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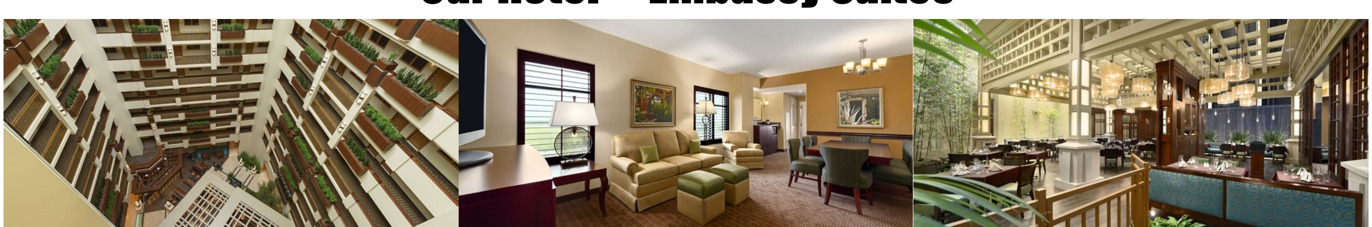

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INNOVATIVE CONVERGENCE: ROBOTICS AND WEARABLE COMPUTING TECHNOLOGIES

Ben Zoghi, Texas A&M University; Abelardo Hernandez Rubio, Texas A&M University;
Roberto Lafaire, Texas A&M University; Jose Sotelo, Texas A&M University

Abstract

In this paper, the authors share the implementation of an innovative hands-free, voice-activated, wireless cloud-based technology for first responders to save lives in hazardous or dangerous environments. Robotics and wearable computing technologies (RWCT) can be field deployed in response to an unpredicted disaster to minimize human and environmental damage. Companies in the private sector are required to handle numerous chemical materials, which may be hazardous to humans and the environment. The RWCT system uses wearable technology, voice-activated control, cloud computing, and wireless connectivity to remotely perform hazard safety management if an unexpected disaster happens. The testing performed on the RWCT system proves the effectiveness of wearable computing for first-responder teams. First responders can communicate with experts located remotely in a real-time fashion. Due to the modularity and scalability of the system, there are multiple applications in which it can be deployed. Applications include chemical, biological, radiological, and nuclear (CBRN) incidents. The quality of the response is measured by the initial hours after a disaster occurs. The quality of the immediate response has the most impact on the quality of life, environment, and economy of the end user. The use of the RWCT system will minimize time and cost of economic recovery from disasters.

Introduction

In this paper, the authors share the implementation of an innovative hands-free, voice-activated [1], wireless cloud-based technology for first responders [2, 3] to save lives in hazardous or dangerous environments. Wearable computing is a proven technology that increases productivity by providing voice-activated control and hands-free capabilities. The modular scalable robotic platform has been designed to provide situational awareness by providing near real-time video and hazardous agent detection. The cloud-based supervisory control software provides first-responder teams with real-time wireless connectivity over Verizon's 4G LTE network with experts located anywhere in the world. This end-to-end wireless connectivity includes sensor data, video, and cell connectivity for experts to provide remote assistance if needed. Due to the modularity and scalability of the RWCT system, there are multiple applications in which it can be deployed. Applications include chemical, biological, radiological, and nuclear (CBRN) Incidents. First responders and experts need to share critical information necessary to make important decisions during emergencies. The wearable computing device (Golden-i) [4-6] can provide hands-free capabilities and control the robotic mobile platform through voice commands. Immediate wireless communications provide connectivity between first responders on site and experts located anywhere with Internet access. RWCT serves as proof-of-concept for further implementations by providing modularity and scalability to integrate the needs of an application.

Conceptual System Design

Figure 1 shows the conceptual system block diagram. A first responder would wear the Golden-i (head-mount display unit). From a distance, the RWCT system will be sent to the exposed area to perform an exposure assessment. To perform this assessment, real-time sensor data and video feed are displayed on the screen of the Golden-i, while controlling it through voice commands. An expert observes the same sensor data and video feed displayed in the Golden-i through the cloud-based supervisory control software (CBSCS). Cloud-based wireless connectivity allows experts to provide expert assistance remotely. The system provides such a level of wireless connectivity in a real-time fashion and there is end-to-end connectivity from the expert's workstation remotely to the robot on site.

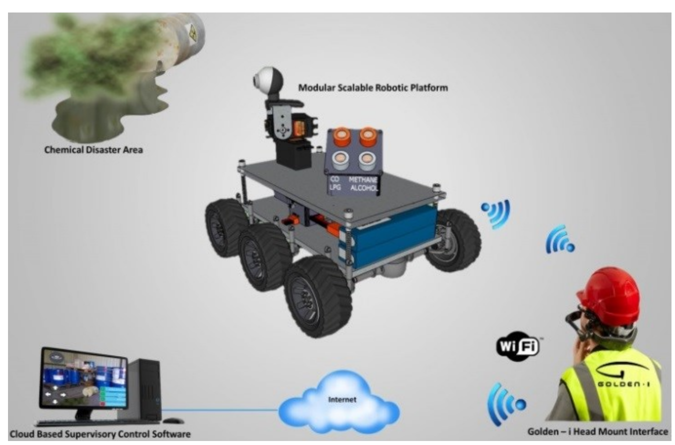


Figure 1. Conceptual Block Diagram

Design Implementation Strategy

The RWCT system provides situational awareness to first -responder teams. The following methodology will be used to achieve such goal: A first responder wears the Golden-i. From a distance, the modular scalable robotic platform (MSRP) is sent to the exposed area to perform an exposure assessment. To perform this assessment, real-time sensor data and video feed are displayed on the screen of the Golden-i, while controlling it through voice commands. An expert observes the same sensor data and video feed displayed on the Golden–i through the cloud-based CBSCS. Cloud-based wireless connectivity allows experts to aid remotely. The RWCT system provides such a level of wireless connectivity in a real- time fashion. There is end-to-end connectivity from the CBSCS to the first responder on site to the MSRP. Figure 2 shows an end-to-end system design, where the robot communicates wirelessly to the first-responder Golden-i module as well as being connected to the cloud-based supervisory control software.

Figure 2. System Topology

The RWCT system includes different technologies and devices that will enable first responders to immediately control a robotic platform through voice commands as well as having access to video and sensor data. The main components of the system are explained in the following sections.

Modular Scalable Robotic Platform

The MSRP consists of a 6-wheel platform with six DC motors. The MSRP was designed using a system integration approach with the BeagleBone Black as the main intelligence board. A motor controller (ROB-12075) controls the motors and servo movements via a dual H-bridge configuration. The WizFi 630 EVB provides wireless communication between the MSRP and the rest of the RWCT system. The MSRP counts with a Logitech c920 camera for video streaming capabilities. Individual sensor boards are integrated into the MSRP and have the ability to measure carbon monoxide, alcohol, methane, and liquid petroleum gas (LPG). A power module designed by RWCT provides the appropriate power to each of the individual modules. Finally, two rechargeable 10,000 mAH batteries provide power to the mobile platform.

Cloud-Based Supervisory Control Software

The RWCT system offers cloud-based connectivity through 802.11 protocols and third-party streaming services. Using a 4G wireless hotspot, all of the information received from the MSRP is transmitted to the CBSCS. The Golden-i and the CBSCS communicate through the same wireless network via standard IPV4 addressing. The CBSCS has a pre-installed GUI that accepts both the sensor and video feeds through a UDP connection at a specified port. This UDP connection begins at the Golden-i application and ends with the GUI at the CBSCS. The Golden-i mirrors the same data that are received from the MSRP. This provides access to users to the sensor data and video feed over the Internet. The data reside in a LiveCast mini-server and are accessed through authentication credentials provided by LiveCast. In case the user at the CBSCS would like to communicate with the Golden-i user, cell connectivity can be accomplished through the Golden-i via Bluetooth connected to a cell phone.

System Analysis

The functional block diagram shown in Figure 3 is a more detailed representation of the conceptual block diagram. Each block represents a major component of the design of the RWCT system. There is a color code where different systems can be identified. The blue blocks represent components that are part of the MSRP. The yellow blocks represent the modules that the RWCT system performs on the hardware design, PCB layout, fabrication, and population. The green block represents the Golden–i head-mount interface. The purple block represents the cloud-based CBSCS, which has access to the sensor and video feed.

Sensor Modules

Individual sensor modules are used as proof-of-concept that the system is able to detect hazard chemicals/gases. The sensor modules consist of multiple sensors that measure methane, alcohol, liquid petroleum gas (LPG), and carbon monoxide. The scope of the project is to deliver a system in which the end user is able to use other sensors and modules that best fit their applications. As proof of concept, the RWCT system uses sensor modules that only detect changes in gas concentration and transmit the data wirelessly. Each sensor has a signal conditioning circuit that conditions the sensor's output signal.

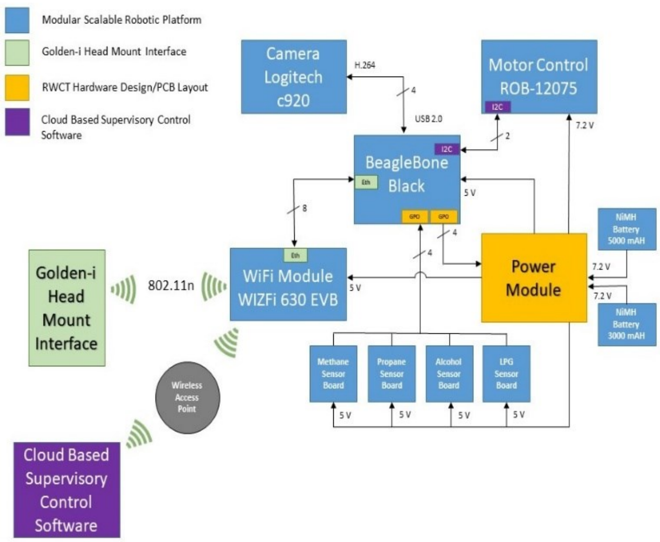


Figure 3. Functional Block Diagram

The gas sensors are tin dioxide semiconductor sensors, such that the sensor's conductivity increases in the presence of the gas. The matrix in Table 1 shows the differences and characterizations of each sensor, such as sensitivity, required load resistance, input voltage, and output voltage. The responses of these sensors depend on several parameters, such as air quality, humidity, and temperature. The sensors are used to detect changes in concentration and not to measure the concentration accurately. Table 1 represents the expected outputs when gas concentration is known.

Table 1. Gas Sensors

	Methane (MG-2)	Alcohol (MQ-3)	Liquid Petroleum Gas (MQ-5)	Carbon Monoxide (MQ-7)
Sensitivity	100 ppm	0.04 mg/L	1000 ppm	100 ppm
Load Resistance	20K ohms	20K ohms	20K ohms	10K ohms
Input Voltage	5V	5V	5V	5V
Output Voltage	2V to 4.4V	0.2V to 0.9V	1.25V to 3.5V	1.6V to 4.2V

Golden-i

The hands-free head-mount display, known as the Golden-i, is an integral part of the RWCT system, as it serves as the bridge between the MSRP and the CBSCS. The specific version of the Golden-i is the 3.8 model. This model provides plenty of features and benefits, including voice commands, Bluetooth, and 802.11n wireless communications. The on-board OS is the Android 4.2.2 Jellybean and comes with proprietary software to easily code in custom voice commands to navigate the menu shown on the small HD display. The Golden-i is designed to be used as a hands-free device only controlled through voice and head tracking. Furthermore, the Golden-i also comes equipped with a 13-MP camera that can also be implemented as a feature in order to provide the CBSCS with a live-feed view of the first responder.

Wireless Communication

The RWCT system has extensive use of the 802.11 b/g protocols. More commonly known as Wi-Fi, the RWCT system uses these protocols to wirelessly communicate between the cloud-based CBSCS, Golden-i, and the MSRP. Within these 802.11 protocols are two-packet structures. These packet structures are used in organizing the information in particular frames that will be sent across wireless channels. Transmission control protocol (TCP) is a packet structure that handles the information in a way such that reliability is ensured and packet integrity is maintained. TCP is the standard for sending information that can be corrupted, due to the nature of the data or the need to always have accurate data at hand. For the RWCT system, the sensor data that will be wirelessly transmitted must be accurate and must not be easily corrupted, due to the sensitive nature of the project. These sensor data are used to evaluate life-and-death situations and, thus, data corruption must be avoided. Utmost reliability must be ensured, thus TCP is the packet structure that was selected for the RWCT system.

TCP provides this reliability by synching with the target host and ensuring that every single packet has been successfully received via acknowledgement return packets. Communication first starts out with the device wanting to communicate and will open a connection to the target host. Once established through pre-defined ports, TCP will perform a 3-way handshake that will sync both the client and target host. User datagram protocol (UDP) is a simpler packet structure compared to TCP and is usually used in applications where the delay must be as low as possible. Thus, UDP is applied where there is a need for near real-time communication between two or more systems. In the RWCT system, such cases exist and require the use of UDP.

The Golden-i transmits voice command data to the MSRP to control its direction and speed. Since the RWCT system assumes a fast response in a dire situation, the amount of time that the MSRP takes to respond to the user voice commands must be as low as possible. The second case, where UDP is applied, is where the video feed is supplied by the camera on the MSRP. The video must be delivered to both the CBSCS and Golden-i headset and be near real time. Thus, UDP is useful, due to its low overhead and small-frame format. Communication via UDP is straight forward and requires a simple setup. All that is required is for the devices to be listening to pre-programmed ports for UDP packets. From here, the device is programmed to act on these packets to ensure that they reach the desired application. In the case of the Golden-i, UDP video packets are received by the Wi-Fi module and, thus, the Golden-i has to use these packets to construct the video feed on the GUI. Similarly, the Wi-Fi module receives voice-command packets from the Golden-i and must be programmed to listen for these packets as well as send them to the BeagleBone Black for processing.

Wired Communication

The RWCT system makes use of three very specific wired communication protocols, all of which are present on the MSRP. These wired communication methods are the primary form of communication found between the modules on the MSRP. The modules benefiting from this form of communications are the motor control module, Wi-Fi module, BeagleBone Black, and the sensor module. The Beagle Bone Black communicates over standard 802.11 Ethernet protocols over a CAT 6 twisted-pair physical wire. This is connected to one of the LAN ports on the WizFi 630 EVB, which acts as a wireless bridge to the Internet. From the perspective of the BeagleBone Black, it is assumed to be connected to the Internet through a wired connection. However, the WizFi 630 EVB provides Internet access through 802.11n protocols. Ethernet itself works within the standard frame consisting of a Preamble, SFD, Destination MAC, Source MAC, Ethertype, Payload, and the terminating FCS.

