nordic nRF52840 microcontroller and development board (Nordic Semiconductor, 2020) was used as the Central Intelligence module for this project. It had Bluetooth Low-Energy and Bluetooth 5 applications over various data transfer rates (2Mbps, 1Mbps, 500kbps, and 125kbps) and a 2.5 GHz transceiver. It was equipped with an ARM Cortex-M4 32-bit processor with FPU and 64MHz clock speed. The nRF52840 implements an ARM Cryptocell-310 cryptographic hardware engine that enabled different methods of encryption for security purposes. The development board was powered from a supply range of 1.7-5.5V. There was 1MB flash and 256kB RAM for data storage capabilities as well.

The Arduino Nano 33 BLE was the microcontroller that was integrated with each sensor to enable Bluetooth 5 connectivity and communication from the Arduino (Arduino, 2020). It used an nRF52840 SoC and, thus, had the same ARM Cortex (M4 32-bit processor with FPU and 64MHz clock speed) and data storage capabilities (1MB flash and 256kB RAM) as the Central Intelligence module. It also had Bluetooth Low-Energy capabilities, while operating between 1.7V and 3V. The ideal shock sensor was a 3-axis accelerometer with a wide range of acceleration scales. In addition, the sensor had low voltage supply requirements and output acceleration values as voltages.

A digital-switch Hall effect sensor was used to monitor the status of the trailer door along with a magnet. The sensor had a wide range of magnetic sensitivity to allow for varying locations on a trailer door and varying distances from the magnet. In addition, the sensor had low voltage supply requirements and was able to operate with at least 1.7 volts.

The sensor used to measure the light level in the trailer was a simple photo resistor, connected in series with a 10k ohm resistor. With a 0 lux light level, the photo resistor reached a high resistance, and with a 10 lux light level, the photo resistor returned low resistance. The photo resistor's full scale covered a range of 0-100 lux. This sensor was chosen for its simplicity, wide voltage and temperature ranges, and low power dissipation. The temperature sensor was used to measure the internal temperature of the trailer, and had the capability of measuring a temperature range of -50°C to 150°C. It could operate in a range of 1.5-5.5 volts and produced an analog voltage output based on the temperature.

The chosen external antenna was a 2.4-2.5 GHz, 13dBi, Right Hand Circular Polarization antenna. This antenna had 10W maximum input power and utilized an N-type female connector. This antenna was installed for transmitting information outside of the trailer, because it had a high gain and an IP67 rating. The chosen internal antenna was a 2.4GHz ISM-band, 5dBi, vertical or horizontal polarization antenna. This antenna also had 10W maximum input power and utilized an N-type female connector. This antenna was installed to receive transmissions inside of the trailer.

Software

MIT App Inventor is an Android application development software and IDE created by MIT for purposes of giving a visually oriented approach to app development. It utilizes visual icons and block programming to design the visuals and functionality of the application, as far as connectivity, information processing and display, and notification commands. Zerynth is the IDE used for programming the Central Intelligence microcontroller. It enabled the microcontroller to be programmed using Python and allowed control over all BLE connections, receiving, transmitting, and data analysis functionalities.

The Arduino IDE with the Arduino programming language was used to program each of the Arduino Nano BLE 33 devices. This software provided all input measurement, data analysis, and Bluetooth 5 beacon functionalities.

To solve the problem of accurately measuring the parameters of a trailer, analyzing the measurements, and relaying the information to the driver, a variety of software processes and algorithms were required. On the sensor level, each Arduino needed to read an analog input from the connected sensor and convert the measurement into a corresponding numerical value. These values were converted using an encryption method that allowed for the data to be beaconed through the Bluetooth manufacturer's data. The calculations and method of converting the measurements varied for each sensor type. The values corresponded to the specific status of the trailer and were updated on event-driven processes or after specified time intervals.

The Central Intelligence module had to act as the center of all trailer measurements and be the sole device to transmit data to the mobile application and be seen by the driver. Using Bluetooth 5, a connection was established with the mobile application and a scanning process was used to collect the data from each individual sensor module throughout the trailer. The Central Intelligence module received data from all of the sensors and conducted further computation. There was a continuous loop of receiving measurements, internal computation, and advertising of the collective data to the mobile application.

The mobile application was a system that utilized a mobile phone's Bluetooth capabilities to connect to the Central Intelligence module and to receive data measurements. Each separate value was updated on the dashboard. The mobile application had to be able to constantly receive and display the sensor measurements, while checking and displaying notifications to the driver, as necessary. The Central Intelligence module began by waiting until a connection was established with the mobile phone before continuing with its operation. Once connected, it began scanning for all of the data that were being beaconed from the sensors. The received data were organized and converted so that they could be advertised through a Bluetooth service to the mobile application. The Central Intelligence module then transmitted all of the measured data to the mobile application to be updated on the dashboard display.

Upon startup, the sensor initialized and captured the battery level. The Door Sensor then read the analog signal coming from the Hall effect sensor. The Hall effect sensor worked like a latch and either sent a low signal or a high signal, depending on the presence of a magnetic field. Once the state was determined by the Door Sensor, it then appended both the door state and the battery level to its Bluetooth manufacturer's data. Next, the code updated the Bluetooth manufacturer's data when the door state changed or the appropriate time was passed to check the battery level again.

Upon startup, the sensor initialized and captured the battery level as well as the initial ambient light. The battery level was assigned to the Bluetooth manufacturer's data and beaconed. The Light Sensor then read the analog signal coming from the photo resistor and compared the new reading to the old reading. If there was a significant difference between the values then a warning was added to the battery level and attached to the Bluetooth manufacturer's data. The new reading then replaced the old reading. On the next loop, the Light Sensor would find that the new and old readings were equivalent but that the warning value was triggered. The warning value would be taken off of the battery level and the Bluetooth manufacturer's data would be updated in order to reflect the fact that there was no longer a change in the ambient light.

The loop continued comparing a new reading to an old reading in order to trigger updates when there was a significant change in the ambient light. This process allowed for the Light Sensor to gradually update its ambient light level, as the natural daylight changed throughout the day. The battery level was updated when the appropriate time interval had passed. The Temperature Sensor checked the ambient temperature and updated the Bluetooth manufacturer's data with the temperature value and the battery level. The values attached to the Bluetooth manufacturer's data needed to be in two-byte increments of hex that would represent values from 0 to 255. Since the Temperature Sensor could read from -58°F to 302°F, special workarounds were used in the Temperature Sensor code to circumnavigate these limits.

Every positive value had 1000 added to it and was then split into separate 2-digit values. For example, 70°F became 1070, which was then split into 10 and 70 to be transmitted. Negative values were turned positive and had 2000 added to them before being split into separate 2-digit values. For example, -25°F became 2025, which was then split into 20 and 25 to be transmitted. While the temperature was continuously being monitored for a problem, it would only update and beacon a change when there was a change of more than 3°F. This saved battery life by only beaconing larger changes inside the trailer. The battery level was updated when the appropriate time interval had passed.

The battery level was attached to the Bluetooth manufacturer's data and beaconed. The Shock Sensor then continuously monitored the accelerometer on the Arduino and checked the absolute value of the x-axis and y-axis to their predetermined thresholds. If the x-axis reading or y-axis reading surpassed their thresholds then a warning value was attached to the Bluetooth manufacturer's data and broadcasted for 10 seconds. After 10 seconds, the warning was automatically removed from the Bluetooth manufacturer's data and the Shock Sensor returned to continuously monitoring the accelerometer values. The battery level was updated when the appropriate time interval has passed.

Battery Level Protocol

The battery level function read the analog input from the voltage divider attached to the sensors' batteries. This value was compared to the Arduino's internal voltage of 2.4V. The voltage divider was necessary in order to ensure that the voltage was below the internal 2.4V. The analog value was read on a scale of 0-1023. Using conversion values, the analog value was converted back to the original voltage coming from the batteries. This voltage was then put on a scale from 3V to 1.7 V in order to represent the remaining battery life of each sensor. The battery level was checked every three hours and updated. Once the reading fell below 20%, the time interval to check the batteries was changed to every hour in order to keep the user better informed the closer the sensor was to dying.

Mobile Application

The mobile application was equipped with a lock screen to act as a form of security for the trailer's status information. When opening the app, the lock screen was displayed and numerical inputs were enabled. Inputted values were compared to a pre-registered "unlock" value. If the values did not match, an error notification was displayed to the user. When a matching input was received, the screen changed to the dashboard display.

Upon unlocking the initial screen, there was a dashboard displaying the status of the trailer, based on the values measured from the sensors. When new values were received from the Central Intelligence module, there was a check to see if any notifications were required to be displayed. If there was a notification of a problem, it would be updated on the dashboard display with corresponding values or icons. Different icons were used to show the status of the trailer in order to allow the driver, while driving, to easily notice and fully understand what situation was occurring. Multiple updates could be triggered at once, so the driver could be up-to-date on all aspects of the trailer, regardless of whether or not there was one or multiple issues.

If at any point during operation, the mobile application disconnected from the Central Intelligence module, an auto-reconnect process was trigger. Once this process began, the mobile application would continuously scan for and try to reestablish a connection with the Central Intelligence module. Once a connection had been established again, the mobile application would resume receiving measurements from the Central Intelligence module.

Mobile App Dashboard

The dashboard used a mixture of numbers and icons to deliver updates and notifications that were easily understandable. From top to bottom, first was a connection status icon. This icon tells the user if a connection to the Central Intelligence module had been established or not. When connected, the icon would be green and show "connected." The icon would appear red and show "disconnected" when there was no connection. During times of operation when the application was scanning for the Central Intelligence module in order to connect, this icon would turn blue and show "scanning." The first row of the sensor's status was the temperature sensor. It has a label identifying that the specific row displayed the status of the trailer's temperature. The column to the right contains a thermostat icon that shows the numerical temperature received from the sensor. The second row is for the status of the ambient light within the trailer. The text shows the status of the ambient light and will show "normal" when there is not a significant change in the ambient light. Also, a "thumbs up" icon is displayed under normal conditions, which implies no warning is needed to be displayed.

The third row shows the status of that trailer's motion measured from the shock sensor. The text shows "no motion" under normal conditions as well as a tremor graph with low amplitudes to the right of the text. The last row shows the status of the trailer's door. The status shows as "door closed" and the icon to the right will display a trailer with closed doors under normal conditions. Each sensor status row also has a battery icon that shows the current battery level of the respective sensor and the battery icon changes based on the specific value. The last object is the logout button, which, when pressed, causes the application to disconnect from the Central Intelligence module and change screens back to the lock screen. Figure 3 shows the dashboard under normal conditions.

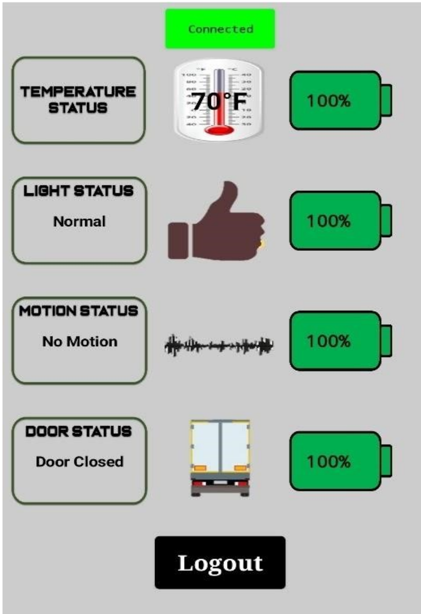

Figure 3. Mobile application dashboard display—normal status.