Inter-integrated circuit (I2C) is the primary communication method between the motor control module and the BeagleBone Black. The RWCT system choses to use I2C as the communication method between these two modules, due to its ease of use and low number of data lines required. The motor control module also works well with the I2C communication protocol and can easily adapt to any I2C interface as well as provide vital information in the form of 24-byte status packets. It also makes it easy to send commands to the motor control in 27-byte command packets. Communication with the motor control begins when the SCL line is set by the BeagleBone Black at 100 KHz and a START bit is sent over the SDA line when SCL is held high. A START bit is simply a high-to-low transition on the SDA line, while SCL is still high. From here, the BeagleBone Black sends a byte, which contains the address of the motor controller, default automatically set at 0x07, as well as one bit that determines if the Beagle Bone Black will read or write from the motor controller. Apart from the three primary communication protocols, there is also the USB 2.0 camera that interfaces directly with the BeagleBone Black. The protocol used, however, is the standard USB 2.0 four-pin structure. The camera has all processing and encoding on-board and sends the video feed already encoded in H.264 format. This is sent through USB 2.0 directly to the BeagleBone Black, where it is then passed on to the Wi-Fi module and sent to the Golden-i.

Hardware Design

The hardware design of the RWCT system includes a power board, PCB layout, connectors, and enclosure design. A power module was designed to provide the appropriate power levels to all of the onboard modules of the MSRP. Figure 4 shows a detailed functional block diagram that represents all of the circuitry of the power module.

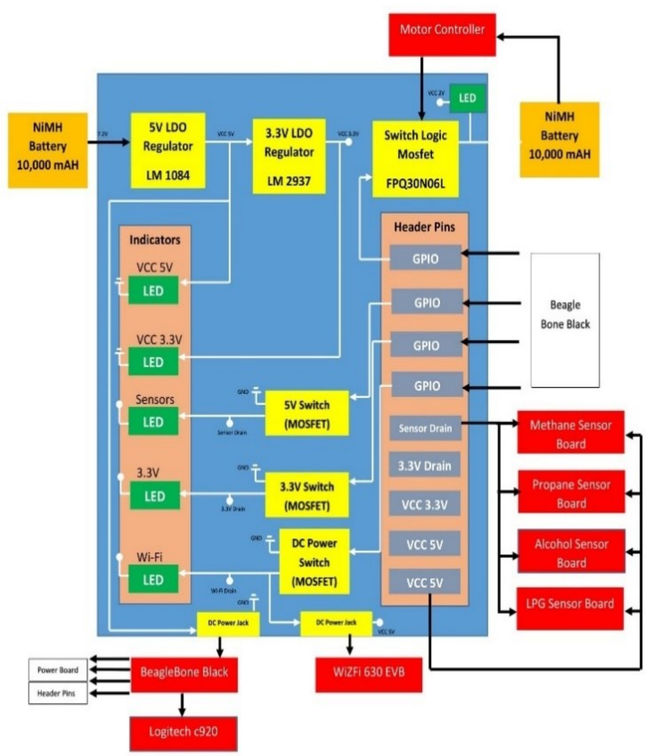


Figure 4. Power Board Functional Block Diagram

The power module receives power through two 7.4 V (10,000 mAH) NiMH batteries. One battery is solely dedicated to powering the motor controller and motors, while the other is used to power the various modules of the MSRP. The motors and motor controller need a separate battery, due to their high voltage and current demands. There are also LED indicators to show the status of the systems that are being supported by the power board. The PCB was designed with the dimensions of 9 cm of height and 6 cm of width. These dimensions were chosen to ensure that the board would fit the DAGU robot chassis. The general specifications of the board are:

- 2-layers, FR-4, 0.062", 1 oz. cu. plate
- Lead-free solder finish
- Min. 0.006" line/space
- Min. 0.015" hole size
  All holes plated
- Green LPI mask
- White legend (silkscreen)

The MSRP required the design/fabrication of three enclosures to protect the different onboard modules—motor-controller enclosure, sensor module enclosure, and main enclosure. These enclosures were designed to fit the necessary modules to protect them from external conditions. Various connectors enumerated below were used in the RWCT system primarily located in the MSRP. Such connectors provide power and communications between different modules of the system. The types of connectors used are:

- Ethernet connector
- DC power jack
- USB 2.0
- I2C wired connections
- BeagleBone Black protoboard cape

Software Design

The software design can be partitioned into three main sections: the robotic mobile platform, the Golden-i, and the cloud web app. These three main systems are engaged in constant communication to deliver seamless connectivity to both the user wearing the Golden-i and the expert observing the action through the web app. The communications between the Golden-i and the mobile platform is a constant two-way stream that involves sensor data, robot commands from the Golden-i, and the video from the camera mounted on the robotic mobile platform. The cloud-based web app only receives sensor and video data from the robotic platform. This is done by overlaying the sensor data with the video and passing it to the web app to allow remote-viewer capability to anyone with Internet access. The cloud-based app is provided by the LiveCast software to be able to stream the video to any expert wishing to view what a certain first responder is using. This app is essentially the LiveCast software field view that allows up to four videos to be viewed. This video also has the sensor data overlaid as it is with the Golden-i to observe the sensor status.

The Beagle Bone Black, on power up, turns on the rest of the modules on the robotic platform and begins initializing its digital I/O lines as well as its sockets to communicate with the Golden-i. Furthermore, it begins processing the video stream and establishes communication with the motor controller through I2C. The motor controller configures its digital I/O pins and sets the PWM and frequency values for the motors. It also assigns itself to the I2C bus as a slave to the BeagleBone Black. The Golden-i initializes its automated speech recognizer engine (ASR) and connects to the BeagleBone Black as a client, while also acting as a server to receive the incoming sensor data from the robot. Figure 5 shows the overall software design hierarchy chart of the RWCT system. This is done for simplicity, as each of the modules has its own embedded software and detailing every aspect does not contribute to the overall functionality of the system. Each of the modules begins with its own initialization phase in which the board powers up and begins setting up the proper parameters for appropriate operation.

The next two phases are essentially the overall system loop, where the system performs during runtime. The receive functions for each of the primary modules depend on the user either giving a voice command or a gas sensor being triggered. The BeagleBone Black receives the sensor data directly from the sensors through its digital I/O lines and the video through the USB 2.0 interface. The video always streams towards the laptop located within the wireless local network, while the sensor data is either a high or a low digital signal. The Golden-i receives the sensor data and the video from the BeagleBone Black constantly, unless there is no change in the sensor data and, thus, no update will be sent until one occurs. The only parameter that the motor controller will receive is the I2C command packets that the BeagleBone Black sends, depending on which voice command was received from the user wearing the Golden-i.

The transmit processes for each of the modules usually follow the receive functions, but most of these processes, including the receive functions, can occur asynchronously of each other and, thus, there is no set order in which they occur. The BeagleBone Black sends the sensor data to the Golden-i whenever the sensor trip level changes. It also is constantly sending the video stream and the voice commands through I2C whenever the Golden-i has sent a command. The Golden-i transmits whenever the user states a

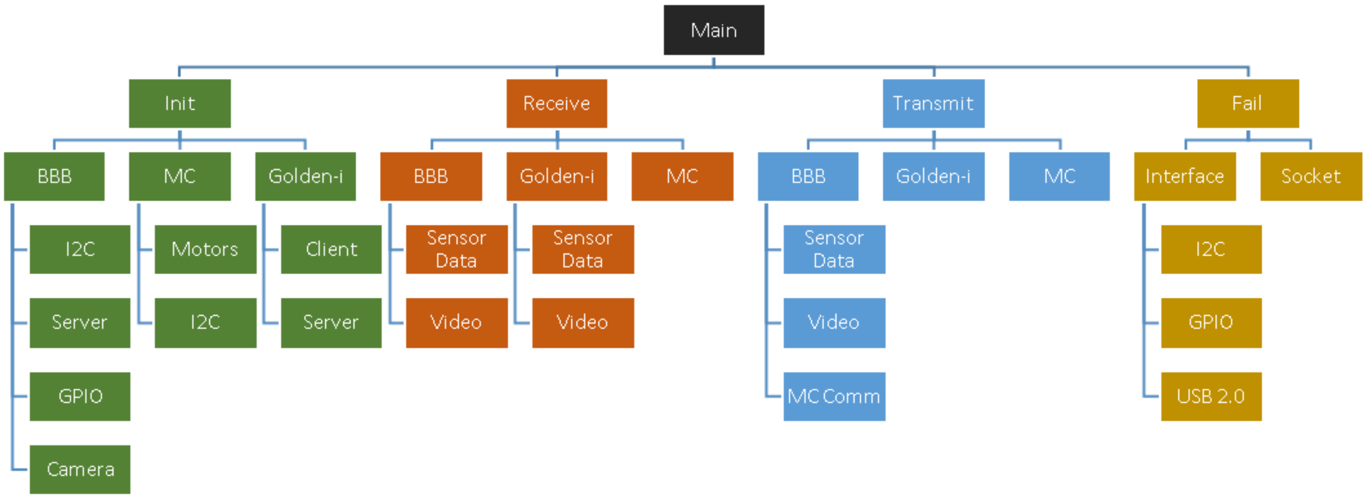
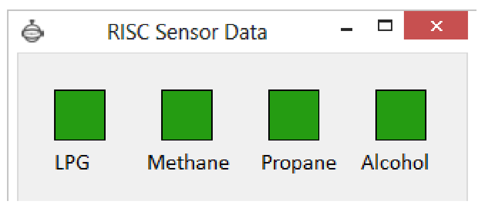


Figure 5. Software Design Hierarchy Chart

voice command to be sent to the robotic mobile platform. It does this by acting as a client to the BeagleBone Black server. The motor controller can transmit to the BeagleBone Black in the form of I2C status packets. In these packets, battery voltage, current per motor, and accelerometer data can be received and processed by the BeagleBone Black. This can be used to see how much battery is remaining and how much current is being used.

The final phase is only entered when a part of the system fails. The software is designed to be an always running embedded platform and, thus, needs a way to deal with errors without breaking programming execution. Thus, each place, where there exists the possibility of failure, is an appropriate fail mode. There are various wired and wireless interfaces that can fail in this system. The wireless systems are basically the two-way communication between the Golden-i and the BeagleBone Black. If either of these sockets goes down, the appropriate error will be displayed and the system will attempt to re-establish the connection. The same process is used with the wired interfaces, except the errors are displayed on the Golden-i and the system continues to try and re-open the failing interface. In the case of the USB 2.0 interface, the only procedure that can be done is to check and see if the interface proper is functioning, as this interface is defined by the USB 2.0 standard.

The Golden-i display shows a graphical user interface in the form of an android application. The application contains a full-screen view of the video coming in from the robot along with an overlay showing four green circular lights that correspond to one of the four sensors. Whenever one of the sensor levels is tripped, the light turns red and remains that color until the gas concentration decreases enough to not trip the sensors. The overlay occupies about 1/5 of the bottom of the screen and is semi-transparent so as to not obstruct the video of the robot. The CBSCS graphical user interface consists of two applications that run simultaneously. Figure 6 shows the sensor data in real-time when a specific gas is being detected.



RWCT Sensor Data Display

Figure 6. Cloud-Based Supervisory Control Software GUI

Cost Data

A financial analysis was performed on the RWCT system. The total cost of the development of the prototype was $1581.43 for a single unit. Similarly, the unit cost for 100 units was estimated to be $1134.95. A cost analysis of the RWCT system was performed by assuming the estimated cost of the Golden-i. The cost difference comes from the individual components of the power board, which was designed by RWCT and the fabrication of the PCB layout, which was reduced significantly when ordering 100 boards. The reason why the cost of the RWCT system can be considered high is due to the implementation of innovative and novel technologies as well as the use of expensive equipment such as servers using 4G LTE connectivity.

Testing

All tests covered by the test plan necessitate that the system under test be connected to a test application environment. A test environment should be designed to minimize any complicating factors that may result in anomalies unrelated to the test. The mobility of the MSRP through the Golden-i was extensively tested. After testing, it was noticed that the articulation of the wording needed to include two words for each command. If a single word is set for instructions, it is possible to activate the command by regular speech of the user. For that reason, all of the commands consist of a two-letter combination. The Golden-i adjusts to different accents and ambient noises present while articulating commands. After a few repetitions of commands, the commands are reliable, depending on the need of the user.

A test of the voice commands, sensor data, and video transmission between the MSRP, Golden-i, and CBSCS, for system integration reliability was successful. The communication between the BeagleBone Black, Logitech c920 camera, motor controller, Wi-Fi module, sensor boards, Golden-i, and CBSCS was successful. The video and sensor data could be displayed on the Golden-i and the CBSCS. The tested range of the wireless communication was between 150 and 180 feet. When the robotic mobile platform was placed in between a train, a bus, and other metal structures, the wireless communications were affected; the wireless signal was significantly affected. This means that the user needs to take into consideration the surroundings of the location. Real-time sensor data were successfully transmitted from the MSRP to the Golden-i and CBSCS. Due to the shortness of the packet structure, the latency achieved was the lowest possible. This means that the Golden-i and the CBSCS GUIs can observe the sensor data in a real-time fashion. The data were wirelessly sent to servers, which store the information, whereas the CBSCS remotely accesses such data. Real-time video transmission was considered a failed test, due to the latency issues that were identified. The video format that the Golden-i accepts is very particular. The use of LiveCast's proprietary software was needed to transmit the video to the Golden-i. To meet the functional video connectivity requirement, the use of a server for transcoding purposes was needed. This action introduced unwanted lag and latency, due to the extra steps that the video transmission requires. On the Golden-i, the video latency measured was around 3-5 seconds, while the CBSCS experienced a 10-15 second delay on the video transmission as well. The traffic on the 4G network also introduced latency and delays, depending on the traffic usage and location. Even though the video was transmitted smoothly, there was a continuous delay in both the Golden-i and the CBSCS. Even though the connectivity was successful, the reason the test was considered a failure was the delay experienced by the user.

The cloud-based connectivity to a computer located anywhere was tested to be successful. The implementation of two separate graphical user interfaces was necessary for the sensor data transmission and video transmission. The reason for this was the limitation of the LiveCast software. The overlay of the sensor data and video in a single app would take a significant amount of engineering work. The command center has two applications running continuously; therefore, both the video and sensor data were observed remotely in a near real-time fashion. The test matrix shown in Table 2 provides a description of the functional requirements that were analyzed and tested. The X-axis of the matrix contains the functional requirements of the RWCT system. The Y-axis of the matrix contains the different tests performed to ensure its functionality. A single test can validate one or more functional requirements.

Table 2. Test Matrix

	Battery Powered	Wired and Wireless Communication	Video and Sensor Data Transmission	Graphical User Interface	Cloud-Based Connectivity
MSRP Mobility Through Voice Commands	X	X		X	
System Integration Reliability		X	X	X	X
Power Board Delivery	X				
Wireless Communication	X	X	X		X
Real Time Sensor Data Transmission		X	X	X	X
Real Time Video Transmission		X	X	X	X
Golden-i Graphical User Interface		X	X	X	
Cloud Based Connectivity Data Transmission		X	X	X	

MSRP Mobility Test Through Voice Commands

The Golden-i was able to successfully control the MSRP through voice commands. The voice commands have priority, due to the fast response needed to effectively control the MSRP at a distance with the Golden-i. The movements of the MSRP worked accordingly. The forward and backward movements were set to be continuous, while the left and right turns were set to turn to a 45° angle. The camera pan and tilt moved accordingly as well depending on the different pre-defined voice commands.

System Integration Reliability

By testing the voice-commands, sensor data, and video transmission between the MSRP, Golden-i, and command office, the system integration reliability could be tested. The integration of the main components of the system was successful. These components included the BeagleBone Black, Logitech camera, motor controller, Wi-Fi module, sensor boards, Golden-i, and command office. The individual modules performed to their desired specifications to deliver the appropriate power to the motors, communicate wirelessly, and receive the video and sensor data on the Golden-i and command office.

Power Board Delivery

The power board received the input of two of the 10,000 mAH batteries located on the MSRP. Once the batteries are plugged in, the BeagleBone Black is the first board to be powered. This action was performed so that the main intelligence board (BeagleBone Black) could power the rest of the modules sequentially. There is a startup script that the BeagleBone Black runs once it is powered. This script enables MOSFETs to power the different modules of the onboard system. This is mainly because the Wi-Fi module needs to turn on before the camera, due to a booting sequence that it requires before transmitting the video stream. After 60 seconds, all of the different onboard modules performed their boot-up sequence and were successfully communicating and ready to engage.

Wireless Communication

The wireless communication between the three elements of the system worked accordingly. The Golden-i communicates through voice commands for movements. The video and sensor data can be displayed in the Golden-i and the command office. The tested range of the wireless communication was between 150 and 180 feet. The environment included trees and a couple of buildings, so if the system is tested in an open environment, the range might improve.

Real-Time Sensor Data Transmission

Once the system was fully engaged, the four onboard sensors were triggered for testing purposes. The sensor data transmission and triggering could be observed in a real-time fashion in both the Golden-i and the command office. The data were transmitted to the cloud through the 4G LTE network and retrieved by both the Golden-i and the command center. Since there was not a large amount of data, the average response time was on the order of milliseconds.

Real-Time Video Transmission

The video transmission from the MSRP to the Golden-i and command office was successful. Users located anywhere in the world can access the video through the cloud-based connectivity that the RWCT system provides. The reason that the test was considered a failure was the latency issue that the system experienced. The video transmission to the Golden-i experienced a latency of 3-5 seconds, while the command office experienced a 15-20 second delay on the video transmission as well. The traffic in the 4G network does not allow the system to provide real-time video connectivity. Even though the video is transmitted smoothly, there is a continuous delay between what is happening and the display of the users. The RWCT system was limited by the capabilities of the Golden-i as well as the 4G network traffic/signal strength.

Cloud-Based Connectivity Data Transmission

The cloud-based connectivity to a command office located anywhere was tested and shown to be successful. The implementation of two separate graphical user interfaces was necessary for the sensor data transmission and video transmission. The reason for this was the limitation of the LiveCast software. The overlay of the sensor data and video in a single app would take a significant amount of engineering work. The command center had two applications running continuously; therefore, both the video and sensor data could be observed remotely in a near real-time fashion.

Analysis

Based on the test plan and the extensive testing performed indoors and outdoors, the RWCT system did meet the customer functional requirements and performance specifications with a modified scope. The scope had to be modified, due to the limitation that RWCT experienced, since the Golden-i was still in its prototype stages and would not be commercially available for two years. The functional requirements were technically met, due to the successful connectivity, but the system had an inherent delay associated with it. Such a delay was impossible to eliminate, so RWCT clearly communicated the issue with the appropriate stakeholders. The RWCT system needs a modified scope in order to be delivered effectively. The best approach for eliminating the present delay on the video is by transcoding the video on the Golden-i itself. This feedback was provided to the developers of the Golden-i, since it is a proprietary device. The internal video transcoding capabilities are a subject for future development and enhancements of the prototype versions of the Golden-i.

Future Recommendations

Based on the testing performed on the RWCT system, the following enhancements are recommended for further development. The video latency can be significantly reduced if the following design changes are made. The on-board camera of the MSRP (Logitech c920) could be replaced with a wireless IP camera that can transmit the video directly to 0the Golden–i. The Wi-Fi module operates on the 2.4 GHz frequency band. RWCT was not able to find a current module that was able to operate in the 5 GHz frequency band. One of the limitations that RWCT experienced was the fact that the Golden-i does not have 4G connectivity. If so, the range between the MSRP and the Golden-i could be increased significantly. There has been development of a dedicated public safety spectrum. The RWCT system could potentially use that band of frequencies to avoid traffic in the network.

Conclusions

Wearable computing is a proven technology that increases productivity by providing voice-activated control and hands-free capabilities. The modular scalable robotic platform was designed to provide situational awareness by providing near real-time video and hazardous agent detection. The cloud-based supervisory control software provides first responder teams with near-real time wireless connectivity over Verizon's 4G LTE network with experts located anywhere in the world. This end-to-end wireless connectivity includes sensor data, video, and cell connectivity for experts to provide remote assistance if needed. Due to the modularity and scalability of the RWCT system, there are multiple applications in which it can be deployed. Applications include chemical, biological, radiological, and nuclear incidents (CBRN). The goal of the RWCT system was to provide an innovative solution to first responders to help them save lives in hazardous or dangerous environments.

Acknowledgements

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Optimization of a Solar Thermal Power Plant Using an Automated Control System

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Abstract

A solar thermal power plant, which is located at the CLECO Alternative Energy Center on the University of Louisiana at Lafayette Energy Research Complex, is a research project that works toward optimizing solar thermal power generation. The project involves the investigation and implementation of new methods that will potentially improve the overall efficiency of a solar thermal power plant that consists of an ElectraTherm Power+ generator that is coupled with two solar collector assemblies. One improvement to the project was recently established by developing a Wonderware InTouch platform that integrated programmable logic controllers and replaced the software control interfaces that were used to operate the power plant. The new application is an independent software control interface that allows the operator to focus on one screen when generating electricity. The application forces the devices to communicate and operate based on QuickScripts. It provides the operator with real-time system efficiencies and the opportunity to make system adjustments to potentially optimize the generation of power. The development of this Wonderware InTouch application improved the automation, reliability, optimization, and safety of the power plant, and the implementation of this application is an essential step toward producing a fully automated solar thermal power plant.

Introduction

The University of Louisiana at Lafayette operates a pilot solar thermal power plant at the CLECO (Central Louisiana Electric Company) Alternative Energy Center in Crowley, Louisiana. The power plant, an alternative energy solution, is an ongoing research project oriented towards the optimization of solar thermal power generation [1]. Figure 1 shows that the power plant consists of two solar collector assemblies (SCAs) and an ElectraTherm Power+ generator that converts heat to emission-free electricity [2], and operates using two SCAs to capture the sun's thermal energy in the form of radiation and concentrate the thermal energy toward heat collector elements. The heat collector elements absorb and transfer thermal energy to a heat transfer fluid (HTF) that is pumped at a constant flow rate, under pressure, through the first closed loop circuit (CLC 1). Whenever the HTF reaches the required minimum temperature, it is fed into the ElectraTherm's Power+ generator and undergoes a process that is based on the working principle of the Organic Rankine Cycle shown in Figure 2 [2, 3]. As the HTF enters the Power+ generator, it is directed into a heat exchanger, where its thermal energy is transferred to an organic refrigerant that has a lower boiling temperature than the HTF [4, 5]. The refrigerant's temperature and pressure increase and are directed by a second closed loop (CLC2) toward an expander. The pressurized refrigerant is forced through ElectraTherm's twin-screw expander, and the expander turns a generator to produce electricity [2]. The refrigerant then enters a condenser, where its temperature is transferred to low-temperature water within the third closed loop circuit (CLC3). The cooled refrigerant is then pumped back to the expander, where it is ready to enter the process again.

Figure 1. Pilot Solar Thermal Power Plant Station Located at the CLECO Alternative Energy Center

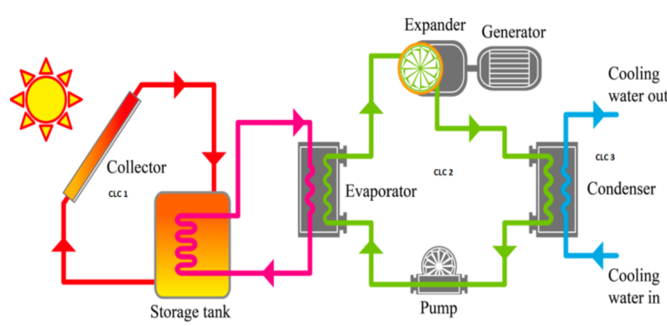

Figure 2. Working Principle of an Organic Rankine Cycle System

Original Operating Configuration

The solar thermal power plant is controlled by three programmable logic controllers (PLCs) and a human operator. The PLCs include two Yokogawa HXS10 solar tracking PLCs (see Figure 3) and one Direct Logic 205 (DL205) PLC. These devices are programmed to control the functions of the power plant when it is operating. The human operator's role is to initiate, monitor, and adjust these functions through the use of software control interfaces. The original operating configuration of the power plant consisted of a software control interface for each PLC. Each software control interface's function will be explained for a full understanding of the significance of the control system issues that occurred.

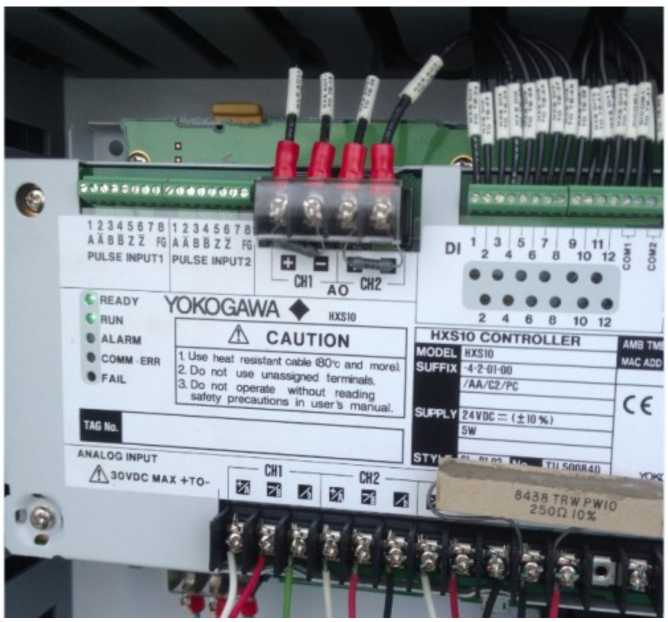

Figure 3. Yokogawa HXS10 PLC Used to Control Solar Collector Assembly Tracking

The solar tracking PLCs control the tracking angle of each of the two SCAs. These two PLCs are programmed to calculate and match the angle of the sun based on their date, time, and location [6]. The PLCs receive temperature and pressure values of the HTF throughout CLC1. These values are monitored and controlled by an operator through the use of SCA controller software control interfaces (see Figure 4). The software control interfaces display the angle of the SCAs, the sun angle, the PLC date and time, the HTF temperature, and the percentage that the hydraulic valves are allowed to open when the SCAs are tracking. When the Virtual Track control is selected, the PLCs force the position of the SCAs to match the sun angle. In a case where the temperature of the HTF increases to a value that is greater than its boiling point, the PLCs signal the SCAs to defocus and track to five degrees (user defined) away from the angle of the sun to reduce the increased heating of the HTF. The Power+ generator's functions are controlled by a Direct Logic 205 (DL205) PLC and its operations are independent of the Yokogawa HXS10 solar tracking PLCs. The DL205 PLC forces the HTF, when below a minimum required temperature, to bypass the Power+ generator. If the HTF is forced to bypass a number of times in a given period, the DL205 program turns off the Power+ generator and its HTF pump. An HTF that meets the required minimum temperature enters the Power+ generator and its thermal energy is transferred to the working fluid. The DL205 controls the working fluid as it is forced through the expander, and also allows the flow of the low-temperature water from the cooling tower.

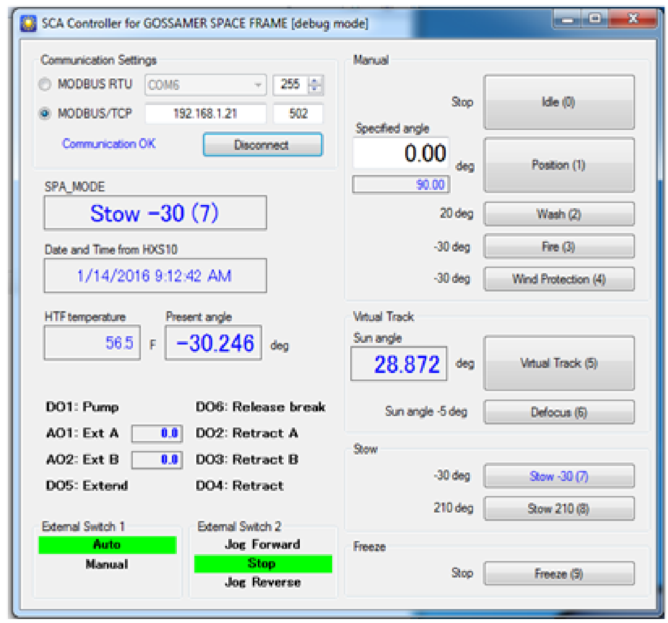

Figure 4. SCA Controller Used to Monitor the Solar Collector Assembly

Control System Issues

The solar thermal power plant's control system presented safety hazards to humans at the CLECO Alternative Energy Center, and the components of the power plant were subject to damage. For example, when the power plant is operating, it is extremely important that the heat transfer fluid pump produce a flow rate of 50 gallons per minute (189 lpm) or more. Once, while the power plant was operating, the heat transfer fluid pump turned off. The solar collector assemblies continued tracking to match the sun's angle and the temperature and pressure of the heat transfer fluid reached a value that resulted in damage to the heat collector elements.

The problem was that the entire safety of the operating power plant lay in the responsibility of the operator. In the absence of the operator, the heat transfer fluid could potentially reach a temperature that would result in the HTF overpressurizing. The operator had to continuously monitor the software control interfaces to ensure that when the Virtual Track control was selected, there was HTF Flow. If the HTF flow stopped, the operator was responsible for selecting the Stow control to ensure that the SCAs would not focus the sun's thermal energy on the HTF without sufficient flow. This problem was unique, due to the independent operation of SCAs that are coupled with ElectraTherm's Power+ generator [2]. A potential solution to this problem was implementing Wonderware InTouch software. The software was designed to allow the development of user-friendly applications that were used to monitor, operate, and modify preexisting control systems. The InTouch software provides users with the ability to write QuickScript programs that force hardware to communicate as well enable real-time data monitoring and storage.