When problems occur within the trailer, and the notification reaches the mobile application, the icons will change accordingly. When an error occurs with the temperature, the corresponding icon will change to show the temperature that caused the error and whether the problem is that the temperature inside the trailer is too hot or too cold. When a large change in ambient light is detected, the light sensor status will show "major change detected" and a warning icon will appear. The warning icon will display when there is a significant change in the ambient light of the trailer. For the shock sensor error, the status will show "excessive motion" and the icon will show a tremor wave with high amplitudes. Lastly, the door status will change to "door open" and the icon will display a trailer with open doors. As the batteries of the sensors become depleted, the exact numerical percentage is displayed and the battery icon's color changes when the percentage falls below, 75%, 50%, 20%, and 10%. Figures 4 and 5 show all of the error statuses and icons.

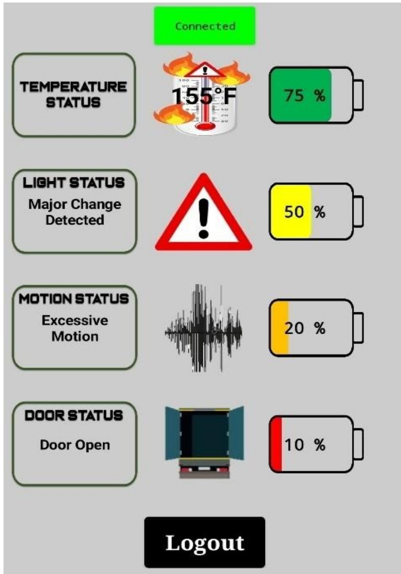

Figure 4. Mobile app dashboard display—error example 1.

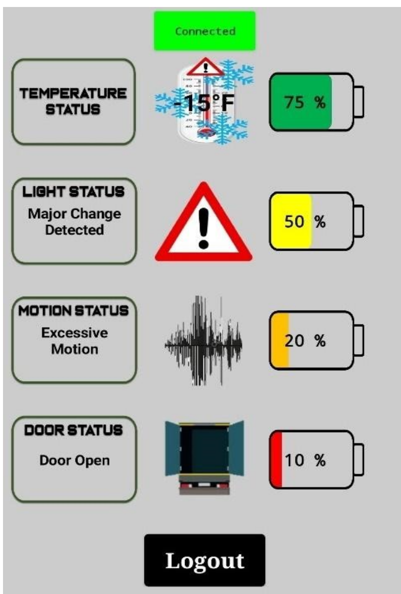

Figure 5. Mobile app dashboard display—error example 2.

Every time an error occurs, it is recorded and stored in the Mobile App. This feature then utilizes a cellular network to store the recorded events on a remote server. Using a separate login code at the lock screen allows a user entrance to the supervisor's access. The supervisor's access screen allows for these error records to be viewed from anywhere. Records are separately held for the temperature, light, shock, and door sensor. Upon login to the supervisor account, labels for each sensor are shown with a respective "show" button. When these buttons are pressed, the error log is shown for that sensor. A "hide" button is used to hide the record log and enable viewing of another log. When an error is recorded, it is saved with a time and date stamp in the format of month/day/year hour: minute: second (am/pm). For the door, specifically, it records when the door is both opened and closed. Figures 6 and 7 show the supervisor's access screens.

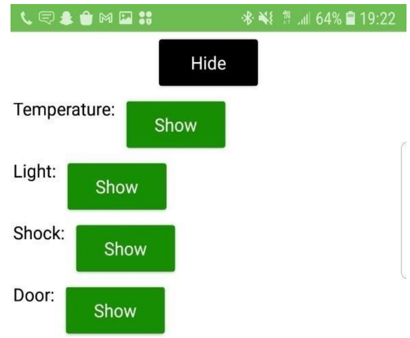

Figure 6. Supervisor access screen.

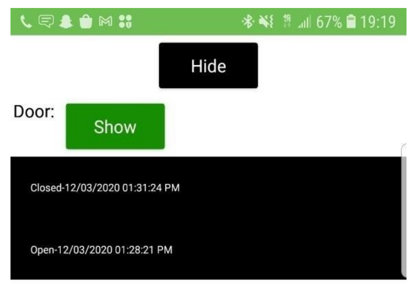

Figure 7. Supervisor access error log—door sensor.

Sensor Prototype

Each sensor's printed circuit board (PCB) layout followed the same format with similar part locations and orientation. Due to the small number of parts, each sensor used a 2-layer printed circuit board. The sensor and other small components—such as resistors, capacitors, and test pads—were placed on the front side of the PCB. Figures 8 and 9 show 3D models of this layout. This is the common layout for each sensor's PCB, with the exception of the actual sensor and sensor-specific components.

To ensure that the sensors and PCBs functioned as expected, each one was tested with a digital multimeter. Test point 1 (TP1) corresponded to the battery input voltage, and TP5 corresponded to ground. Then, test point 2 (TP2) was tied to the voltage-divider output. The voltage divider consisted of a 120k ohm resistor in series with a 100k ohm resistor; with a 3V input, the expected output voltage was 1.36V. Test point 3 (TP3) was tied to the output of the sensor. TP4 was tied to pin A0 of the Arduino, in case of a need for an output from the Arduino. Pin A0 was not used and should read 0 volts.

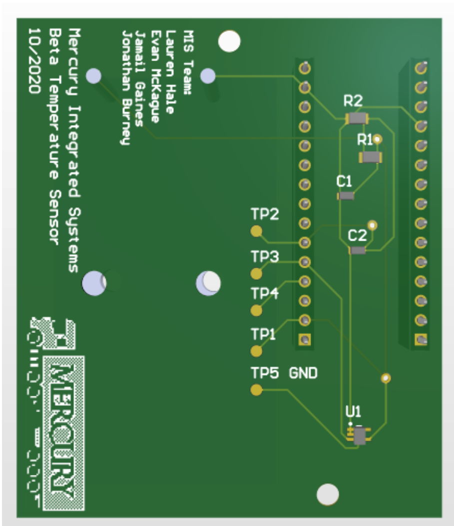

Figure 8. Sensor prototype—front side.

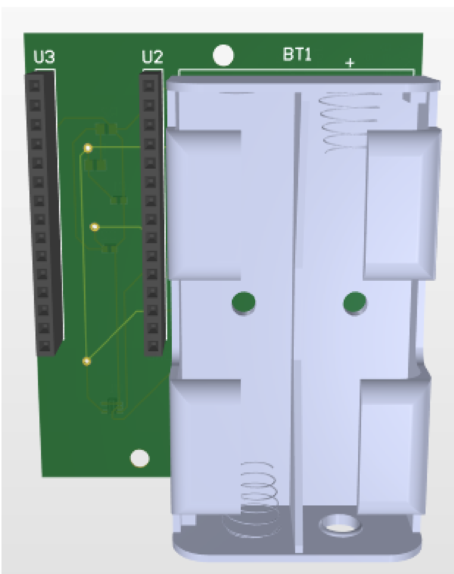

Figure 9. Sensor prototype—back side.

Significant Challenges and Solutions

Bluetooth 5 proved to be very challenging to integrate across the Arduinos, Nordic, and Android cell phone. There are very limited resources and support libraries available, since Bluetooth 5 is still very new. The Smart Trailer made use of several very unique software codes in order to be able to accurately transmit data across separate development platforms. Monitoring the battery of each sensor proved to be difficult as well. It was only possible by using the Arduino's internal 2.4V reference and a voltage divider to compare a voltage below the reference. The resulting input voltage was applied to a scale to determine the percentage of remaining battery life.

The original project plans did not include any antennas, with the expectation that Bluetooth 5 products would be able to provide sufficient transmission strength and range. However, after some testing, an antenna on the inside of the trailer had to be included to collect all of the transmissions from the sensors at various locations in the trailer to get to the Central Intelligence module along with another antenna on the outside of the trailer to extend communications into the cab of the truck.

Results and Future Work

All of the Smart Trailer components were tested on a semi-truck and trailer used for research at a major university. Each sensor was tested individually for functionality and threshold limits after which the full system was tested together. The full Smart Trailer system worked as expected, reporting all four sensor readings (door state alerts, shock alerts, changes in internal light level, and temperature) to the mobile app dashboard accurately. In the future, the product could be improved by implementing a Bluetooth 5 microcontroller with more developed libraries. The Arduino Nano 33 BLE used in the Smart Trailer lacked extensive sleep libraries that would allow for lower power consumption. The Arduino's large current draw put some limitations on the project; for example, the type of batteries used and the size of each sensor's PCB. In addition, adding an option to power the sensors with solar cells could solve any issues with battery size and allow for smaller sensors.

The Central Intelligence module could especially benefit from this since, due to its location, it would be very easy to route a solar panel from its Nordic NRF52840 to the outside roof of the trailer. The Smart Trailer system could also benefit from an increase in the types of sensors offered. Possible expansions could include monitoring the brake lines, the tire pressure and temperature, and brake lights and other external lights. In the future, the system could be connected to a cellular network so that supervisors could monitor trailer conditions remotely and in real-time, instead of only receiving error reports.

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Survey of and Best Practice Identification for Course Development and Integration of Technical Communications for Engineers

Alyson Eggleston, The Citadel; Robert J. Rabb, The Citadel

Abstract

In this paper, the authors report on current modes of integrating technical writing courses and content in U.S. bachelor degree-granting engineering programs and synthesizing trends in curricula adoption, and proposing a model of best practices for maximizing alignment with Accreditation Board for Engineering and Technology (ABET) student learning outcomes. Providing students with technical communication skills is an imperative for engineering programs and future employment. ABET asserts the importance of effective communication skills for engineering students, a learning outcome that is echoed in industry surveys of recent graduates, who report significant writing-related tasks that impact productivity, advancement, and success. Meanwhile, engineering programs are feeling the pressure. Faced with an already content-rich, sequential curricular structure, slotting an additional discipline-specific communications course can be a challenge. Instructor selection can also be an issue, as many engineering faculty report either a disinclination for integrating technical writing instruction, or a concern that engineering faculty are not appropriately trained to teach technical writing and communications (TWC).

A review of embedded and stand-alone communications curricula in engineering schools indicates that student impact and skill development are most noticeable in programs featuring strong synergy between engineering and communications faculty. The objectives of this current study were to: 1) identify the program structure in the surveyed colleges and universities; 2) determine the degree of interdisciplinary work present on which the schools collaborate to reinforce the student learning experience; and, 3) suggest a roadmap or model that can be implemented for engineering programs to include more TWC-related opportunities in their programs.

In the initial review of 98 engineering programs, only 28% included a separate course on technical writing in their respective curricula, with 10% of the programs opting to embed aspects of technical writing into their programs. The remaining majority of institutions did not overtly emphasize technical writing in their stated curricula. A range of institutions from research to teaching universities were included in the survey. Data provided a broad picture of the status of technical writing and communications in engineering programs.