Software Control Interface Solution

In order to optimize the generation of electricity, it was necessary to establish a system that provides data monitoring and historical data storage [7]. Wonderware InTouch is unique, because it allows users to integrate devices of different brands as well as develop applications to monitor and store data [8]. The authors developed a Wonderware InTouch application that replaced the software control interface shown in Figure 4. The InTouch platform was used to integrate the three devices and develop an application that displays real-time data changes. To integrate the three devices, it was necessary to form a connection between the Yokogawa HSX10 solar tracking PLC and the Wonderware InTouch through the Modbus TCP data acquisition server within the Wonderware ArchestrA System Management Console. Similarly, in order for data from the DL205 PLC to be displayed within the Wonderware application, it was necessary to establish a connection within the FactorySuite Gateway server in the ArchestrA System Management Console.

The Wonderware InTouch program is an adequate solution, because it allowed QuickScript programs to be written to prevent an operator from selecting the SCAs Virtual Track control without turning on the Power+ generator. One program only allows the Virtual Track control of either SCA to engage whenever there is an HTF flow rate of 50 gallons per minute (189 lpm) or more. Another program was written to ensure that the HTF had a flow rate of at least 50 gallons per minute. If the flowrate of the HTF decreases to a value that is less than 50 gallons per minute, the SCAs Virtual Track control will be de-selected and the Stow control will be selected. The Virtual Track control, shown in Figure 5, is a pushbutton control and it is only operable whenever the desired conditions are met. The program written to regulate the operation of the Virtual Track control is as follows:

```
IF WSCAFLOW<50 THEN WSCA=7;ENDIF;
IF WSCAFLOW<50 THEN ESCA=8;ENDIF;
IF WSCAFLOW>=50 THEN WSCA=5;ENDIF;
IF WSCAFLOW>=50 THEN ESCA=5;ENDIF;
```

These four programs were executed simultaneously and the conditions were checked at least four times an hour for the first 48 hours of operation.

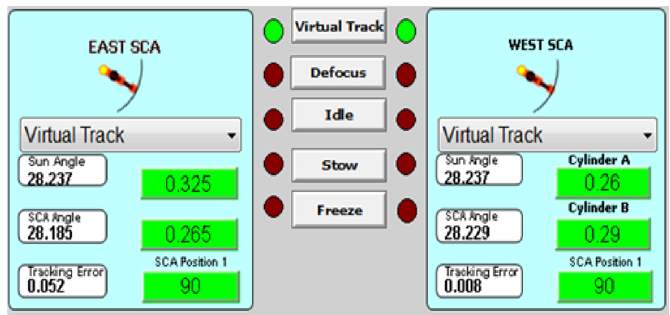

Figure 5. New SCA Controller Portion of the Wonderware InTouch Application

Organic Rankine Cycle Change in Temperature

Similar to the original Power+ generator's software control interface, the InTouch application shown in Figure 6 allows the operator to control and monitor the Power+ generator. The significance of the InTouch application is that it provides the operator with real-time hot water and cold water temperature changes. These changes in temperature are directly proportional to power plant efficiency. The hot water change in temperature (HWΔT) indicates the difference in temperature between the HTF that enters the Power+ generator and the HTF that exits the Power+ generator. The cold water change in temperature (CWΔT) indicates the amount of heat gained by the cooling tower fluid. It indicates the difference in temperatures of the cooling tower fluid that enters the Power+ generator and the cooling tower fluid that exits the Power+ generator. The large ΔT shown at the bottom of Figure 6 displays the difference in temperature between the HTF that enters the Power+ generator and the cooling tower fluid that enters the Power+ generator. The value of the System ΔT is a clear indicator of how efficiently the power plant will operate. A larger value of System ΔT will result in a higher net power output. When supplied with the same temperature heat source, the Power+ generator will generate more power in cooler climates than warmer climates [2].

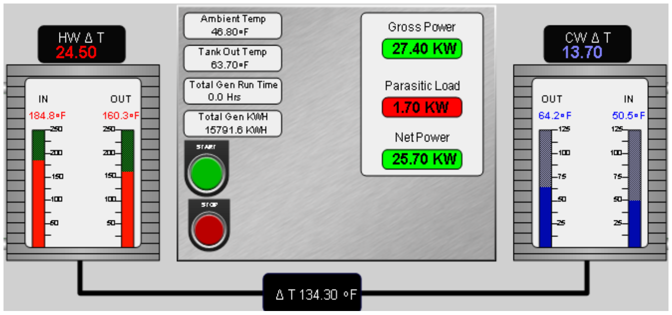

Figure 6. Power+ Generator Portion of the Wonderware InTouch Application

System Optimization

The Wonderware InTouch application allowed the integration of a fourth device, a Campbell Scientific CR1000 data logger. The data logger records data collected by a SOLYS 2 sun tracker and a graph that displays this data on the InTouch application is shown in Figure 7. The measured data include the direct normal irradiance (DNI), the global horizontal irradiance, and the diffuse horizontal irradiance [9]. The Cosine Adjusted Direct Normal Irradiance is a calculated value that is based on the DNI.

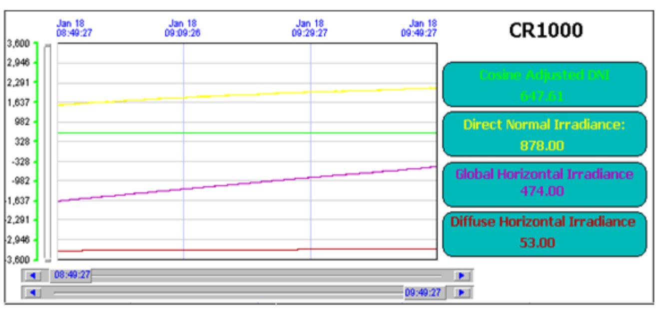

Figure 7. SOLYS2 Sun Tracker Data Recorded via the Campbell Scientific CR1000

The measurements shown indicate how much available sunlight is present at the CLECO Alternative Energy Center and are used to determine exactly how efficiently the power plant operates [10]. With the use of the Wonderware InTouch application and its QuickScript programming, real-time efficiencies can be calculated based on the SOLYS 2 sun tracker data. The system efficiency of the power plant is calculated by comparing the output of electricity that is produced to the input of thermal energy that is taken in. More specifically, the calculations are based on the measured available sunlight, the amount of thermal energy that is captured by the SCAs, and the amount of electricity that is produced [11]. Figure 8 shows how the power plant efficiencies are calculated and displayed on a real-time graph within the InTouch application. The collector efficiency determines how effectively the SCAs capture the sun's thermal energy; the Organic Rankine Cycle (ORC) efficiency displays how efficiently the power plant uses the collected thermal energy to produce electricity; and, the system efficiency represents how efficiently the power plant operates. The system efficiency is a ratio of the available thermal energy to the electricity generated.

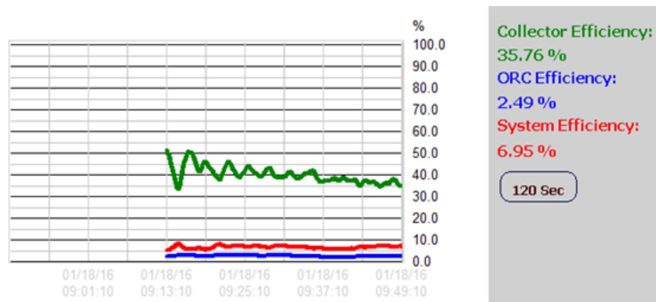

Figure 8. Real-Time Power Plant Operation Efficiencies

In order to match the constantly changing sun angle, the SCAs must track at an almost continuous rate. Hydraulic cylinders are used to move the SCAs and their movement is controlled by opening and closing of poppet valves. The frequency at which these valves open and close affects how accurately the SCAs match the angle of the sun as well as how efficiently the SCAs capture thermal energy. The efficiency data provide the operator with the ability to control the amount that the valves open when tracking the SCAs. Based on the instantaneously calculated system efficiencies, the operator can change the size of the valve opening to decrease the tracking error. This will improve the collector's tracking efficiency and result in the optimization of the thermal energy captured by the SCAs, which will optimize the generation of electricity.

Heat Transfer Fluid Temperature Graph

In the initial operation of the power plant, the temperature of the HTF throughout CLC1 fluctuated greatly. The temperature stabilized as solar thermal energy was focused on the HTF. A real-time graph was developed to display temperature measurements throughout CLC1. This graph serves as a visual tool that allows the operator to quickly compare temperature differences throughout CLC1. Figure 9 shows the solar thermal power plant software control interface and Figure 10 shows the hierarchical diagram. Wonderware InTouch was used to create the power plant software control interface. The entire operation of the solar thermal power

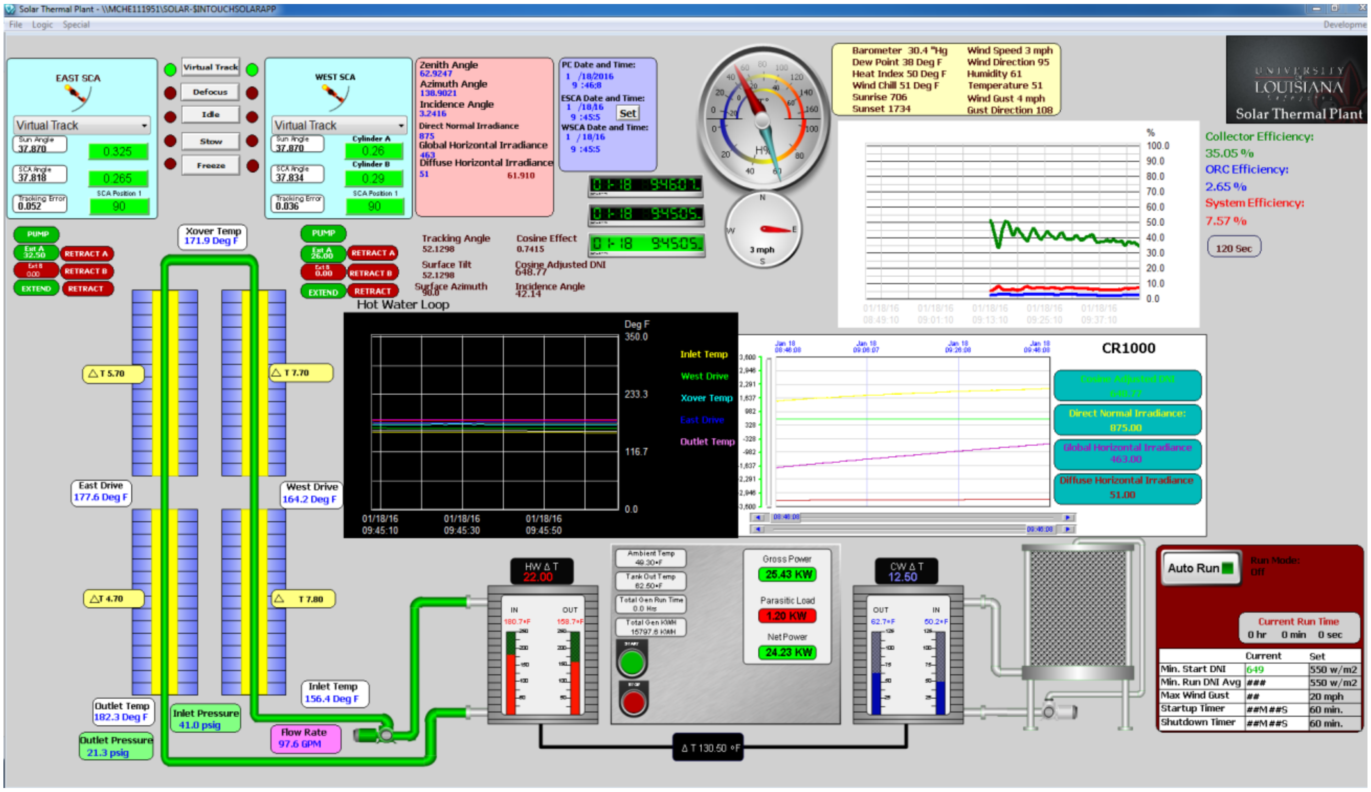

Figure 9. Pilot Solar Thermal Power Plant Software Control Interface Screen

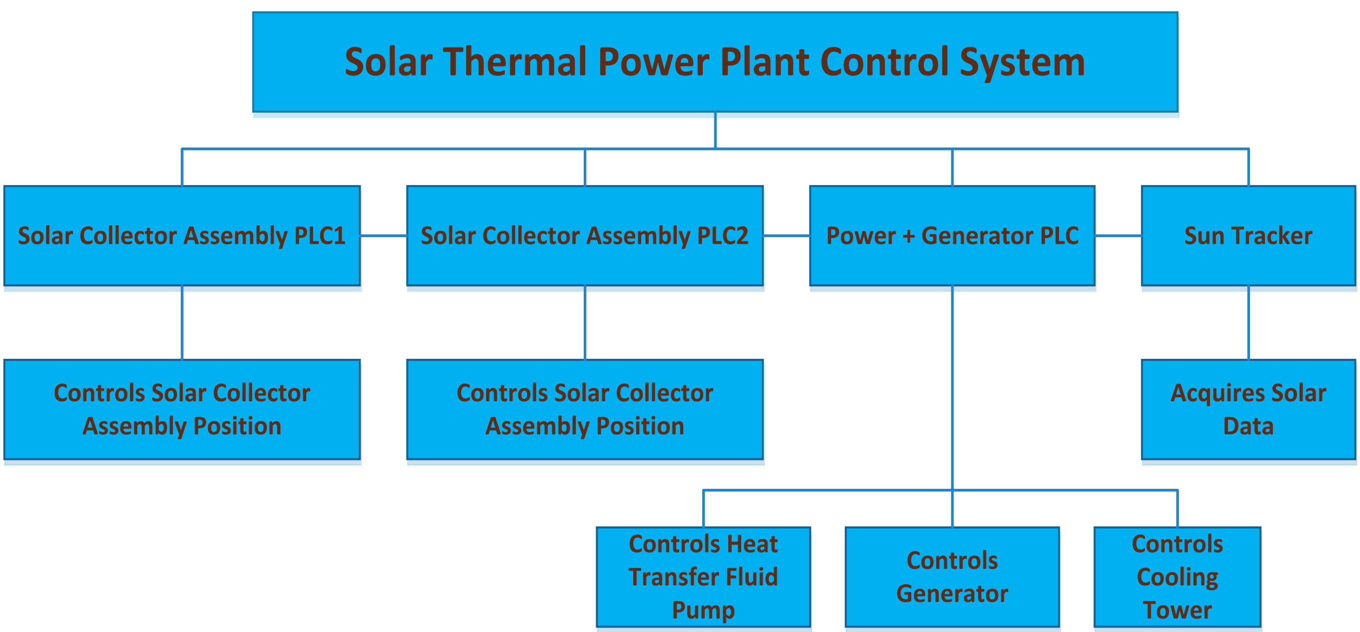

Figure 10. Pilot Solar Thermal Power Plant Software Control System Hierarchical Diagram

plant was controlled and monitored through this new application. It displays live data measurements, calculates real-time system efficiencies, and performs historical data storage.

Future Work

The Wonderware InTouch application, shown in Figure 9, is a platform for many future improvements. The next major step toward solar thermal optimization will be to establish a connection with an onsite weather station. Weather data is a clear indicator of how much power the plant will generate and is also necessary for establishing an autorun control (see the lower right-hand corner of Figure 9). This control will begin power generation whenever the solar conditions are appropriate. When the autorun control is used to generate power, additional safety features can be added. For instance, if the wind speed reaches 30 miles per hour (48 kmh) or greater, the power plant should change the SCAs control from Virtual Track to Stow in order to ensure that the SCAs do not face wind damage. Weather data could also be used to program the power plant to automatically wash the SCAs. Whenever enough rain is present, the program should start the power plant and track its SCAs to an angle that will allow them to be washed.

Conclusions

The goal of this project was to demonstrate how the implementation of a Wonderware InTouch software control interface improved the operations of the pilot solar thermal power plant that is located at the CLECO Alternative Energy Center. The power plant's control system presented safety hazards to humans at the facility and the components of the plant were subject to damage. Three PLC units used in the plant worked independent of each other and did not communicate. Wonderware InTouch software was implemented to resolve the safety issue. QuickScript programs were written to only allow the operator to select the Virtual Track control of the Yokogawa HXS10 solar tracking PLCs whenever the HTF pump produced a flow of at least 50 gallons per minute (gpm). These programs ensured that if the HTF's flowrate decreased to less than 50 gpm whenever the Virtual Track control was selected, the Virtual Track control would automatically be de-selected and the Stow control selected. The Wonderware InTouch software provided the plant staff with the ability to develop a one-screen software control interface application that displayed all of the controls and data needed to operate the plant. The application calculated real-time system efficiencies and stored historical data. With the use of the application, the operator could make system adjustments to potentially optimize the efficiency of the power plant. The Wonderware InTouch application improved the automation, reliability, optimization, and safety of the power plant and is a step toward the development of a fully automated power plant.

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IMPROVING THE PRACTICE OF ACCREDITATION ASSESSMENT

Xiaobing Hou, Central Connecticut State University; Shuju Wu, Central Connecticut State University

Abstract

The objective of this paper is to introduce the accreditation efforts made for a Computer Engineering Technology (CET) program. Over the past several years, the authors have led or extensively participated in the ABET program accreditation process. Based on the experience, a systematic approach was developed to coordinate and accomplish the accreditation tasks for the program's first-time ABET accreditation. As a result, the program was recently accredited for six years, after which a general review is required. First, the authors introduce the approach and lessons learned for future improvement. Motivated by the accreditation experience and the systematic approach used by the program, an accreditation management system was developed. The system can help the program or department in performing periodical assessment tasks and managing the assessment results over years for continuous improvement. An online management system can greatly facilitate the accreditation process and reduce the resources needed. It will also save the extra load and time of the involved faculty that would otherwise have to be put in for those tasks. The system and the approach introduced in this paper will help improve the efficiency and reduce resources needed for a program pursuing ABET accreditation.

Introduction

ABET is a nationally and internationally known accreditation body. Students from an ABET-accredited program are recognized as having received a quality education for professional employment and advanced studies. In addition to the benefits for students, getting and keeping accreditation is significant to the program as well, since it keeps the program in continuous self-assessment and improvement cycles. A program seeking ABET accreditation must demonstrate that it satisfies all of the General Criteria and the Program Criteria [1] defined by ABET. One of the important demonstrations is the program self-study report, which addresses how the program satisfies these criteria. The program must ensure that the most up-to-date accreditation criteria and documents are used. Obtaining and maintaining accreditation are non-trivial tasks and can be a daunting periodic process. Among the current eight General Criteria, Criterion 2 (Program Educational Objectives) and Criterion 3 (Student Outcomes) should be assessed periodically to demonstrate continuous program improvement, as specified by Criterion 4, and the other criteria focus on the current program status in terms of students, faculty, resources, and support. Accreditation activities related to Criteria 2, 3, and 4 are the most time-consuming tasks and involve many faculty members, and efforts span years to keep accreditation up to date. Activities related to accreditation include periodic student work collection, assessment rubric development, assessment, further action planning and implementation, student outcomes revision and program educational objectives revision, and self-study report writing. Another challenge is the coordination among the activities performed by faculty for each course and each semester, industrial advisor board (IAB) meetings, alumni surveys, senior surveys, composing results, etc.

Considering these challenges, it is very important to set up a systematic approach in this process for motivation, efficiency, and effectiveness. Recently, the CET program at Central Connecticut State University conducted its first-time ABET accreditation task and has been fully accredited for six years, based on the accreditation criteria and the on-campus visit. Through the process, the authors have accumulated experience and learned valuable lessons, which they will share here. First is the introduction of the systematic approach adopted by the program. Many programs planning for first-time ABET accreditation may face the same situation, and the approach and experience can provide a reference for those in need.

Even though the initial accreditation was successful, the amount of time and effort paid by the accreditation coordinator and faculty raised the concern regarding the sustainability of the process if there would be no continuing resources and load support. To better facilitate the faculty's work and improve efficiency and effectiveness, a new initiative was started after accreditation was granted—an accreditation assessment management system. The system consists of an accreditation web portal with a database server (hosting accreditation information, schedules, instructions, tasks, etc.), a member module, an accreditation coordinator module, and an administrator module. The member module enables faculty members to keep track of their progress, input assessment results, edit rubrics, upload required materials, and browse previous results. The accreditation coordinator module enables the coordinator to easily track the overall accreditation progress, create and assign tasks, compose data, and run analyses. The administrator module creates and manages accreditation projects and databases. Currently, the CET program is integrating this system into its continuous assessment cycle and the system functions will be continuously enriched and strengthened.

Systematic Accreditation Approach

There are a number of publications on ABET accreditation, including ones in the ASEE annual conference proceedings. Wear et al. [2] summarized the lessons learned from their first-time ABET accreditation experience in terms of each ABET criterion; Barr [3] provided insight into preparing the self-study report with desirable results from a PEV's viewpoint; Sala et al. [4] described the first-time accreditation experience of a two-year program. This current study is different from these previous studies in that it focuses on identifying important accreditation activities and how to efficiently organize and coordinate the activities in the accreditation process. The authors further expand on the early stage of the work [5] and introduce the complete process and experience.

The program seeking ABET accreditation must submit a program self-study report months before the ABET visit. This gives the Program EValuators (PEVs) enough time to understand the program and the assessment that has been done. Therefore, preparing the self-study report is one of the most important tasks and the first demonstration of program satisfaction to the accreditation criteria. Many activities need to be performed to collect and/or generate the information to be incorporated into the self-study report. The timeline to perform the various activities could affect how efficient the entire process is. Overall, the self-study report should be written after the program has made good progress on Criteria 2, 3, and 4. Other activities, such as presenting the current curriculum, faculty, facilities, enrollment, and graduates, focus on the most up-to-date information and can be incorporated later before the submission of the report.

The lesson comes from the program's previous experience. The program initiated an accreditation effort years ago without any experience. The process started with the collection of faculty resumes, course syllabus, curricula, laboratories, and facilities information; self-study report writing was started in order to incorporate such information. However, assessment and continuous improvement were not systematically performed and documented. As a result, when the program resumed the accreditation a few years later, the previously collected information was out of date. This lesson motivated the authors with more insights into developing a systematic approach for the new accreditation process. First, related activities were identified with the complexity, time consumption, faculty involvement, and, most importantly, the relationship between activities as some activities depend on the outcome of others. The new accreditation process started in the fall of 2014 and the accreditation visit was scheduled for the fall of 2015. Two semesters (fall 2014 and spring 2015) were used to carry out major accreditation activities, and fall 2015 was used to prepare for the ABET on-campus visit and continuous improvement. The identified major activities, their features, and the timeline were summarized in the previous study [5].

A faculty member has served as the accreditation coordinator to lead the activities, including coordinating meetings, providing support to other involved faculty members, coordinating data collection and assessment, creating tools and templates to ensure consistency among different courses and faculty members, and writing the self-study report. It is very important and beneficial to study the ABET website for accreditation documents, tutorials, and updated requirements. In addition, the CET program did not need a Readiness Review, because the school already had other ABET-accredited programs under the same accreditation commission. Following are the lessons learned through the process.

- Be simple yet clear; try not to confuse the accreditation team. This requires the presentation of a self-study report and visiting materials to be well-organized and to the point. The PEVs will appreciate the time saved in trying to understand the program through the report and during the short visit.
- For programs with no prior accreditation experience, a fundamental assessment workshop is very beneficial. Try to avoid advanced and complex assessment and continuous improvement approaches for new accreditation programs.
- Understand the time relationship between different activities and prioritize activities accordingly.
- For a program new to accreditation with a short timeline, it is better to demonstrate at the outset the program's satisfaction to the criteria by assessing as many SOs as possible. In addition, a continuous assessment and improvement plan should be in place even if no action has been taken. Although it is acceptable to assess only a few SOs per year (based on the assessment plan), the CET faculty should collect and assess data for all of the SOs in one year. This means involving and educating all of the related faculty and instructors in one year. This was found to be highly effective.
- A supportive industry advisory board that is actively involved in program advancement and accreditation is very important. Documents that show the IAB supports should be kept and provided to the ABET visit-

ing team. The team also meets with IAB representatives.

- Accreditation is a teamwork process. The coordinator plays an important role in keeping activities on track and moving forward. The prepared tools and templates, such as document bins, labeled folders for different assignment types and courses, Excel assessment templates, and résumé templates, etc., reduce inconsistency and faculty workload, thus promoting timely completion.
- Spread activities over time to avoid overwhelming faculty members at the end of a semester.
- There is no defined procedure, but best practice on how a program accomplishes the accreditation process is that it is a team decision. For example, the following introduction of the CET SO data collection and assessment activity cycle for continuous improvement is purely based on the CET faculty's preference.

Six-Year SO Activity Cycle

For ABET accreditation, there is a commonly used six-year cycle on the SO assessment, which provides at least two cycles of data collection, assessment, evaluation, action taking, and review and revision of outcomes, mappings and indicators, etc. Programs may choose any number of SOs in a year for certain activities. Therefore, in a six-year period, each year there will be some SOs undergoing certain activities. This approach spreads the data collection over years, thus faculty members responsible for multiple SOs are not overwhelmed in one year. However, this also means that program-wide, all of the activities have to be performed every year for different SOs.

Accreditation Management System

Accreditation requires institutions to invest a lot of effort. Keeping track of the progress for each course sometimes becomes confusing and out-of-schedule. For the accreditation coordinator, trying to ensure that the current tasks will be accomplished by related faculty members on time is especially difficult. Normally, email reminders, announcements in meetings, paper notes, and office visits are used to keep things on track. Often, a single task requires rounds of digging through emails, going through accreditation boxes, and check-marking on papers back and forth. This consumes a great deal of energy and motivation of both faculty members and the coordinator, and results in less willingness for the tasks down the road. An accreditation assessment management system is required to guide and facilitate faculty members with accreditation policies, procedures, tasks and schedule, assessment, information and repository of documents, etc. Meanwhile, the system should help the coordinator to organize the collected materials, check the progress, query results, and automate data analysis from different courses and years. Most of the current accredited programs either do not use management software to facilitate the process at all, or use a tool for a specific task only. The Start Early philosophy [2] considers having a faculty member get training for accreditation by volunteering as a program evaluator of ABET. This approach depends on an experienced faculty member to coordinate the accreditation activities. Yale University uses a web portal [6] for ABET accreditation. In this system, there is no data analysis automation across different courses and different years. Shankar et al. [7] used a web-based tool for course assessment result input, which also provides a student's results for different courses. However, this tool is designed to meet ABET Criteria 3 only. In this paper, the current authors present a more generic system that is designed to run different and multiple accreditations and expand the original idea and preliminary version of the system [8]. The system was redeveloped and optimized with more features implemented.

The system consists of a web server, a member module, an accreditation coordinator module, and an administrator module. The web server is also a database server that hosts accreditation information, schedules, instructions, tasks, collected work, and assessment results. The information is saved in databases and web interfaces are provided to users. Different roles in the system reflect users' responsibilities in the accreditation. The member module allows normal faculty members to keep track of their progress, download requirements and instructions, upload materials requested, input assessment result, edit rubrics, and browse previous results. The accreditation coordinator module enables the coordinator to easily track the overall accreditation progress, create and assign tasks, send messages, monitor progress, compose data, and run analyses. The administrator module creates and manages accreditation projects and databases. The major responsibility of an administrator is to manage the accreditation projects in the institution. Multiple accreditation projects can be created and carried on at the same time. The administrator does not need to understand accreditations, but manages the system and provides technical support to the users. Several functions have been added to the administrator's page. The administrator can create, edit, or delete an accreditation project, assign a project to a coordinator, and create and manage user accounts. Figure 1 shows how the administrator creates an accreditation project and assigns it to a coordinator. The coordinator will see a list of the accreditation projects assigned. Regular members will see a list of accreditation projects they are involved in. From there, coordinators and members can select and enter a project.

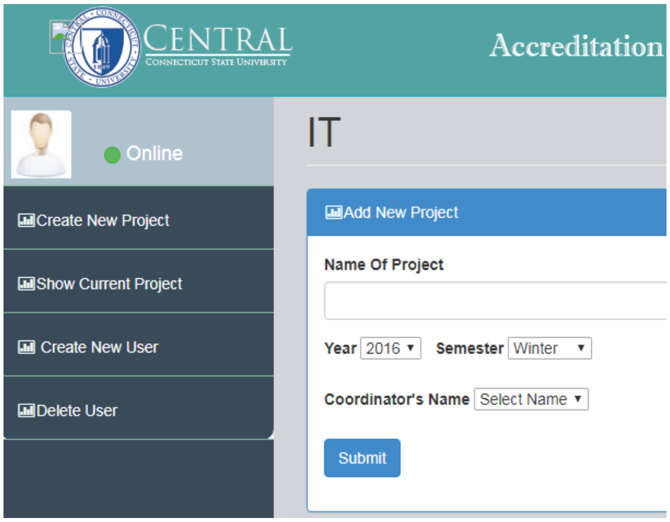
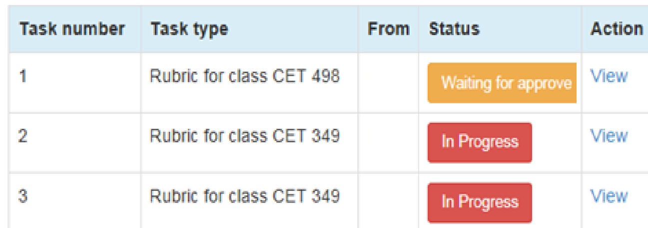


Figure 1. Administrator Page for Creating a New Project

Members are users, who participate and contribute to the accreditation. Usually, they are the faculty members involved in the program pursuing the accreditation. However, other parties on campus could be a member, too. Some examples are instructors of general education courses, department chairs (if not a coordinator), the dean's office, the provost's office, etc. Members can see the tasks assigned to them by the coordinator and conduct the tasks. Figure 2 shows the implemented member's module with tasks assigned.