In this paper, the authors propose strategies to best support engineering programs, as they undergo a pivot toward increased interdisciplinary content, and one that signals shared values and goals between the disciplines of engineering and communications. Writing research indicates that embedded TWC content and separate TWC coursework are both viable methods for supporting student success, though separate coursework is preferable. A best-practices approach to TWC implementation relies on interdisciplinary collaboration, iterative assessment, and benchmarking to drive curricular goals.

Introduction

An effective engineer must have the technical skills to be able to gather and analyze data and, at the same time, communicate the results to engineers and non-engineers alike. Research shows that performance in the workplace, especially for engineers, depends on the ability to communicate effectively (Prusty, Dwivedy, and Khuntia, 2015). Engineers must be technically proficient and be able to communicate their expertise. The Engineering Body of Knowledge (EBOK) by the National Society of Professional Engineers (NSPE) outlines several guiding principles that include "The increasing need to incorporate societal impact considerations in engineering decision-making will require better communication, management, leadership, and other professional practice skills on the part of engineers. Collaboration with non-engineers will be critical" (National Society of Professional Engineers [NSPE], 2013).

For decades, engineering disciplines have emphasized the need for improved verbal and written communication skills (Eggleston & Rabb, 2018). The American Society of Civil Engineers (ASCE) Vision 2025 states, "Civil engineers will learn to lead and become motivated to initiate, communicate, negotiate, and participate in cross-professional efforts to envision societal changes that shape the quality of life." ASCE further proposes, "Communications knowledge and skills are embedded in every civil engineer's education and encourage their continued enhancement throughout every civil engineer's career" (American Society of Civil Engineers [ASCE], 2009). The American Society of Mechanical Engineers (ASME) Vision 2030 calls for greater skills for mechanical engineers, pointing out that "Graduates' professional skills such as effective communication, persuasiveness, diplomacy and cultural awareness are as important as technical skills to industry" (American Society of Mechanical Engineers [ASME], 2012).

ASME Vision 2030 identifies feedback from both recent engineering graduates and their supervisors, citing a need for more robust professional skills (e.g., oral and written communication, negotiation, conflict resolution, and interpersonal skills). Calls for enhanced communication outcomes rises to the highest levels of engineering. ABET, the accrediting board for engineering programs in the U.S. and many international schools, defines student outcomes as "what students are expected to know and be able to do by the time of graduation." One of the Student Outcomes is "(3) demonstrate an ability to communicate effectively with a range of audiences" (ABET, 2019). These strategic documents are more than aspirational and guide the curricula of all engineering programs. In order to effect change in student outcomes, faculty must foster habitually effective communication skills in students.

Research Questions

At The Citadel, one goal of the collaborative work with Technical Writing and Communication instruction and the School of Engineering is to ensure the ABET communication student outcome is addressed in a meaningful way, identify knowledge or skill gaps, and be part of the continuous improvement of the engineering programs. Several questions the researchers wanted to answer included:

1. What instructional strategies are engineering programs using or requiring for technical writing and communications?
2. Are there differences in TWC emphasis at teaching- versus research-oriented schools?
3. What are some of the best practices for TWC instruction?

Technical Communication Instruction: Characteristics / Types

Writing is almost certainly not an engineering student's favorite academic task, and developing writing skills among engineering students is not one of the easiest tasks in the engineering curriculum. Several reasons contribute to this challenge, including that technical writing is different from previous writing instruction, and students prefer hands-on activities rather than words. The instructor, whether engineering or writing faculty, may provide motivation by linking the role of technical writing to real-world deliverables. The technical communications instructor should consider purposefully the type of teaching material and activities to facilitate student development and practice of technical communication skills (Rus, 2015). Technical writing and communication (TWC) instruction is a mixture of lectures and examples, reinforced by individual and project-based assignments for specific TWC content.

<u>Lectures</u>

Classroom lectures on specific topics of technical communications are the typical format for delivering content. Some institutions have a separate technical communications course, either as part of the curriculum or an elective, and others embed technical communications content in an engineering course.

<u>Individual Work</u>

In addition to traditional lectures, individual assignments allow the instructor to evaluate and assess specific skills and outcomes in order to provide focused feedback for the individual. Examples of individual work include executive summary, memos, short briefing papers, description of a physical process, technical paper review, and in-class, low-stakes writing assignments.

<u>Project-Based Learning</u>

Group projects allow students to work as a team on a more complex topic. The team hones verbal and presentation skills, while producing a report or presentation at a higher quality than if done individually. Peer feedback also contributes to individual development in technical communication skills. Examples of projects include assembly/disassembly instructions and repair instructions (Eggleston & Rabb, 2019).

<u>Feedback</u>

In technical communications, instructors provide feedback to students on both technical content and communication skills. Technical communications feedback includes more than the basic mechanics of being clear, simple, brief, and providing better word choice. In addition to instructor feedback, peer feedback can be beneficial for the students receiving the feedback as well as developing the assessment skills of the students. Peer review offers several benefits to both student and instructor.

1. By reviewing the work of others, students see examples of how the assignment may be completed. Students are generally quite good at determining good or bad documents and comparing their work to others.
2. Peer review encourages students to revise their documents before submitting them to the instructor for final evaluation. Feedback from peer reviews can guide the students' revisions of their documents.
3. When using peer reviews for student work, instructors are generally more satisfied with the final documents they receive (Carvill, Smith, Watt, & Williams, 2002).

Instructional Strategy

Even after decades of emphasis on better communication skills for engineers, many engineering programs may not be addressing this need. Some do not formally instruct any TWC, but simply feel they have a sufficient number of writing requirements, such as lab and design reports, in which they are assessing TWC. A survey of nearly 100 schools and eight different undergraduate engineering programs across the schools (if the discipline was awarded) shows two prevalent methods: a completely separate TWC course, and TWC embedded in another engineering course.

Many undergraduate engineering programs require students to take a technical communications course. Faculty and graduates have cited the need for explicit curricular improvements to supersede the standard, default composition course in writing with a course on technical writing and communication (TWC) (Sageev & Romanowski, 2001; Reave, 2004). When aligned with engineering content, studies have found this approach effective, if it is supported in later semesters (Adams & Manion, 2005). The content of a separate TWC course typically emphasizes technical writing and may include verbal briefings and pitches. TWC course outputs focus on engineering project proposals, instructional writing, reports, and product specifications—all communication modes that are reinforced throughout an engineering student's curriculum (Reave 2004).

Earlier studies found improvements in technical writing by integrating more written assignments across the curriculum of undergraduate engineering courses, outside of specific technical writing courses (Berthouex, 1996). Writing assignments for design projects have been effective, and the use of writing assignments in more courses provides more opportunities for students to improve through practice (Paretti, 2008). This methodology makes use of existing curricula with no new, writing-specific courses required. It combines written communications with engineering courses, technical problems, and projects, similar to engineering practice.

Merits

Absent subject matter expertise, faculty specializing in rhetoric and language provide both expertise in communication and an ideal audience to practice communicating with non-experts. Engineering students benefit from practicing communication strategies that mimic real-life scenarios with non-subject-matter expert clients, managers, and investors (Reave, 2004). TWC instructors are typically better suited to provide communication-specific feedback, as they are focused on audience reception, wording, verbal and writing skills. On the other hand, engineering faculty, sufficiently trained, can provide good feedback, but many focus on the technical aspects of the project or exercise. Not only are faculty trained in communications typically better at feedback, they are also trained in developing the skills needed to improve. They have additional resources known or available to them to share with the students. Peer reviews in either approach do provide some skill development and do help the reviewer develop his or her own self-assessment skills.

Limitations

TWC consists of two major tasks: communicating effectively and communicating technically. Faculty may have partial expertise in each area. Writing faculty are best trained to teach strategies that leverage attention to formatting, structure, syntax, and word choice. Technical faculty are best trained for conveying technical content, analysis, and the interpretation of results through the application of engineering principles. Engineering professors delivering technical communication instruction may lead to communications becoming inward-looking. Communication between engineers is often full of terminology and technical terms that only engineers understand (Reave, 2004).

Different technical disciplines can require different emphases for specific skills in TWC. Civil and construction engineers may require expertise in detailing plans, listing specifications, and preparing project bids. Mechanical engineers may have a greater need for producing analytical reports and for writing memos communicating recommendations. Electrical and computer engineers might emphasize writing user instructions, manuals, software test procedures, and results.

Data

A recent US News and World Report ranking (US News and World Report, 2019) of some of the top U.S. colleges and universities was used to gauge TWC requirements. Eight undergraduate engineering disciplines were chosen, based on benchmarking what was offered at the institutions' campus and local interest. Engineering disciplines included civil, electrical, mechanical, computer, construction, environmental, industrial, and chemical engineering. Looking at the curriculum maps and cross-referencing course descriptions, this survey helped to determine TWC requirements and administration, if any. Criteria included: 1) a separate TWC course required in the undergraduate curriculum; 2) an embedded TWC course in the curriculum; 3) a TWC course listed as an elective; 4) a TWC course not available. All programs surveyed were at the undergraduate level.

BS/MS-only Institutions

Using the 2019 ranking of Colleges and Universities from US News and World Report, the top 46 schools that awarded up to an MS degree were identified. The authors' institution was in this tier and offers five of the eight engineering disciplines assessed. The peer institutions that awarded up to an MS degree were generally more teaching focused than research focused. Some programs were not offered at these schools, so the data reflect 146 engineering programs from 46 schools. Figure 1 reflects the aggregate data of the eight engineering disciplines (if offered) at these 46 schools.

Figure 2 shows a similar percentage for some of the larger engineering disciplines (mechanical, civil, electrical, and computer). The three traditionally larger programs—mechanical, civil, and electrical—show a fair consensus of having a TWC course required that is separate from the traditional engineering curriculum. Computer engineering had nearly 50% of the programs requiring it separately or embedded.

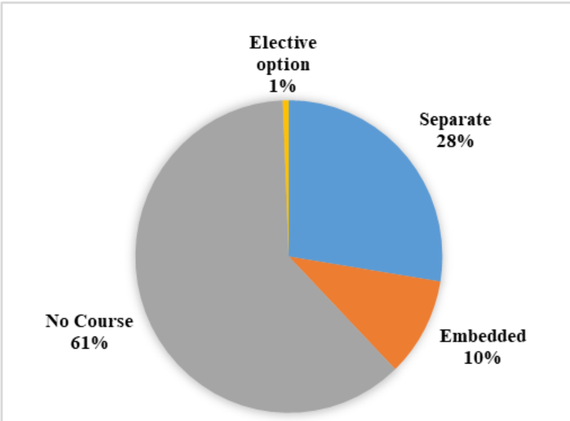

Figure 1. BS engineering programs—non-PhD institutions.

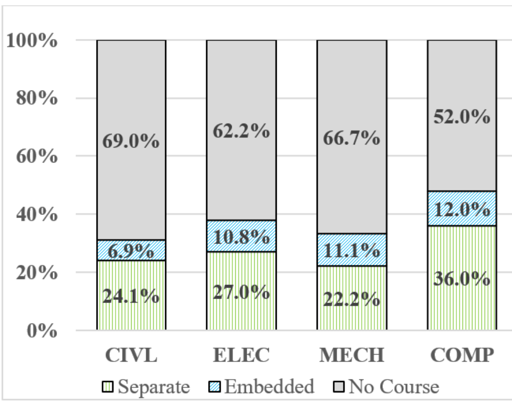

Figure 2. TWC course requirement for civil, electrical, mechanical, and computer engineering programs (non-PhD-granting).

Figure 3 shows more disparity between the smaller engineering disciplines (construction, environmental, industrial, and chemical). These lower-enrollment engineering programs were not available at many of the schools surveyed in this study, so results were more sensitive to variation.

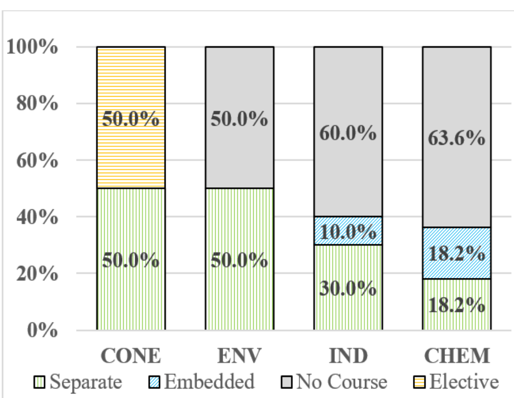

Figure 3. TWC course requirement for construction, environmental, industrial, and chemical engineering programs (non-PhD-granting).

Tier I / Research-oriented Institutions

Using the 2019 ranking of Colleges and Universities from US News and World Report, the top 52 schools that awarded a PhD degree were identified using the same eight engineering disciplines assessed previously. Research-focused schools were of interest in case these institutions realized TWC requirements in different ways. Some programs were not offered at these schools, so the data reflect 269 engineering programs from 52 schools. Figure 4 reflects the aggregate data.

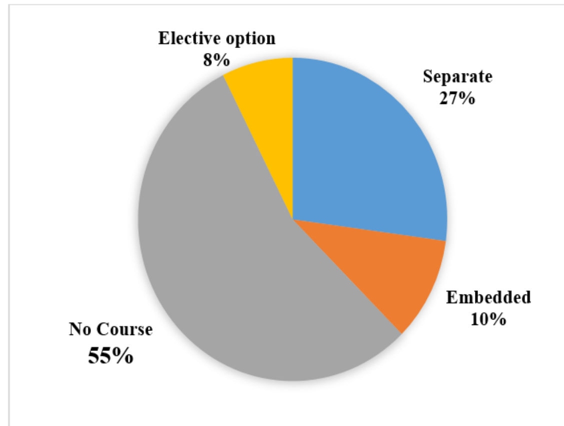

Figure 4. TWC course requirement for the top 52 schools (PhD-granting).

Figure 5 shows, for some of the larger engineering disciplines (mechanical, civil, electrical, and computer) at PhD-awarding institutions, a slightly higher percentage that have a TWC course separately or embedded. However, in these four engineering disciplines, many more had a TWC course as an elective in their programs.

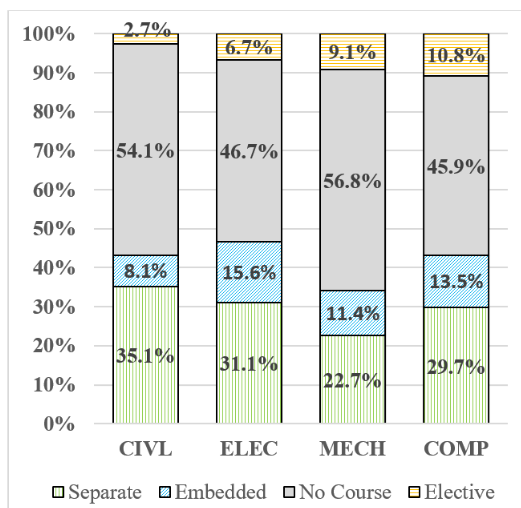

Figure 5. TWC course requirement for civil, electrical, mechanical, and computer engineering programs (PhD-granting).

Figure 6 shows that, again, when looking at the smaller engineering disciplines (construction, environmental, industrial, and chemical) at PhD-awarding institutions, there are more that have a TWC course as an elective. However, the percentage of TWC courses in these particular programs, either separate or embedded, is generally lower.

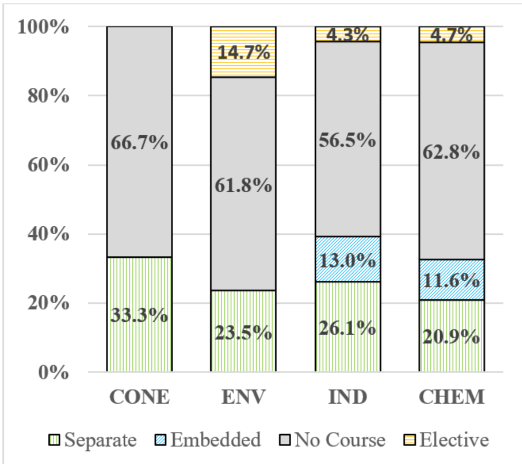

Figure 6. TWC course requirement for construction, environmental, industrial, and chemical engineering programs (PhD-granting).

Discussion

Industry is stressing the need for engineering graduates to have improved communication skills, but programs and schools are challenged in their efforts to add more TWC content into their curricula. Approximately 40% of the engineering disciplines with the most graduates annually at the nation's top-ranked schools appear to have TWC instruction specified. Results were about the same for teaching-focused and Tier 1 research schools (required = 27-28% in a separate course, and 10% in an embedded course). None of the eight engineering disciplines that had a majority of programs surveyed could exceed a rating of 50% combined for separate or embedded TWC instruction. TWC courses were offered as an elective in PhD-awarding programs at a higher rate (10%) versus the teaching-focused schools (1%). However, there were no data for determining how many of the students took a TWC course as an elective. Tier 1 research schools are typically larger campuses with more robust departments in the humanities that may be able to absorb the student load.

The first research question examined in this current study concerned the delivery methods engineering programs were using or requiring for technical writing and communications. When engineering programs have technical writing and communication instruction, the predominant methods were as a separate course or embedded within an engineering course. It is important to note that, as a separate course, there were often multiple disciplines in the course, so instruction may or may not have been tailored for specific needs. When the instruction was embedded in an engineering course, technical writing and instruction was often by engineering faculty, and some instruction may have been minimal. It was difficult to determine if TWC was embedded in more than one course in this survey.

The second research question was to determine the differences in TWC emphasis at teaching versus research-oriented schools. A first analysis of the data showed that, when taught separately or embedded in a course, the overall rate between teaching and research-oriented schools was about the same. However, research schools had it as an elective at a much higher rate (10% versus 1%). Although there was much emphasis on engineers to develop their professional skills and to include communications, fewer than 50% of the schools had any formal requirement for TWC.

The third question was to identify some best practices for TWC instruction. Best practices emerging from this current study developed similar findings in a Canadian study (Reave, 2019). Revisiting her previous work on the common features associated with writing pedagogy and best practices, Reave conducted a study of the most highly rated Canadian colleges and universities, according to Maclean rankings, a national review. The top ten institutions had in common writing across the courses in the curriculum and writing in the discipline courses. Further analysis indicated that the following three environmental conditions were among those most associated with student writing success (Reave, 2019):

- New writing course initiatives outside of the Humanities.
- Writing courses that professionalize students and address market values.
- Government demands for accountability.

Best Practices

From author experience and corroborated with literature, some of the best practices are listed below. Many of these recommendations can be implemented with some coordination and comparatively few resources.

a) Communication lectures demonstrate best practices in communication, exemplified in selections of writing or presentations from the students' own work. Using exemplars of student writing has been found to support student understanding of writing quality (To & Carless, 2016).
b) The current authors see value in the periodic review of engineering curricula and outcomes as a result of their principle charge: developing new engineering programs and service courses for those programs. While early studies did not cite data supporting periodic review of engineering curricula and discipline needs (Reave, 2004; Carew & Cooper, 2008), alignment reviews are needed at the program, institutional, and national levels in order to maintain technical

currency and capture objective measures of student learning. In fact, ABET requires periodic alignment reviews of curricula and student outcomes (ABET, 2019). Many engineering programs focus on technical content in their programs. A champion within the engineering program or a separate TWC course instructor who keeps the communication instruction relevant is necessary.

c) For TWC faculty, partner with an engineering faculty contact for each engineering discipline. This helps identify knowledge and communication skill gaps in each discipline and is a best practice supported by the MIT Communications Lab, which provides engineering discipline-specific communications support and coaching for students (Summers, Olivier-Mason, Dang, & Chien, 2019).

d) Technical communications skills require sustained skill development over a long period of time and cannot be accomplished over one or two semesters. Stand-alone TWC courses should distinguish plainly the benefits and significance of content so that they can be integrated in the student's experience throughout the engineering curricula. Communication skills need to be reinforced in order to help students reach desired learning outcomes. Educators should seek opportunities to apply TWC within the engineering curricula to include presentations, design reports, lab reports, and even simple in-class verbal briefings within the engineering curriculum.

e) Students need formal instruction and examples. They have a lot of exposure to bad examples of grammar, spelling, slang, jargon, and incomplete sentences on social media and advertising. Likewise, students need positive examples in order to gain confidence and competence, complimented with high-quality instruction and feedback. Communication experts are a campus asset, especially when they direct their strengths toward the development of TWC programs that integrate with engineering school curricula (Volpatti, et al., 2020). This positions TWC as a skill multiplier. Students are not equipped to bridge the communications skill gap through composition and writing-intensive courses typically found in the humanities and social sciences. Traditional essay writing and presentations in regular engineering courses also do not adequately fulfill students' need for technical communications.

f) A well-designed TWC program will feature a stand-alone course or integrated TWC instruction and reinforcement throughout the curriculum (Andreou, 2021).

Conclusions and Future Work

In this paper, the authors presented the importance of technical writing and communication instruction in engineering curricula and the results of surveys focusing on the emphasis that engineering programs place on this skill set. This brief study revealed opportunities for programs to improve. There are many opportunities to support the goals of the engineering profession and improve students' specialized skills. Not everything needs to be accomplished within a particular program. Incorporating communication skill development in an engineering curriculum is not easy, but programs should realize the benefits of coordination with non-engineering faculty and nesting assessment with the goals of the institution. Communication skills are important elements in the education of the modern engineer. Institutions that require formalized communication instruction are narrowing the gap between engineering education and the requirements of industry and society. Technical communication courses and embedded instruction/assessment are an important part of continuous learning.

Future work includes expanding and updating the database of schools with TWC in their engineering curricula to increase the sample size of engineering programs. In addition, the authors plan to identify the delivery pathways for TWC in each engineering discipline (labs, capstone, separate course, etc.) at their institution, and map opportunities to reinforce and expand TWC instruction to specific engineering requirements.