The coordinator usually takes more responsibilities during the accreditation process, thus the coordinator module in the system offers the most comprehensive functions. A coordinator is usually the head of the department or the program, but can be any faculty member, who is assigned the role. The coordinator should understand the entire process and all the tasks required by the accreditation. The module has been redesigned and optimized compared with an earlier version [8], and more functions have been implemented.



Task number	Task type	From	Status	Action
1	Rubric for class CET 498		Waiting for approve	View
2	Rubric for class CET 349		In Progress	View
3	Rubric for class CET 349		In Progress	View

Figure 2. Member Page with Tasks Assigned

Figure 3 shows the coordinator's work page of a project. When working on the project, the work area shows all of the tasks created thus far. The coordinator is supposed to arrange the tasks according to the order in which they should be conducted so that it demonstrates a clear timeline of the project. Tasks can also be organized according to the logic relation preferred by the coordinator. Eventually, all tasks of an accreditation project form a tree. The completed tasks are in green, the ongoing tasks are in red, and the unassigned

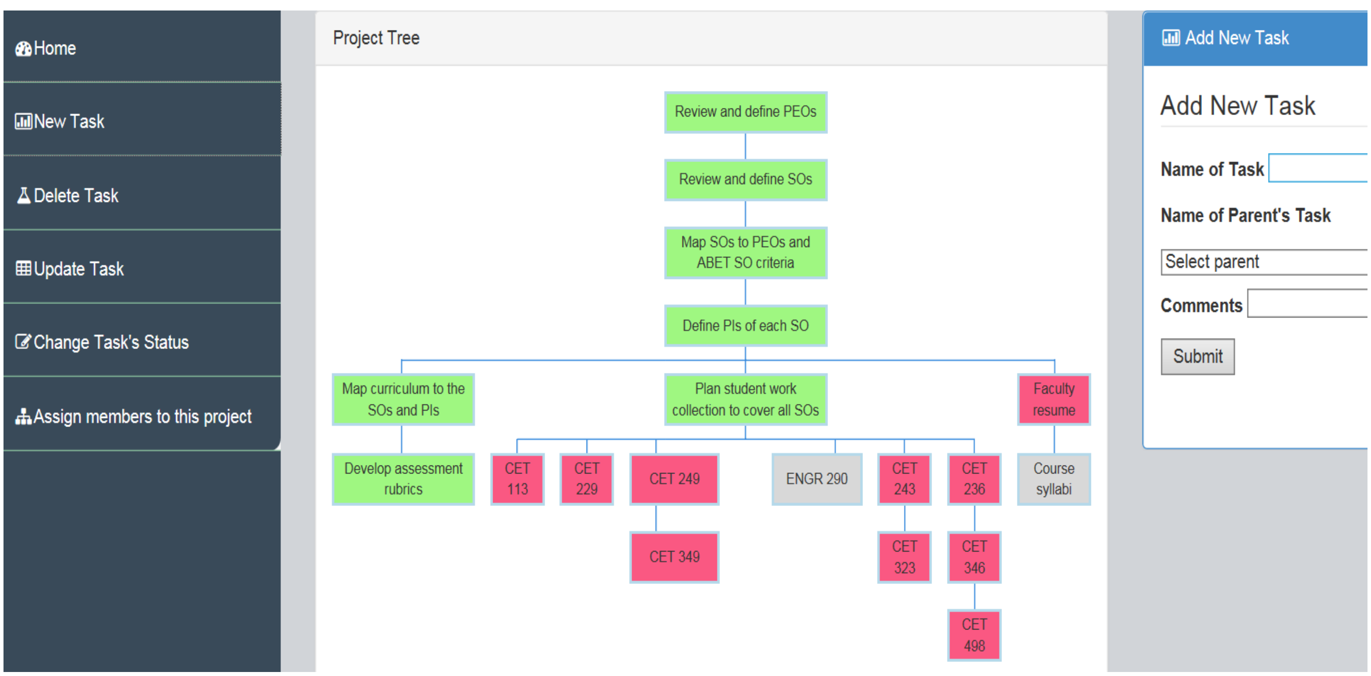


Figure 3. Coordinator's Project Work Page

ones are in grey. The coordinator can click each task to review or change its configuration, such as instruction, deadline, members assigned to, etc. The materials submitted by the members can be reviewed also. The coordinator can add different types of tasks. Currently, three task types have been implemented, including review tasks, submission tasks, and rubric tasks. The review task allows the coordinator to upload a document as well as instructions for other members to review, and members can submit their feedback to the coordinator. Similar to the review task, the submission task shows instructions from the coordinator pertaining to a particular task. In addition, members can upload the required file as well as any comments, and send it back to the coordinator for review. The rubric task is used for class instructors to assess performance indicators of a student outcome.

Before the rubric tasks can be used, the coordinator should create an assessment plan, as shown in Figure 4, which represents student outcomes and performance indicators in ABET. The system will automatically create a matrix that shows the mapping of courses and SOs and PIs, as shown in Figure 5. The mapping is generated when the rubric task is created. The color shows the status of each task and the coordinator can click each PI to review the rubric submitted by faculty, as shown in Figure 6. The rubric contains the score of student work assessed for each student and the average. The coordinator can accept the rubric or send it back to the faculty member if more work is needed.

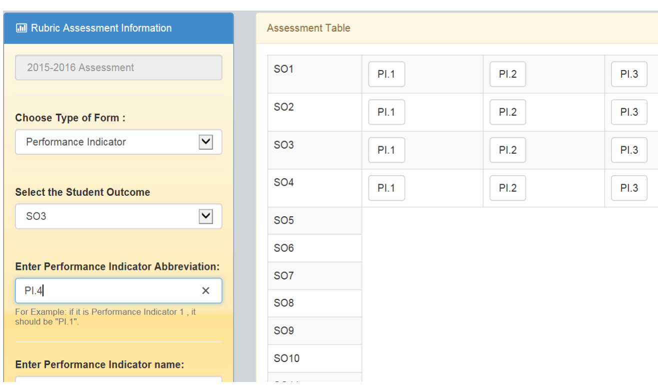


Figure 4. Coordinator's Assessment Plan Page

There are more features implemented to support the accreditation effort, including an assessment analysis to facilitate continuous improvement. Since all of the assessment data are saved in a database, the system can easily help an institution analyze student performance. Currently, the rubric data of a performance indicator can be summarized and displayed with a chart. Figure 7 shows a simple example. When more data become available, the chart will display results over the years. More ways of using the data can be added in the future.

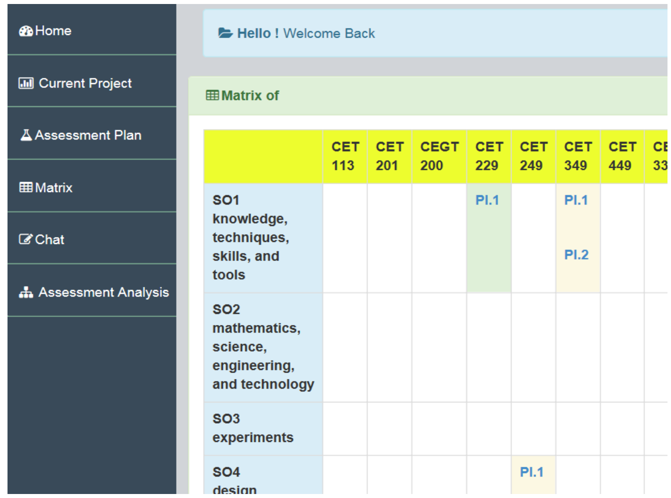


Figure 5. Coordinator's Matrix Page

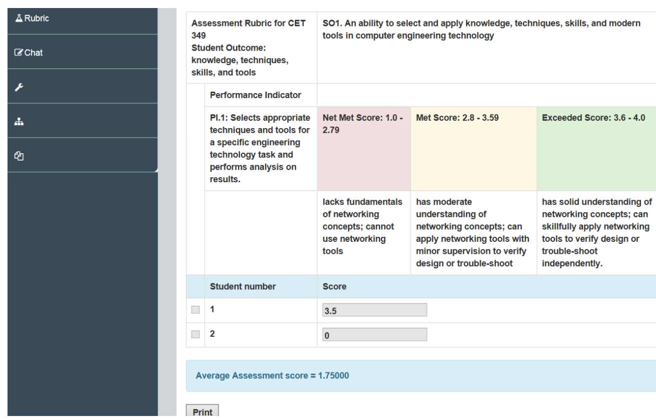


Figure 6. Coordinator's Rubric Page

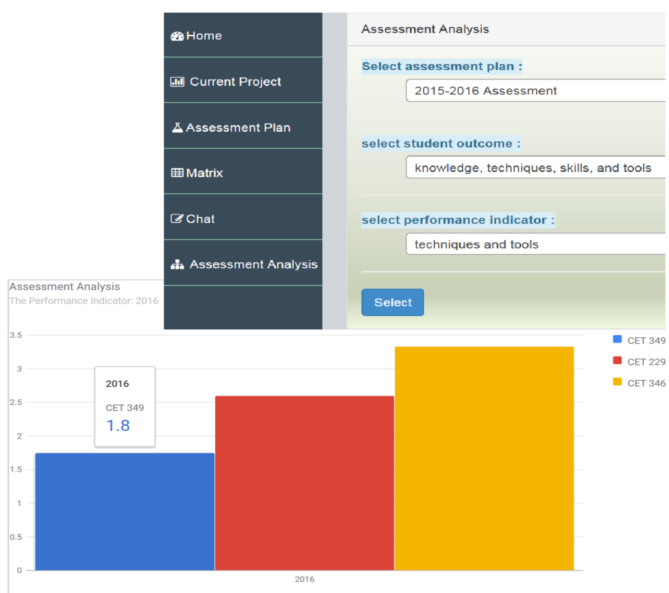


Figure 7. Assessment Analysis

Another feature implemented is Chat, as shown in Figure 8. This feature provides users with the ability to communicate in real time with other members of the system, and saves content of the chat into the database for future reference.

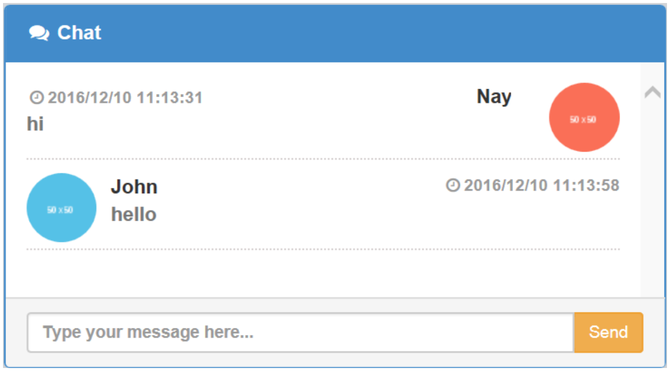


Figure 8. Chat

Conclusions

The accreditation process is long and time-consuming, and there is no set way of demonstrating how a program satisfies the accreditation criteria. The assessment plan, schedule, and actions could vary with programs and resources allocated. I this paper, the authors introduce an updated accreditation assessment management system. The authors also believe that there are many other features that can be integrated into the system to provide users with more tools, such as more accreditation project templates for accreditations other than ABET and ATMAE, and more reports on data saved in the database to better facilitate the continuous self-assessment.

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Biographies

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INTEGRATING OPEN SOURCE RESOURCES IN ROBOTICS EDUCATION

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Abstract

The open source movement has already revolutionized a number of industries by empowering end-users to contribute to the products that they need and want, and fueling grass-roots development of projects in completely new areas, as well as their continual improvement. Robotics is the branch of mechanical engineering, electrical engineering, and computer science that deals with the design, construction, operation, and application of robots as well as computer systems for their control, sensory feedback, and information processing. The nature of collaborative works in robotics over multiple engineering and science disciplines makes it perfect for open source, which not only leverages minds much greater than ours on specific fields, but also connects college students, industrial developers, hobbyists, educators, and researchers. In this paper, the authors offer a case study for integrating open source resources into robotics engineering technology teaching. The case study is an embedded system course that benefited from open source software, hardware resources, and project-based learning (PBL). The course project was to target a robot competition at a national student conference. The students use collaborative platforms such as GitHub, Webex, etc. to communicate with and get help from experts in navigation, programming, circuit design, CAD modeling, etc. They also use many open source resources such as grabCAD, Github, etc. so that they design and develop their robots on predeveloped and tested work that are made available by others. This greatly reduced the development time and improved project quality.

Introduction

Embedded System Design is a core course of the Robotics and Mechatronics Engineering Technology program at Central Connecticut State University. It covers hardware and software design for higher-end embedded systems development and includes structured laboratory exercises in programming, peripheral interfacing, device driver implementation, real-time operating systems, structure programming, task scheduling, simple digital signal processing (DSP), and other related topics. In the spring of 2016, the course was redesigned using the PBL (project-based learning) model. PBL is a student-centered learning model in which students learn about a subject through solving an open-ended problem. Students learn domain knowledge and problem-solving skills through the project. This model also promotes team work and communication skills. The goal of this year's project was to design a Micromouse robot for the 2016 IEEE Region 1 annual student conference Micromouse competition on April 16, 2016. A Micromouse is a small robotic vehicle that is able to navigate its way through an unknown maze. It is autonomous, battery-operated, and self-contained, encompassing computer technology, robotics, and artificial intelligence. The main challenge for the Micromouse designers is to import to the Micromouse an adaptive intelligence, which enables exploration of different maze configurations, and to work out the optimum route with the shortest run time from start to destination and back. In addition, the Micromouse must reliably negotiate the maze at a very high speed without crashing into the maze walls. Students in the class formed three teams to work on their Micromice. Open source resources were introduced to teams and used in the project. This also got students familiar with what industries are doing in project developments [1, 2].

Open Source-Based PBL Model and Its Application in the Course

There are four reasons that open source resources were integrated into the PBL model of this course: 1) open source resources are readily available in software, hardware, and mechanical systems; 2) open source is more and more popular for hobbyists, academia, and industry[3]; 3) entrepreneurs and companies are using open source resources in research and development[4]; 4) technologies such as Webex and Github made it possible to include humans, which is the most flexible and important part of the open source resource [5]. PBL has been researched by many people over the last two decades [6]-[12] to promote engineering science and technology education by integrating real-world problem solving and hands-on skills. Figure 1 shows the PBL model for this course divided into four stages.

For students, the Micromouse robot competition has always been a focal point of the conference, because it provides a playground for participating students to apply their knowledge of science, engineering, and technology. It also promotes teamwork, creativity, leadership, and communication skills. And above all, it is fun!