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When History and Technology Education Meet

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Abstract

In the current era of standards-based accountability, many schools across the country are placing less emphasis on the social sciences and are instead focusing on the fields of science, technology, engineering, and mathematics (STEM). Despite this trend, there remains a lot of value in maintaining curricula in the social science areas such as history. Because of this, there is considerable interest in combining the areas of the social sciences with the STEM fields. These concepts were put into practice in May of 2019, when faculty and graduate students at Millersville University partnered with the Rock Ford Foundation and I.U. #13 to conduct a standards-based, experiential workshop in which area high school students were taught about 18th century manufacturing processes and how they have evolved into the processes that are seen today. The results of the workshop and subsequent technology and engineering camps demonstrated that it is feasible to integrate aspects of the social sciences effectively into a STEM curriculum.

Introduction

In the current era of standards-based accountability, much of the focus is on preparing students for success in the fields of science, technology, engineering, and mathematics (STEM). Unfortunately, little time is spent helping students understand other important academic areas, such as the social sciences, which some feel have little place in a child's education (Postma, 2011). History provides a cultural literacy, or an ability to understand the impacts of important historical names, dates, events, and concepts that continue to shape our present and our future. With the current events of the COVID-19 crisis gripping the world, much can still be learned from the 1918 influenza pandemic and the many parallels that can be drawn between the two. Many of the methods that were used in 1918 to slow the spread of the pandemic mirror efforts taken today, such as closing schools, wearing masks, avoiding large gatherings, or holding them outside when possible. But much like today, certain methods, such as wearing face masks like the ones illustrated in the 1918 photograph seen in Figure 1, were unpopular with large segments of the population (Jonas, 2020).

Historical case studies like this, and others that tie into current events, can be a valuable segue into class discussions about numerous issues relevant to modern society. The world in 1918 was not unlike that of today, and many felt that the ordinances requiring people to wear masks in public were an overreach of governmental authority (Hauser, 2020). Public sentiments against wearing masks led to demonstrations in which gatherers refused to wear masks and many became ill and subsequently died from the influenza virus (Little, 2020). Examples like these aid in the development of students' understanding of the world around them by connecting with people in history and making them not just pages in a book, but real, living personalities that are not so different from their modern counterparts. When students can empathize with people of different eras, when they can identify the problems and struggles that they faced, they also learn critical thinking skills that can help find common threads and potential solutions to the problems that they may be faced with today and going forward.

But how do educators move forward with incorporating the social sciences into the classroom, while at the same time working within the boundaries of domain-specific, standards-based education? And even more so, how do they justify incorporating these elements into STEM-related curricula? And how do educators address this, while adhering to the newly revised Standards for Technology and Engineering Literacy (STEL) (ITEEA & CTETE, 2020) and those which address historical aspects and use of primary and secondary source materials, such as 8.2.9.B (Commonwealth of Pennsylvania, 2009), which compares the impact of historical documents, artifacts, and places in Pennsylvania that are critical to U.S. history?

Figure 1. People waiting for masks in San Francisco in 1918 (Hamilton H. Dobbin Collection, 1880-1930).

Social Sciences and STEM

Recently, there has been considerable discussion focusing on the need to incorporate the social sciences into STEM disciplines. Advocates for this trend state that, when taught correctly, history can capture students' imagination, motivating them to critically assess past events, as they explore how they potentially impact current events (Hoodless, 2008). Furthermore, a merger between the social sciences and STEM can foster creativity and improve empathy, while at the same time creating a better understanding of the human condition (Zaman, 2016). Aside from the abstract benefits that can be obtained from a multidisciplinary approach to teaching these fields, there are other tangible benefits. For instance, civil engineers have long known that aging infrastructures present complex problems, but understanding who designed and built them along with historical methods of construction is oftentimes vital for both preservation and preventative maintenance of these structures (Alessandro, Swenty, & Collins, 2014). Students who are exposed to the historical context in which the buildings were constructed in their civil engineering classes are likely going to be able to make better decisions when maintaining and restoring aging structures. This is important, because engineering students are often experiential-based learners who want to know how their coursework affects their career readiness (Carriere, 2011).

History has shown that sometimes the greatest discoveries have been the result of individuals who have worked through repeated failures but still demonstrated the persistence that is necessary to succeed in scientific endeavors. Thomas Edison once said, in regard to a question on the results he had obtained during the development of a nickel-iron battery, "Results! Why, man, I have gotten a lot of results! I know several thousand things that won't work" (Dyer & Martin, 1910). Though Edison would go on to become one of the greatest inventors that the world has ever known, the story of his persistence is one that can be a great lesson for students today. When explored through the lens of historical analysis, these lessons come alive and demonstrate that many of the great discoveries of the past were made by individuals who lived in societies not unlike those of the present. These figures were constrained by some of the same adverse conditions found today, and yet through perseverance, they were able to overcome these obstacles and find success (Zaman, 2016). Lesson like these can provide much needed motivation to students struggling with their own barriers in life and can help them see the value of hard work and perseverance as they face these struggles.

Case Study: Historic Rock Ford

Historic Rock Ford sits on 33 acres of land on the southeastern edge of Lancaster County, Pennsylvania. Rock Ford was once the home of General George Washington's Adjutant General, Edward Hand. Hand, born in 1744 in Clydruff, Ireland, is seen today as a controversial figure but very much a product of his times. He was a husband, father, doctor, soldier, immigrant (Zervanos, 2018), and also a slave owner (Huynh & Schwartz, 20122). Though Edward Hand only represents one facet of the population surrounding Lancaster in its early years, the Historic Rock Ford Foundation exists to tell the story of the American Revolution, domestic life and politics in 18th century America, and the uncomfortable truths about slavery in 18th century Pennsylvania. The foundation's website states that their mission is to "provide opportunities to connect with and explore the life of Edward Hand, the diverse communities and material culture of early Lancaster County, and the complex issues that shaped our nation in its formative years by preserving and interpreting Historic Rock Ford and its collections."

To meet this mission, the Rock Ford Foundation partners with different entities in the region to conduct seminars, classes, and other events. These serve to inform the public about the life and times of Edward Hand. Many of these seminars involve bringing middle- and high-school-aged students on the foundation's property to experience what life was like in the 18th century. Since many children historically lived on the property, many of the foundation's seminars focus on establishing connections between today's children and those that lived and played here during the 18th century. It was one of these seminars that provided the opportunity for the faculty and students at Millersville University to partner with Rock Ford and conduct a workshop for area high school students that illustrated 18th century concepts and blended them with 21st century material processing methods.

American Folk Toys

The origins of toys can be traced back to Mediterranean antiquity. Greek and Roman excavations have discovered that children used to play with items like spinning tops, dolls, balls, and hoops. These toys were often handmade by parents, or by the children themselves, from items they had at their disposal (Turner, 2013; Hammond, 2020). These toys typically had an educational or religious purpose to go along with the child's play. The Industrial Revolution brought about changes in toy creation. Instead of being made within the home, board games, books, puzzles, and cards were purchased by parents. In the late 1700s, with the intention of teaching geography, John Spilsbury designed a map that was cut into pieces to become the first jigsaw puzzle (Turner, 2013). During the 19th century, life now included leisure time, and thus toys took on a different role. Despite technological evolution, the basic principle in support of toys often remains the same: the reflection of a child's perception of the adult world or as an enhancer of skills.

One of the focal areas of the Rock Ford Foundation mission is helping today's citizens understand the world that existed in the 18th century through the study of historical artifacts. Since many of the foundation's participants are middle- and high-school-aged children, toys are a natural focal point for many of these seminars. In the 18th century, children enjoyed playing with toys in much the same way as children do in modern times. This connection, a love for play, can be leveraged even with older students, who are still not so old as to have forgotten their own fascination with toys and play. Before helping students relate to life in the 18th century, there must be an understanding of the history and purpose toys have had throughout time. According to author Dick Schnacke (1981) the definition of a "folk toy" would be similar to that of a "folk tale," or a "folk song." Though the origin of these terms seems to have been lost to history, the meaning remains that of something created by people. In the days before toys were commonly available through mass production, parents and children often fashioned their own toys using commonly available materials, such as wood, cloth, corncobs, or other economically available materials (Schnacke, 1981).

Although various toys have been in existence for centuries, and though considerable advancement has taken place in recent times, many aspects remain unchanged. Some of these items include dolls, dollhouses, puppets, wagons (carts), hoops, pull-toys, stick-horses, rocking horses, games, bubble-blowing, construction kits, tops, yo-yos, and toy weapons (Harris, n.d.). The LEGO Group, known for interlocking plastic bricks, evolved from a carpentry shop on the brink of closure, due to the Great Depression. In 1932, LEGO turned its focus to making wooden toys for children, such as yo-yos, blocks, pull-along animals, and vehicles of all kinds (Lipkowitz, 2009). Some of the other standard toys that were present during the Rock Ford era included cup and ball, nine pins or skittles (similar to bowling), quoits (a ring-toss game that possibly goes back to Ancient Greece, eventually leading to horseshoes), and Mancala, a game played in Egypt by 1400 BC (Hammond, 2020).

These toys can provide a link to the past and can still inspire a child to use his or her imagination, experiment, and build, while offering nothing tangible but the impact sound and pure tactile pleasure of the substance (Turner, 2010). In addition to building these connections with the past, there are many principle lessons in science, math, engineering, and technology that can be learned from many of the folk-toy designs. The clever designs of many of these toys both fascinate and amaze modern audiences, creating ideal circumstances to draw their attention to a further discussion on the more complex STEM disciplines which made them the ideal project for the following program.

Student Enrichment Experience Program

In May of 2019, a workshop was conducted at the Historic Rock Ford site. During this time, high school students from area schools participated in a two-part, hands-on event that was held in collaboration with Historic Rock Ford, I.U. #13, and Millersville University faculty and graduate students. The focus of the event was to help students understand and relate to life in the 18th century, as it would have been experienced by the Hand family and citizens of the surrounding communities. This was done by leading the students through a series of activities in which they were exposed to a variety of 18th century artifacts. The artifacts were presented to students not only as examples of 18th century life, but also to illustrate how they related to modern academic fields, such as ecology, economics, and engineering principles (Smith, 2019).

For the first activity, led by staff at the Rock Ford Foundation, students were exposed to five-step object lessons, where they were shown and allowed to handle period objects in the 18th century Georgian-style Hand house. These explorations gave students the opportunity to see and touch a selection of artifacts and learn about the ways that they related to fields of ecology, economics, technology, and engineering. One activity involved students working in groups to assemble both a rotating and tilting tea table and kitchen jack that the Curator, Sarah Alberico, had previously dismantled (Smith, 2019). These types of activities helped students gain a better understanding of how people in colonial America lived, but also a better understanding of how the craftsmen or engineers of the time thought about things from a design perspective. Additionally, this lesson provided a context for the procedures and processes of making things in the 18th century that would play a role in contributing to the standards-based aspect of the curriculum. These object lessons also provided an ideal transition into the following hands-on fabrication activity.

The next stage of the workshop took place in the 18th century barn on the Rock Ford property. Before starting the fabrication portion of the activity, students were brought together as a group and asked a series of questions designed to get them thinking about the process they were about to follow. This type of engagement is crucial, as research has shown that engagement both increases student attention and focus, while at the same time motivates them towards practicing higher-level critical thinking skills (Carini, Kuh, & Klein, 2004). To aid in the conversation, examples of two styles of folk toys were introduced to the students. Figure 2 shows the first toy, a ball and cup, known in France during the 18th century as a bilbocquet. These toys were advertised by Charles Shipman as early as 1767 in America in the New York Journal (Victoriana Magazine, 2020). The ball and cup is a simple design, with a turned wooden cup attached to a handle. A small wooden ball with a string is secured to the handle and the object is to swing the ball so that it falls directly into the cup. This game is an excellent way to develop hand-eye coordination and has remained popular with children of all ages for centuries.

Figure 3 shows another toy that was introduced as an early form of balancing that today has come to be known as a skyhook. These types of balance toys were very popular in the late 18th century and can be dated back to ancient China and India. Though students were introduced to each toy, it was the skyhook that quickly caught their attention and resulted in the most discussion. To most observers the device appears almost magical and people wonder how it is possible for it to hold a heavy object (in this instance a stiff leather belt) without any visible means of support. Once the student's curiosity was piqued, many of them were able, after some discussion, to arrive at the secret as to how the skyhook operates. The solution is really quite simple. The skyhook works through the manipulation of the center of gravity (Zimmerman, 2013).

Figure 2. High school student playing with the ball and cup toy.

Figure 3. High school student testing out the skyhook toy that he just fabricated.

Providing some time for students to learn about the history of the toys was important for the discussion that followed pertaining to the types of processes that were commonly used during that period to construct the types of toys that were just shown and might have been similar to ones that could have entertained not only the Hand children (Zervanos, 2018) but those in the surrounding areas around Lancaster. The discussion continued with a series of questions regarding their knowledge about life in the 18th century, focusing on how the toys that were just demonstrated might have been built.

The discussion was gradually moved towards material processing equipment that was common during this era, and how it has evolved into what is commonly used today in modern industry. Figure 4 shows an example of a modern screw-cutting metal lathe, a device that was created in the late 18th century by Henry Maudslay (Woodbury, 1963). Further discussion revealed that sophisticated lathes were being used regularly by the fourth dynasty in ancient Egypt for complex turning operations in both wood and stone (Hassaan, 2016). The lathe was the primary tool that students would use to fabricate the ball and cup toys that were part of the activity.

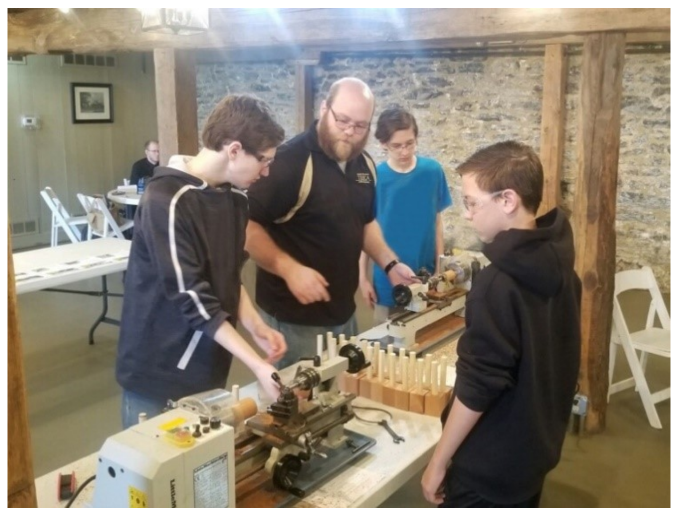

Figure 4. High school students working with a Millersville University graduate student to turn wood ball and cup toys on a 7"x16" bench-top metal lathe produced by Little Machine Shop.

A similar discussion was also started regarding the use of the scroll saw, another tool that has origins pre-dating 18th century America (Huynh & Schwartz, 2011). The fine-cutting, thin, steel sawblades were first developed in the 1500s by German craftsmen (Scrollsaw Woodworking & Crafts, 2010). Later, these blades were added to simple frames, but it was in the 17th and 18th centuries that the craft of marquetry became refined to the point that author Andre Roubo dedicated an entire volume to its craft in his "Le Menuisier Ebeniste." In plate 292, Roubo shows what he refers to as a "marquetry saw," which is a metal frame that, in modern times, would be referred to as a coping or jewelers saw (Schwarz, 2009). By the mid-19th century, reciprocating saws using these thin blades became commonplace, with the first patent being issued in 1829 to Mr. M'Duff, an invention for which he was later awarded the Dr. Fellowes' Annual Prize for the Best Machine Invented by a Working Member of the London Mechanics Institute (Scrollsaw Woodworking & Crafts, 2010).

These demonstrations, occurring prior to the start of the fabrication activity, were important for developing rapport with the students and ultimately helped to truly engage with them in a way that promoted the learning process. Based on the discussions that were observed, there was evidence that this had been achieved and that the students were taking ownership for their part in the activity and also asking questions that demonstrated critical thinking. Students were also beginning to make connections between the evolution of humanity's ability to shape new, harder materials and the evolution of the tools used to create everyday objects, thus contributing to the applicable standards attainment as well.

Fabrication Activity

Before the start of the fabrication activity, each student was provided handouts that covered common safety procedures and also more specific procedures for use with each power tool. To further ensure the safety of the students, either a faculty member or a graduate student was present with the student for operation of the individual machines. Additionally, all participants in the workshop wore safety glasses and hearing protection throughout the activity. Due to time constraints of the workshop, some materials were prepared beforehand. Blanks for the ball and cup were prepared using square blocks of cherry that had been glued to a poplar dowel. This eliminated the difficulties and expense of turning the project from a solid block of wood, and also gave a convenient method of holding the workpiece (by the dowel) in the three-jaw chuck of the metal lathes that were used for the activity. Figure 5 shows how students worked in pairs, under close supervision, and were able to use the controls of the metal lathe to turn the cup portion down to a proper diameter, and the tailstock to drill out cup portion.

Following these controlled cutting operations, students were given the opportunity to do some free-hand turning, using the same methods that were used on a wood lathe with a turning chisel and tool rest. Figure 6 shows how the pieces were finally sanded in the lathe and a turner's friction finish was applied. The skyhook toys were drawn on pre-planed cherry and poplar boards by the students with the aid of a template. Some discussion was had prior to this, concerning the importance of grain direction when laying out these parts. Students were urged to keep the grain flowing lengthwise through the part as much as possible for additional strength of the finished piece. Figure 7 shows that, once the pattern was drawn on the board, students were shown how to cut the part out using the scroll saw that had been previously discussed and demonstrated. Figure 8 shows that the boards that the students used were kept purposefully long in order to provide a safe way of holding the material during the cutting operations.

Figure 5. High school student working with a graduate student to turn wooden ball and cup toys on a bench-top metal lathe.

Figure 6. High school students working with a graduate student to sand the ball and cup toys on a bench-top metal lathe.

Figure 7. High school students cutting out skyhooks on the scroll saw.

Figure 9 shows that, as students completed the cutting portion of the projects, they were rotated to finishing stations, where they sanded, painted, and applied different finishes to complete the toys. Figure 10 shows that, by the conclusion of the activity, students had plenty of opportunities to test the toys that they had made; in the case of the skyhook, they were encouraged to try different designs and see how they performed.

Figure 8. Faculty member demonstrating the correct profile of the skyhook.

Figure 9. High school students finishing the toys that they have just made.

Relation to Academic Standards

As with any other academic field of study, technology and engineering education has a defined body of knowledge and a set of standards that educators use to optimize their curricula and teach best practices. The newly revised Standards for Technology and Engineering Literacy (STEL) (ITEEA & CTETE, 2020) represent a reimagining of the content area and defines the role of technology and engineering in STEM education. When analyzing the learning at the American folk-toy workshop at Rock Ford through the lens of *STEL*, the workshop contributed to the attainment of two benchmarks of standard six and one of the eight technology and engineering practices with *STEL*.

Figure 10. High school student testing the skyhook he had just made.

The folk-toy workshop contributed to the attainment of two of the Grades 9-12 benchmarks of standard six, which relates to the history of technology. The first benchmark that the workshop contributed to the attainment of was benchmark 6F—Relate how technological development has been evolutionary, often the result of a series of refinements to basic inventions or technological knowledge (ITEEA & CTETE, 2020). The workshop met this benchmark through the discussion of the history of the scroll saw and the lathe and how they evolved into the modern machines that students were using that day. Students were walked through the origins of the tool, the major evolutions of materials that make up the tools, and the switch from manual operation to motor-driven operation that is commonly used today. Through this discussion, students became aware of the evolution of the machine and, therefore, contributed to the understanding of technologies as evolutionary and standard 6F.

Benchmark 6G calls for a verification of the symbiotic relationship between the evolution of civilization and the development and use of tools, materials, and processes. In an effort to bring to light this relationship, this concept was discussed when examining the historical predecessors and their modern machine-tool analogs. By engaging the students with the notion of the ancient Egyptian lathe and early saw blades and how, as an understanding of materials science and manufacturing capabilities grew with civilization so did the tools themselves, students gained an understanding of the relationship between civilization and their tools and processes. By doing so, the lesson contributed to the students' attainment of benchmark 6G and expanded their understanding of the relationship between humans and their tools and processes. Additionally, the folk-toy workshop engaged students with the making and doing practice that is crucial to technology and engineering education. *STEL* calls out this practice as "…central to technology and engineering education. This remains its signature trademark, differentiating technology and engineering from other content areas" (ITEEA & CTETE, 2020, p. 77). Students engaged with this practice as they created their folk toys using the lathe and scroll saw. As they did this, they were engaging with an authentic learning experience and taking the theoretical knowledge they gained from the previous discussion about the machines and toys and applying it to craft their own. Through this act of making and doing, the learning that occurred was made "real" for them and contributed to the practice that is critical to technology and engineering education.

It is important for educators to provide students with a background in the areas of history-social sciences that reflect our commitment to history-social science education. These standards, such as Pennsylvania's 8.2.9B (Commonwealth of Pennsylvania, 2009), which compare the impact of historical documents, artifacts, and places in Pennsylvania and which are critical to U.S. history, can help to emphasize these historical narratives by highlighting the roles of significant documents or artifacts that convey a more complete understanding of the chronological events of history that find parallels in modern times. These standards, and others, serve as the basis for assessments, curricular frameworks, and instructional materials, that, when combined with the revised Standards for Technology and Engineering Literacy can help students achieve a better, more complete understanding of history and help to create authentic learning environments.

Modifications

The nature of this activity is well-suited to be scaled up or down to different audiences and grade levels. Though the focus of the workshop was on manufacturing technology and how it has evolved since the 18th century, the same activity could be done, with some modifications, in other STEM areas. For instance, a similar activity could be done connecting the historical aspects of a toy like the skyhook and adapting it into a science curriculum with a focus in physics. The principle that the skyhook operates on, center of gravity, could evolve into an excellent activity in which students research the origins of when scientific knowledge had evolved to the point where it could explain the principle operations of the toy. This can go back as far as the famous Greek mathematician and physicist, Archimedes, and his early works related to the study of mechanics.