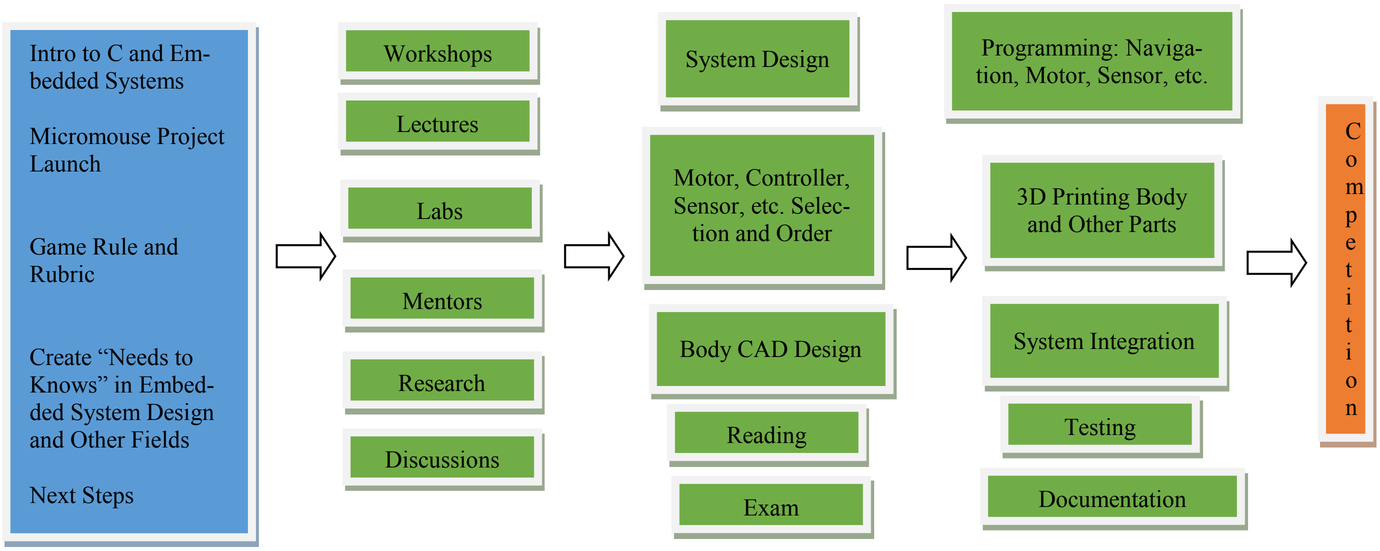

Figure 1. Process and Components of the PBL Model

In the beginning of the class, introduction to C language and embedded systems was given. The Micromouse project was introduced to the students, who were asked to study game rules and the score rubric. They were also asked to do a study on previous years' Micromouse design and generate a need-to-know list for the project. On the list, they identified what things were part of an embedded system and what things were not. They also discussed what they already knew and what they needed to learn. This gave them the guidance for what to do next. In the second stage, more lectures about embedded systems were given. Three options for controllers were presented to the students: Arduino Uno, Raspberry Pi, and Tiva C Launchpad. The online workshops, labs, and open source communities were introduced to the students, which the students then researched and studied as teams.

Three workshops were arranged to help students become familiar with open source resources and the Micromouse design. The first workshop was about robotic hand design and its open source resources. The presenter was invited to give the workshop on campus. Students learned the current status of open source mechanical systems, 3D printing, and its application in a robotic hand design. The other two workshops were conducted via distance learning through WebEx, due to the availabilities of the presenters. A Micromouse design expert ran the second workshop and gave in-depth introduction to Micromouse design. Students learned an overview of the game, motor and sensor choices, Micromouse motions, and navigation algorithms to solve the maze. The third workshop was about collaborative development using Github with an example of development of a commercial GoPiGo robot. All three workshops had Q&A sessions to engage students and address their questions. The workshops greatly helped students in solving project-related problems with real-world examples and applications.

In addition to the help of the professor, three volunteer mentors were available to help them with programming, circuit design, and simulation through Github, email, or tele-conferencing. Students were encouraged to help and teach each other in the team and between teams. In the third stage, one team chose to use Tiva C Launchpad, one team chose to use Arduino Uno, and the third team chose to use GoPiGo robot with Raspberry Pi. They decided and ordered their motors, sensors, and other components. They designed their Micromice in SolidWorks. They also decided navigation strategy and motion control. In the last stage, they worked on programming sensors, motion control, and navigation. They fabricated components such as chassis and wheels using 3D printing. They assembled components and completed wiring. They built a small portion of the maze and tested their Micromice in it. Figures 2-4 show students testing their Micromice in the partial maze. Figure 5 shows a CCSU Micromouse during the 2016 IEEE Region 1 student conference Micromouse competition.

Example of the Design Process of One Micromouse

The objective of the Micromouse competition was to build a small autonomous robot that could navigate within a grid of known size but with unknown obstructions or walls;

the grid is known as the Maze. The known geometry of the maze is as follows:

1. Each "Cell" is 180 mm x 180 mm.
2. The "Maze" is constructed in a manner that is 16 cells x 16 cells.
3. The walls are 5mm tall and 2 cm thick.
4. Each cell must have a post in every corner; the exception to this is the winning position, which actually consists of four cells with only a post in the middle.
5. The robot always starts in a corner of the maze and all robots in the competition start in the same corner.

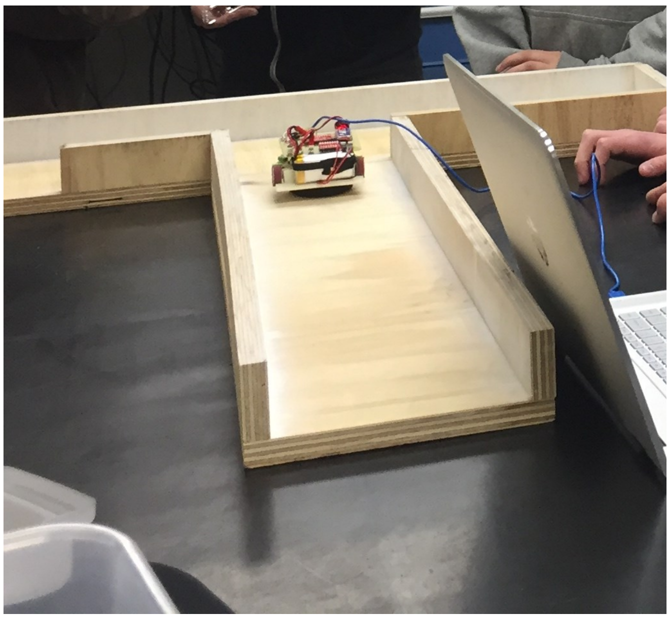

Figure 2. Testing of Micromouse with Tiva C Launch Pad

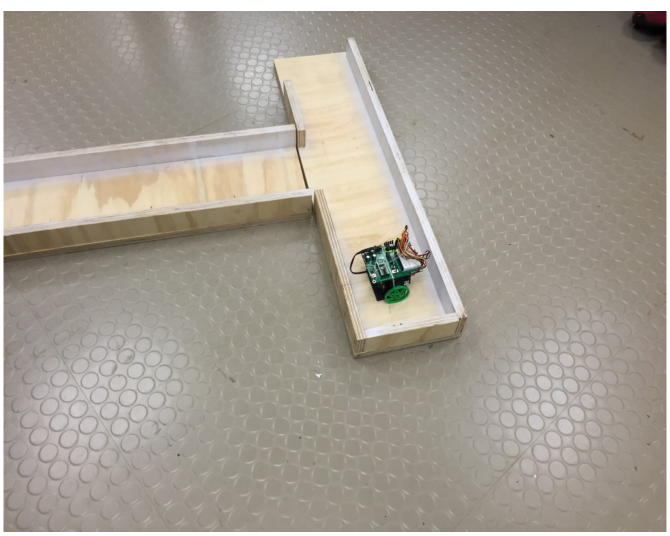

Figure 3. Testing of Micromouse with Arduino Uno

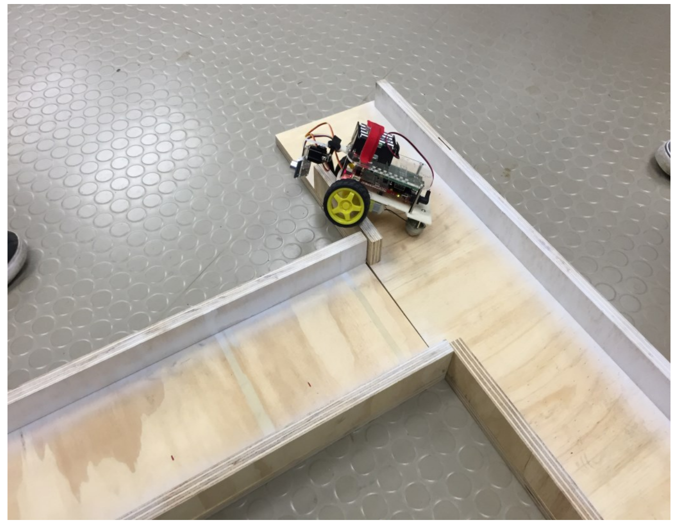

Figure 4. Testing of Micromouse with GoPiGo with Raspberry Pi

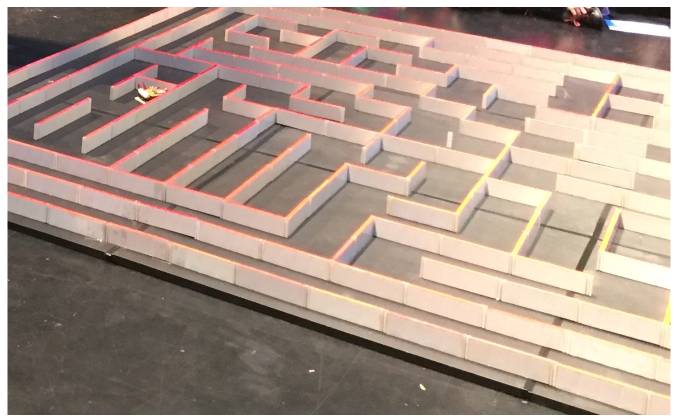

Figure 5. Micromouse Competition in the Real Maze

The robot, hereafter referred to as George or Team George, went through a major revision only days before the contest, due to a faulty motor controller, so the robot that actually competed was dubbed George 2.0. And while most revisions in engineering are done from a standpoint of improving performance or reliability, this revision was done out of necessity to produce a working robot for the competition using only parts on hand. George 1.0 and 2.0 actually only varied by three hardware components, two motors, and a motor controller. However, the motors used in George 1.0 were high rpm dc gear motors with encoders, whereas George 2.0 was dependent on a pair of fixed RPM constant-revolution servo motors. George's specifications are

- 2 Wheels with magnets embedded for wheel encoding
- A front skid to level the base and ride over bumps
- 5 IR photo transistors – TEFT4300 920 nm

- 5 IR 5MM LEDs
- 3D printed base, wheels, and skid
- DIY PCB boards created with "Toner Transfer"
- Gyro/accelerometer MPU9150
- Texas Instruments Arm Cortex M3 TM4C123 – CPU
- Powered by dual 3.7 volt LiPo batteries and a BEC power transformer
- Rev 1.0 dual 10,000 RPM dc motors with a 9:10 gear reduction, driven at 7.2 volts with a dual H-bridge motor controller
- Rev 2.0 dual continuous rotation constant RPM servo motors, driven from the on board PWM of the CPU

All of the code for George was written in C++ using the library of functions provided in the SDK for the Texas Instruments series of ARM cortex processors. Over the course of the development, a total of 55 commits were appended to the code repository, which was/is hosted on GitHub. Fifteen of the commits were done after the major hardware revision from 1.0 to 2.0, although not all of the post revision commits were directly related to the change. The total codebase consisted of about 2600 lines of code at the time of competition. The basic design of George was a 90 mm x 90 mm platform with a 180-degree radius on the front. These dimensions, coupled with the dimensions of the cells of the maze, simplified the calculation of turning math as the robot was half the width of the cell and the rounded nose prevented/limited the ability of the robot to get hung up on a wall during a turn. The IR sensor angles were determined so that the angular sensors would be able to "see" the next cell as the robot was passing the midpoint of the current cell. The side-facing sensors were used to keep the robot centered in the cell as well as trigger turns and also to work as an input to the PID loop for the motors.

The IR system was developed around the importance of ambient IR rejection as well as resolution. The components chosen had both a narrow beam angle as well as a very narrow spectrum of emission/reception, and that spectrum was chosen to be 920 nm, as that ambient emission of that spectrum even outdoors is limited. Additionally, the beam angles were restricted even more through the placement of heat shrink over the sides of the diodes. However, in initial testing of the IR system, the sensors were being flooded and returning abstract values of no meaning; it was eventually determined by sheer luck that the color of heat shrink tubing that had been chosen instead of blocking the emission was actually acting as a diffusion mechanism causing the light to be broadcast in all directions. This issue was only found due to the fact that the team ran out of the problem color while replacing the emitters and receivers unnecessarily as it turned out.

George 1.0 was designed to take advantage of a flood-fill method of maze solving, which is dependent on the collection of data about the maze as it passes through; however, George 2.0's motor speed was so much of a reduction from 1.0 that it was decided that a random-solve algorithm was more likely to result in a solution in the eight minutes that were given to solve the maze. It was also much easier to implement in the compressed timeline after being required to recode the motor control only three days before the completion. Figure 7 illustrates the design components and process of George.

Results

Two teams developed and built the Micromice from scratch. One team used the GoPiGo kit with customized parts and focused on programming. All three Micromice had their sensors (IR or ultrasonic) and motors (DC or Servo) working well. However, they all had issues in making good turns. The main reason is that it was the first time they participated in the competition. The learning curve was high and the time was short. Most of the time was spent on developing hardware with very little time left for programming and testing. But it built a solid foundation for the same course for the following year for the competition. Even without winning the competition, all students learned a lot about embedded systems through designing and building a robot. It reflected the foundation of PBL: leaning by doing. The project's target as a competition excited and engaged them from beginning through the end of the project. The integration of open source resources greatly improved their project development speed and quality. They not only leaned with a professor, but also the entire open source community.

Conclusions

In this paper, the authors discussed how open source integrated PBL models can significantly improve student learning interests and outcomes. It turned the traditional professor-student teaching-learning model into a professor-guided open source integrated PBL model, which is more efficient and acceptable to the students. The method can be readily applied to other robotics courses. Competitions are good choices for course projects.