The concept was later expanded upon in the summer of 2019 and played out in the technology and engineering camps that were conducted at Millersville University. Maintaining the folk-toy theme, students participated in a three-dimensional (3D) design and printing camp, where they learned how to design folk toys using SolidWorks. Though the focus of the previous workshop focused on traditional, subtractive methods of manufacturing, the focus of these camps was on more non-traditional additive methods of fabrication. Following the design portion of the project, they were able to print their designs using one of the 3D printers available to them at Millersville University. Since most folk toys are simple designs, they were ideal projects to use as an introduction to 3D-modeling software. Figure 11 shows how this proved to be an engaging activity that the students seemed to enjoy, as evidence by the enthusiasm they showed during the class.

Figure 11. Engineering camp student and teaching assistant work with a 3D-printed buzz-saw toy.

The same concept was also applied to another class taught that summer. In the Machining for Kids camp, students learned how to operate a small bench-top metal lathe. Figures 12 and 13 shows that a spinning top was selected as the main project for this class. During the course of the week, students learned how to safely operate a bench-top metal lathe and learn how to use it to produce parts that were, in some cases, within tolerances of 0.001". As with other camps, the kids were excited about the project and, in many cases, ended up making two or more tops during the course of the week, thereby learning a great deal about precision machining and how to read technical drawings in the process. These are just a few examples of how these areas might be modified to suit the needs of different programs. In many cases, time is going to be the deciding factor on what can, or should, be covered. There is always going to be a limited amount of time available to teach students the desired outcomes, and each program director will have to assess how best to accomplish those within existing constraints.

Conclusions

The great philosopher and poet George Santayana once famously said, "Those who cannot remember the past are condemned to repeat it." (Santayana, 1905). Santayana's words are as true today as they were when he wrote them in 1905. Though it can be difficult at times to address areas of social science, particularly with the current trend towards standards-based accountability and the direction towards STEM fields, it is still important to remember Santayana's words, which should be viewed both as an inspiration for educators to do better and also as a cautionary note about the follies of forgetting the past.

Figure 12. Engineering camp student and instructor learn how to safely operate a bench-top metal lathe.

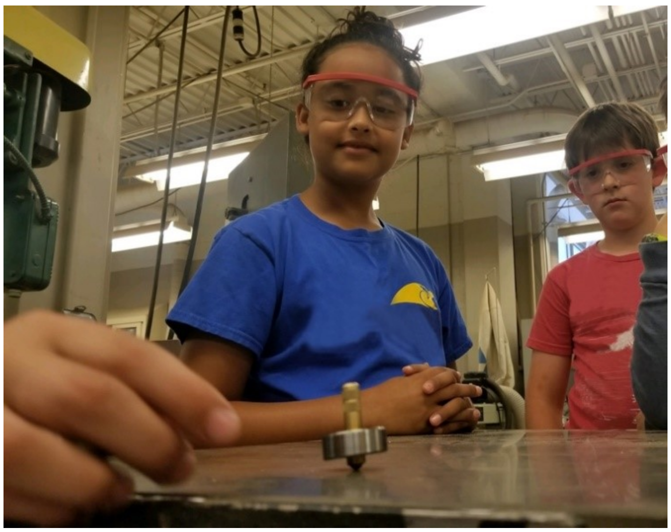

Figure 13. Engineering camp students test the tops that they made using a bench-top metal lathe.

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The Need for Integration of Smart Glasses in Policing for the 21st Century: Is the Technology There Yet?

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Abstract

In policing, the adoption of body-worn cameras (BWCs) provide incomplete data, such as lack of resolution and quality of sound, which makes the job of policing difficult when the actions of officers are questioned. The body-mounted models often do not capture the full range of an interaction, or possibly become dislodged during a foot pursuit or physical altercation. Videos of police activity need to provide, to the extent possible, a clear and undistorted picture of every action an officer takes, when performing stops and arrests that the public might deem questionable. Undistinguishable videos can lead to misinformation and confusion that can cause potential civil unrest. Since the Ferguson, Mississippi, incident, there has been a public outcry and the expectation that an officer's actions in the field will be recorded. BWCs were the first step in solving this problem. With advancements in smart glasses, or augmented reality (AR), law enforcement can stream information such as facial recognition and better record interactions to provide increased accountability by allowing for higher resolution and field-of-view capabilities. In this paper, the authors discuss current AR technology and its advantages and disadvantages in improving police accountability.

Literature Review

The interest of body-worn cameras (BWCs) among American law enforcement agencies has increased rapidly since 2014, but little academic research into the technology has been done, much of which suffers from weak methodology (Adams & Mastracci, 2017). Prior to the Ferguson incident, there was the police shooting death of Eric Garner and the infamous video footage of the attack on Rodney King in 1991 in Los Angeles, California. These and other similar events have created the need and growing expectation for police departments to adopt and utilize BWCs in the field when interacting with citizens. Police body cameras can be an effective tool for protecting citizens, increasing police accountability, and ensuring fact-finding (Dhillon, 2015). Goetschel and Peha (2017) reported that the list of potential benefits of BWCs is long, ranging from measurable decreases in citizen complaints against officers to more abstract benefits such as improving police-community relations or increasing police transparency and accountability. Conversely, there have been arguments regarding the ethics of officers being recorded and recording those they come in contact within the community. In addition, police officers have expressed concern that BWCs can undermine privacy and erode trust between officers and their superiors (Goetschel & Peha, 2017).

Barak (2017) reported a relative reduction of roughly 50% in the total number of incidents of use of force complaints compared to the twelve-month prior. However, it was 2015 that set the BWC debate in America. One month after a grand jury decided not to indict Ferguson, Missouri, police officer Darren Wilson in the killing of teenager Michael Brown, the White House released the Interim Report of the President's Task Force on 21st Century Policing (Crow, Snyder, Crichlow, & Smykla, 2017). According to Crow et al. (2017) the President's Task Force report recommended greater use of police officer BWCs, improved collection of officer-involved shooting data, sanctions against police departments using unnecessary military tactics and equipment, and allocation of $75,000,000 to fund the purchase of BWCs. Since the adoption of the BWC movement in America for law enforcement, several small, pager-sized camera versions that could be affixed onto an officer's uniform (or even a headset) and allow for the recording of audio and video footage of items within the officer's line of sight (Dhillon, 2015) have become the norm. Dhillon (2015) states that "Police body cameras or BWCs can provide evidence of police abuse of authority but cannot make juries and judges convict officers." Some officers believe that continuous BWC footage could be weaponized against them in split decision making in the field. Furthermore, BWCs could impact discretionary decisions to act or not act, due to the fear of reprisal from others in their own agency, the general public, or the media.

Regardless of the pros and cons of BWCs, these tools have become engrained in policing. Citizens overwhelmingly believe BWCs can improve police behavior by treating citizens, crime suspects, and crime victims with more respect, while also reducing police misconduct and excessive force (Goetschel & Peha, 2017). Lipper and Newell reported that, while BWCs have been piloted and slowly implemented in public police organizations in Europe, the U.S,, Canada, Australia, and elsewhere for years, it was the events of Ferguson, Missouri, in 2014 that led to greater public and political considerations of these devices as a solution to inadequate police accountability, thereby raising the visibility of body-camera adoption around the world (Lippert & Newell, 2016).

The question now, though, is how to improve the effectiveness and safety of BWCs moving forward? There is a growing need for media storage, better resolution, and affordable technology that can be integrated with a police officer's duties, while not compromising safety. The focus of this current study was to provide an analysis of the limitations of assimilating the existing commercial use of AR smart glasses (primarily used in industry, such as warehousing) and integrate the technology into policing. The goal of this study was to provide the argument that AR smart-glass technology would allow police officers greater opportunities for engaging with citizens, having lighter weight equipment more reliable technology, along with having higher-quality recordings for police investigations. Furthermore, it would increase officer safety and create greater accountability with community members. However, the current AR technology, although appealing, has limitations and health concerns that warrant attention and further research.

The Technology Dilemma with BWCs

Hamann (2018) noted in her research that police and prosecutors and the sharing of information is not fluid. Jurisdictions operate with different budgetary constraints, various operating systems, and often antiquated technology for their investigations. High-resolution cameras are more expensive and generate larger files that are more costly to store (Suss, Raushel, Armijo, & White, 2018). Enhanced technologies, such as facial recognition software, may simplify the redaction process in the future; however, there will always be a need for double checking each frame of a recording to make sure that the redaction was complete and properly made (Hamann, 2018). Furthermore, the body-worn cameras currently on the market have significant limitations, such as the lack of integration with an officer's radio communication system in the field. As a BWC is recording from a chest-mounted position, the officer remains on his or her portable radio asking for requested information from police headquarters, such as wanted-person information, previous criminal history, missing person(s) information, threats toward law enforcement, stolen vehicle information, stolen property, or criminal trespass information. More common calls over the portable radio are requests for a case number during an investigation or call sequence number as well as assistance from other agencies such as fire, EMS, or other law enforcement entities. Regardless, during this time of relaying information and then waiting for a return there is the possibility of officers talking over one another on the radio or "multiple units" keying up on their portable at the same time.

Second, if the communications officer is inundated with requests, there can be a delay in the return information for that officer. All of these things can increase danger for an officer by the delay of information or interruption in assistance by having multiple units calling in at the same moment. A second limitation is the quality of capturing images with the BWC. The badge-style clip-on cameras are acceptable for life-logging applications but are horrible for photography (Elgan, 2017). Elgan (2017) reported that "the physical cameras move around, sit at odd angles and are not directly controlled by the user (they tend to shoot photos at intervals, or take video), the picture is universally bad." The BWC will only capture or record what is directly in front of the lens, often with limited resolution and storage capacities. The higher the resolution, the more storage space is needed, thereby incurring more cost for police departments. For example, at a video graphics array (VGA) resolution of 640x480 and a frame rate of 30 frames per second, an hour of video recording would take approximately 550-1100 MB of storage (Hung, Babin, & Coberly, 2016), whereas high-definition (HD) resolution, also called 720P, is 1280x720; an hour of recording would take approximately 1650-3325 megabytes (MB) of storage (Hung et al., 2016). The difference in choosing storage space and resolution for a police agency could be thousands of dollars in an annual budget. Smaller or rural departments would not be able to afford the higher-quality resolution options requiring massive amounts of storage capability. Similarly, there is the question of the audio capability with BWCs. The placement of the microphones on the BWC may impact the quality of the recording, especially for head- or shoulder-mounted systems (Hung et al., 2016).

Another issue is the placement of the camera. Most cameras that are manufactured and worn in the U.S. are worn or mounted on the chest of the officer. There has been a plethora of problems with this style of BWC. A chest-mounted or a torso-mounted model limits the image or recording when performing daily tasks. For example, a camera mounted to an officer's chest during a vehicle pursuit could be partially obscured by the steering wheel and dashboard (Suss et al., 2018). Additionally, in tactical situations, an officer's handedness and eye dominance can influence which side of the body is exposed when taking cover or when returning fire during a critical incident (Suss et al., 2018). Under other circumstances during a fight or physical scuffle, cameras can be knocked out of alignment or fall off their mount completely (Suss et al., 2018). Another consideration is during a foot pursuit (or foot chase); a mounted camera will record as the officer is running and the video will be distorted, or possibly fall off the officer's chest during the pursuit or lost entirely. There are also issues of battery life, connectedness, uploading data, and storage.

Because of these limitations, missing or distorted media from an officer's BWC may leave jurors or judges with the impression that something was averted or intentionally left out of an investigation. Although unlikely, the current environment of mistrust among law enforcement with the claims of excessive force or deadly force cannot be overstated in terms of accurate depictions of each civilian encounter. Currently, the production of BWCs is not regulated by standards or guidelines; vendors, therefore, develop their products based largely on perceived needs, customer demands, and technological possibilities (Suss et al., 2018).

The Emerging Technology of AR Smart Glasses

In the U.S., AR smart glasses have been implemented in the business and medical fields. For instance, in warehousing, storage, and distribution-center industries, smart glasses have increased efficiency and effectiveness in reducing errors in orders and locating items for rapid distribution with low error rates. The same technology could be adopted to aid law enforcement in the U.S. with the goal of meeting the expectations of society in the recording of police actions, receiving critical information from centralized databases, and ensuring officer safety. The next generation of AR glasses is experimenting with a micro-display, or heads-up-display (HUD), tucked into the field of view, whereas other glasses provide for augmented reality (AR) in which the glasses can overlay translucent visuals right into the field view (Michel, 2018). The same technology offers a multi-mode option with voice control. These smart glasses have integrated microphones and speakers and voice-solution vendors have been closely involved with them (Michel, 2018). So how does this technology in warehousing suggest an overreach into contemporary policing in the U.S.? The potential applications in policing are limitless, when it comes to engineering smart glasses or AR models to meet the needs of the average first responder.

In a pilot program in Centerville, Georgia, the police department purchased 12 pairs of AR glasses and field tested them in 2015. These models did not have facial-recognition or license-plate recognition (tag scanning) capabilities. The glasses did activate by either voice command or touch using the built-in mouse in the right rim of the glasses (Purser, 2015). In this pilot program, the chief complaint was the battery life and extra equipment required to extend the life of the battery in the field (Purser, 2015). Regardless, the AR glasses provide viewers with a view into what the officer was seeing at the time of the activity or encounter in the field. A lightweight frame with a wider range of visual recording and heads-up display would allow police to identify individuals, record interactions, receive critical information in real time, and communicate with one another. Such a tool would have been advantageous during the 2020 riots in recording criminal violations, identifying individuals using facial-recognition applications, and determining who among the activists might have been a fugitive from justice at the time.

In the field, when an officer contacts a citizen, a facial-recognition program could identify an individual in seconds in order to ascertain whether a person was being truthful about his or her identity. Another benefit of this technology would be to have the ability to record more details beyond that of a BWC or handheld video recorder at a crime scene such as a homicide. When officers typically arrive on a crime scene, there are people standing behind the crime scene tape. Often the suspect is there and observing the police among the spectators. The smart glasses would allow officers to scan the crowds and start identifying potential suspects or, at a minimum, record what they are seeing for the investigation. Second, the evidence and the integrity of the crime scene can be better preserved when smart glasses are utilized, by allowing an investigator to take still photos and/or video to record the investigation through the eyes of that officer. Officers who work at night would have the ability to use night-vision applications for more efficiency in the field as well as officer safety.

The authors of this current study searched for police agencies that have adopted smart glasses in policing. In one study, China began experimenting with smart glasses in their railway police divisions in 2017, developed by the company Xloong. China reported that those officers, using smart glasses or augmented reality (AR) glasses, apprehended seven wanted fugitives and successfully identified and arrested 26 individuals traveling under false identities (Chin, 2018). "These successes were due to the implementation of smart glasses that were outfitted with fixed facial recognition systems that remotely connect cameras to vast facial databases stored in the cloud, the police glasses are wired directly to a hand-held device that connect to an offline database allowing them to work more quickly" (Chin, 2018). These same models receive and could have access to existing data systems in the U.S., such as Tiburon, Central Square, and other record-management systems (RMS) or related operating systems. Smith (2019) further stated that the Chinese smart glasses meant that officers can look in the direction of an individual and have a variety of information, such as identity, gender, and ethnicity, and address past crimes or outstanding warrants. Yang (2019) reported that "additional information was incorporated in the use of the AR glasses such as access to real time facial, identification card and vehicle plate information that were linked with a national database." Such information leads to officers safety and the decrease of officer complaints by citizens. This tool allows officers to maintain situational awareness and react to a threat more quickly.

Vincent (2019) reported that the Dubai-based firm Innovative Technology Company (NNTC) has introduced the iFalcon AR glasses. This product has an 8-megapixel camera embedded in the frame which allows the wearer to scan faces in a crowd and compare with a database of 1 million images (Vincent, 2019). The NNTC have produced 50 pairs of facial recognition-enabled glasses, and that they are currently being deployed into several security operations (Vincent, 2019). In Moscow, Russia, a similar program was launched in 2019. According to Smith (2019), the implementation of smart glasses by Russian officers will be fed information from 1500 cameras across Moscow, linked to a database of individuals wanted by the police. This integration allows officers to quickly identify terrorists, members of organized crime syndicates, and other wanted individuals. In the Netherlands, the National Police Unit has begun implementing and testing the use of smart glasses called the

Vuzix Blade Smart Glasses. The pilot test in the Netherlands used the smart glasses with the mounted and on-foot police officers to provide heads-up hands-free routine information for unfamiliar areas as well as additional information including notifications of crimes, suspect pursuit and troublesome locations (Netherland's national police unit using Vuzix blade smart glasses in police work study, 2020). Having a tool such as this allows officers in the field to continuously produce global positioning, while identifying individuals they come into contact with in the field.

Limitations of the AR Glasses

The current models of AR glasses in production, while attractive to police agencies, are not without limitations. Calvert (2019) reported in a review of the Solos smart glasses that, although they weighed 65 grams in total, the arms were non-foldable, due to the technology housed in them and, when tested in running, the glasses bounced slightly. This made reading the HUD screen difficult (Calvert, 2019). However, in a different review of the Solo glasses, the wearer reported that the glasses stayed firmly in place during a forty-five-minute run when testing durability but felt a little bulky in terms of style (Baragona, 2018). More field tests are needed to adequately provide stability for the lenses. In 2013, the Byron Police Department implemented a pilot test of the AR glasses in the field. At the end of the field test the department reported that the downside to the glasses was the short battery life, the aggravation of adding another gadget and wire on the police uniform (Purser, 2015). However, this was seven years ago and since then this technology has evolved in some areas, such as longer battery life, wireless or blue tooth connections, and providing prescription lens when needed. Still, there are more areas in which progress is being explored, such as media storage, improvements in the lens applications, and frame designs that would be lighter in weight while being more aesthetically appealing to officers.

Second, there have been reports of negative side effects affecting the health of the wearer. It should be noted that the existing research is limited. First, the existing studies identify the terms virtual and augmented realities synonymously. In one study, the authors measured the negative side effects of medical students, who were assigned to study groups using virtual reality, augmented reality, and computer tablets. The group that was using in the virtual reality (VR) goggles had the most significant differences in reported health issues. The VR group in their course work reported loss of spatial awareness, dizziness and disorientation, seizures, nausea (also known as cyber sickness), and eye soreness. Cybersickness a relatively new term that is defined as a type of vertigo. This condition is due to a sensory mismatch, which happens when the visual system tells the person that the body is moving, while the vestibular system tells the person that the body is stationary (Moro, Stromberga, Raikos, & Stirling, 2017). Moro et al. (2017) concluded from their study that the AR user group also reported having signs of cyber sickness, but the VR users reported significant ailments when compared to the AR group, such as dizziness (40%), blurred vision, and double vision issues were reported as well. Additional research is needed in the areas of mental health and long-term exposure that may cause issues similar to those of internet addiction.

Legal Concerns

Ironically, the law makers and advocates that were calling for more transparency in police actions and reform when body cameras were introduced are the same ones now citing privacy concerns when using AR glasses in the field. The American Civil Liberties Union (ACLU) recommends strong privacy policies for police departments that use body cameras and be limited to uniformed officers, who should notify citizens when they are being recorded and the data kept no longer than necessary (Purser, 2015). AR glasses are essentially computers with recording and uploading capabilities. All the actions in the field have the potential to be recorded by an on-duty officer. Policies and protocols would have to be clearly defined and align with the Freedom of Information Act (FOIA) requirements. This will inevitably lead to ongoing state and federal court decisions on interpreting what will be considered public versus private activities when being recorded by officers. This will further warrant ongoing analysis of Fourth Amendment clauses with regards to the right to privacy, unreasonable search and seizures, and the plain-view doctrine. Another point of mention is that AR technology will be able to capture more detail and information beyond what the average officer may see or miss. This would challenge the current interpretation of the inevitable discovery doctrine as stated in Nix v. Williams (1984) and State v. Garner (1992).

Conclusions

Are smart glasses equipped with high-resolution recording, maximized range of view, and facial recognition needed in the U.S.? The answer is a resounding yes. During 2020, there were riots, looting, and domestic terrorism across the nation. Along with the COVID-19 pandemic, economic recession, and attacks on police, there has never been a time in which such technology has been needed for both police and society. As technology demands increase, so will the need for balancing boundaries between what is construed as private versus public information in society in the court system. Regardless, the migration towards embracing technology such as the smart glasses assisting law enforcement, the military, and even civilian jobs such as physicians or private industry is underway. The traditional body-worn cameras served as the first stage of recording and working with the public in policing. Over time, BWC limitations have come to light in policing, thus calling for changes with the existing models for dependability, safety, and ergonomics.

With its impending arrival, there will be a race for market share to produce quality products that will only benefit first responders and increase the trust within their community. The overarching goal with this technology will be the same as the iPhone or Android models—produce a small product that can store large amounts of data and perform infinite amounts of applications by the user, while sustaining a long battery life when in use. Further technological advancements would be having the technology to synchronize all of the officer's smart glasses at a call to create a panoramic visual representation for others to review.

A second desired goal would be to use similar technology in AR smart-glass science in the visor of the ballistic helmet for officers in tactical units, such as riot control and special weapons and tactical (SWAT) units. The final possibility is incorporating the AR HUD into the windshield, windows, and back window of a patrol unit in the field to provide navigation and recordings with a greater field of view. The ability to record from various vantage points from an officer's perspective would be invaluable. Similar goals have been achieved in other areas of technology in the past and continue to evolve. The race for smart or AR glasses in policing is just beginning. As the market has seen an increase in demand for the commercial use of smart glasses, engineers are continuously seeking to improve the resolution of the lens, sound quality during recordings, and increasing the life of the battery for each product. In turn, what this means for police is that, soon, AR glasses will be affordable and provide the technology and durability needed in the field to provide officer safety and accountability. At the present time, the full adoption and implementation of AR glasses for policing with the limited storage, limited battery life, and limited field of view is premature.

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