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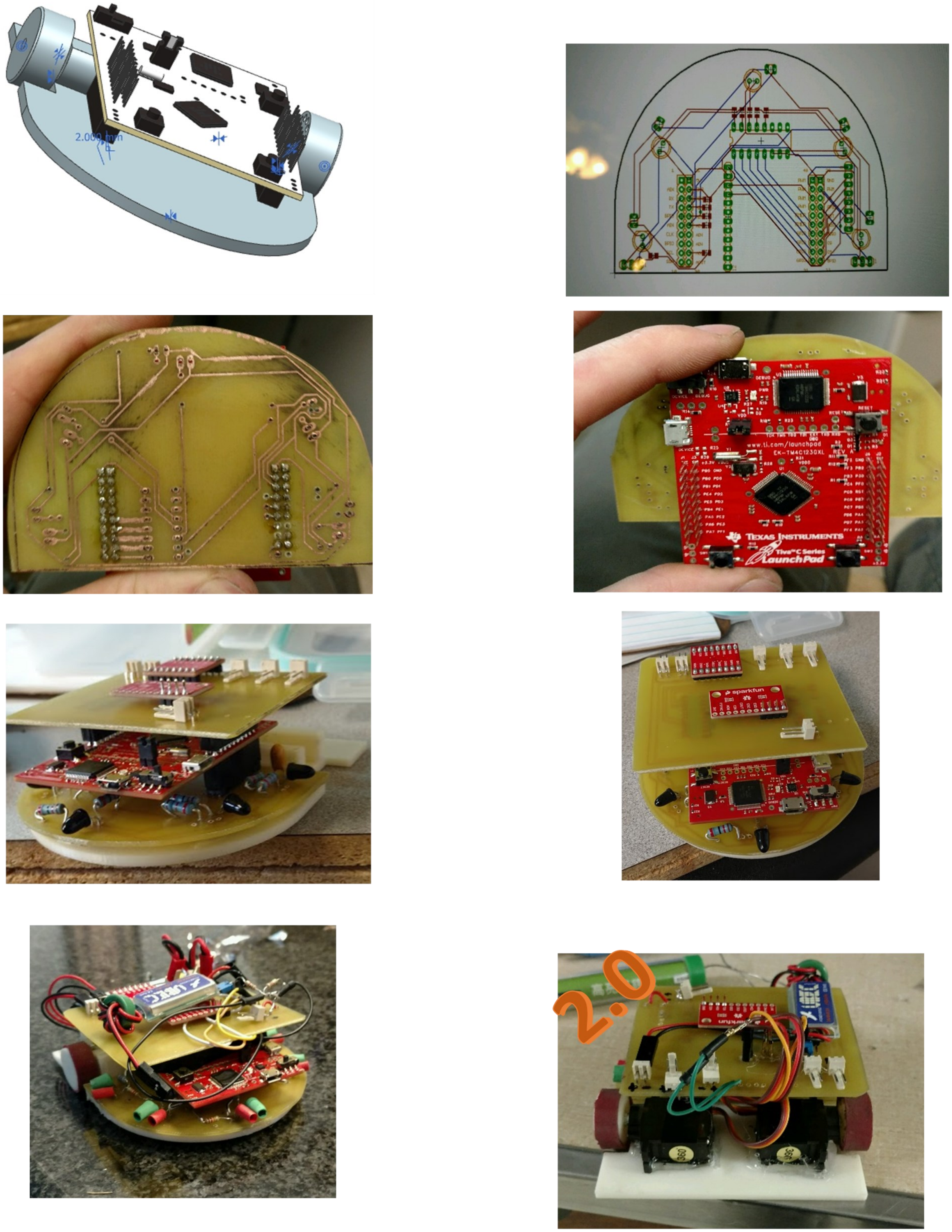

Figure 7. Micromouse George Design Process

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Biographies

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A REDESIGNED ABET ASSESSMENT PROCESS: LEVERAGING FACULTY RESOURCES

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Abstract

In this study, the author illustrates the redesign of the ABET assessment process used by the Mechanical Engineering Technology (MET) faculty at Eastern Michigan University (EMU). The objective was to develop an efficient student outcome assessment process that leveraged existing faculty resources. To this end, existing assessment data from the current ABET assessment cycle were first sorted. The criteria used to sort these data included: assessment data type (formative or summative), assessment method (direct or indirect), assessed ABET a-k outcome, and thematic area. After sorting the existing assessment data, a sustainable assessment process was designed that focused on summative (end of program) data using direct assessment methods. Results from the redesigned assessment process and the corresponding program improvement actions are presented here.

Introduction

As defined by ABET Criterion 3 (Student Outcomes), "the program must have documented student outcomes that prepare graduates to attain the program educational objectives (PEOs). There must also be a documented and effective process for the periodic review and revision of these student outcomes" [1]. To determine compliance with ABET Criterion 3, ABET evaluators check that the learning outcomes are documented, prepare learners to achieve the PEOs, and contain the characteristics of each of the ABET a-k outcomes [2].

To be useful, an assessment process must generate evidence for determining whether or not the learning outcome objectives are satisfied [2]. To ensure a sustainable ABET assessment process, the assessment process must also leverage existing faculty resources, which means that student outcome assessment information must be collected from data that is part of course grades [3]. In the MET program at EMU, existing assessment data include: faculty-designed exam questions, laboratory reports, employee cooperative education evaluations, and capstone design project presentations and/or reports.

Several engineering educators have published their experiences with developing sustainable ABET assessment processes. For example, in 2015, Garry [3], a member of the Department of Construction and Operations Management at South Dakota State published a study on keeping the assessment process and the outcomes assessment activities separate. In 2013, scholars from Iowa State University [4] published a paper describing the revised assessment process used by their Electrical and Computer Engineering programs. In addition to leveraging existing resources, their revised approach involved more faculty. Also in 2013, professors from the Electrical Engineering department at Qassim University (Saudi Arabia) published their experience and the quality assurance system that they used to obtain ABET accreditation [5].

Scholars at Auburn University published a remarkable assessment process improvement paper in 2012 [6] in which they structured their junior-level embedded systems design laboratory course in the Electrical and Computer Engineering programs to provide opportunities for students to demonstrate the degree of attainment of six of the 11 ABET a-k outcomes. In 2008, a team of researchers from Washington State University (WSU) published a direct assessment method that simultaneously measured the ABET outcomes related to professional skills [7]. Student teams were presented with an engineering problem within their discipline and asked to propose approaches for solving the problem. A rubric was used by trained faculty to assess recorded student responses. The intent of each of these studies was to either develop or maintain a sustainable ABET assessment process.

In this current paper, the author illustrates the redesigned ABET assessment process used by the Mechanical Engineering Technology (MET) faculty at Eastern Michigan University (EMU). Specifically, an efficient assessment process was developed that focused on summative (end of program) assessment data using direct assessment methods. Besides leveraging existing faculty resources, the following process design requirements were considered: MET program educational objectives, ABET a-k outcomes, ASME program criteria, and the contractual teaching responsibilities of the MET faculty. The resulting assessment process did not significantly increase the workload of the MET faculty, which was an enabler for sustainability. Results from the redesigned assessment process and the corresponding continuous improvement plans are also discussed here.

Summary of the Previous Assessment Process

In general, the degree of attainment of the ABET a-k outcomes was assessed throughout the MET curriculum. Eleven of the 12 MET core courses were assessed and assessment data were collected on 3 or 4 outcomes per course. Several of the assessments were either formative or the outcome attainment was determined at the course level. For example, the following outcomes were assessed in the Statics course:

3b. "An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies" [1].

3f. "An ability to identify, analyze, and solve broadly defined engineering technology problems" [1].

3i. "An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity" [1].

This assessment process resulted in ABET accreditation. However, the resulting inefficiencies and increased faculty workload were not sustainable.

The Redesigned Assessment Process

A sustainable ABET assessment process must be efficient and integrate into the faculty's day-to-day teaching responsibilities. With this in mind, the assessment process used by the MET program at EMU was redesigned since the last ABET assessment cycle. The redesigned assessment process was implemented at the start of year four of the current 6-year ABET assessment cycle. In this section, the details of the redesigned assessment process are presented. Specifically, the data collection strategy and corresponding performance indicators are discussed. The existing assessment data sets from years 1-3 of the current 6-year ABET assessment cycle were first sorted. Figure 1 is a flowchart that describes the data sorting process. The data sets were organized according to:

- data type (formative or summative)
- assessment method type (direct or indirect)
- assessed ABET a-k outcome
- thematic area that the data represents (i.e.; solid mechanics, dynamics, thermal/fluid sciences, mechanical design)

After sorting the existing data, a summative data set was selected to assess each student outcome. The selected assessment data sets included: faculty-designed exam questions from the finite element analysis; kinematics of machines and mechanical vibrations courses; fluid dynamics lab reports; senior design project reports; and, employee cooperative education evaluations. These data sets contained summative data from the four thematic areas within the MET curriculum, including solid mechanics, dynamics, thermal/fluid sciences, and mechanical design. The data collection plan in years 4-6 of the 6-year ABET assessment cycle mimicked the assessment data that were selected from years 1-3. In other words, each outcome was assessed, using similar data, twice during the current ABET assessment cycle.

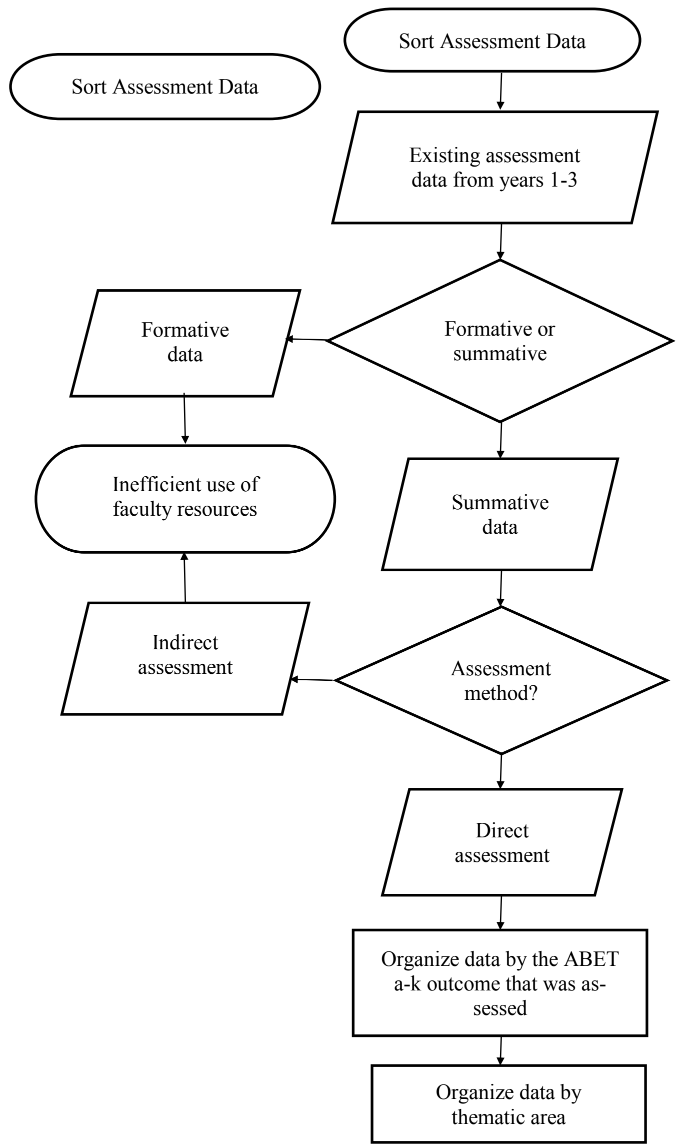

Figure 1. Assessment Data Sorting Process

Table 1 contains the resulting data collection plan. After implementing the redesigned data collection plan, performance indicators were written to reflect the desired technical and professional skills of students after completing the MET program at EMU. Each of the ABET a-k outcomes were defined by 2-3 high-level performance indicators. This ensured consistency between faculty, and efficiency, which encourages sustainability. Table 2 shows the performance indicators for each student outcome. In the following section, examples from the results of the redesigned assessment process are discussed for student outcomes (3a) and (3f)—from Tables 3 and 4, respectively. Besides performance indicators, these tables include the educational strategies that provided students an opportunity to demonstrate the performance criteria; the assessment method; where summative data were collected; the assessment cycle length; the years when the assessment data were collected; and, the performance target. The tables are followed by the assessment results, evaluations, program improvement actions, and implementation plans.

Table 1. Data Collection for Each Student Outcome over the Current 6-Year Assessment Cycle

Student Outcomes		Selected Assessment Data	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
3a	"An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities" [1]	Finite Element Analysis (exam question)		O		X		
3b	"An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies" [1]	Mechanical Vibrations (exam question)				X		X
3c	"An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes" [1]	Fluid Mechanics Lab Reports		O			X	
3d	"An ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives" [1]	Senior Design Projects Project Reports Design Reviews			O			X
3e	"An ability to function effectively as a member or leader on a technical team" [1]	Employer Co-op Evaluations			O			X
3f	"An ability to identify, analyze, and solve broadly-defined engineering technology problems" [1]	Kinematics of Machines (exam question)			O			X
3g	"An ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature" [1]	Mechanical Vibrations (exam question)		O		O		
3h	"An understanding of the need for and an ability to engage in self-directed continuing professional development" [1]	Senior Design Projects Project Reports Design Reviews			O			X
3i	"An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity" [1]	Dynamics (ethics essay)	O		O			
3j	"A knowledge of the impact of engineering technology solutions in a societal and global context" [1]	Senior Design Projects Project Reports Design Reviews			O			X
3k	"A commitment to quality, timeliness, and continuous improvement" [1]	Senior Design Projects Project Reports Design Reviews			O			X

O = Existing data, X = Data collection plan

Table 2. Student Outcomes and Performance Indicators

Student Outcomes		Performance Indicators
3a.	"An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities" [1]	3a.1 Students can construct a CAE model of a mechanical component to predict stress 3a.2 Students can analyze CAE data 3a.3 Students can evaluate CAE analysis results
3b.	"An ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies" [1]	3b.1 Students know the meaning of a derivative 3b.2 Students can compute the derivative of harmonic functions 3b.3 Students can apply the chain rule
3c.	"An ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes" [1]	3c.1 Students can use literature to correctly find measured engineering values 3c.2 Students can calculate engineering values from experimentally measured data
3d.	"An ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives" [1]	3d.1 Students can articulate the engineering design process as a structured and iterative problem solving and decision making process 3d.2 Students can write engineering specifications in the form of instructions 3d.3 Students can create and/or select a system configuration to solve a predefined engineering problem
3e.	"An ability to function effectively as a member or leader on a technical team" [1]	3e.1 Students work well with other people 3e.2 Students are usually dependable
3f.	"An ability to identify, analyze, and solve broadly-defined engineering technology problems" [1]	3f.1 Students understand the function of kinematic diagrams for solving multibody dynamics (MBD) problems 3f.2 Students can derive the velocity response of planar mechanisms 3f.3 Students can derive the acceleration response of planar mechanisms
3g.	"An ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature" [1]	3g.1 Students can accurately identify and communicate mechanical vibration problems 3g.2 Students can use engineering principles to develop and communicate a hypothesis describing the root cause of vibration problems 3g.3 Students can communicate viable solutions to mitigate vibrations problems
3h.	"An understanding of the need for and an ability to engage in self-directed continuing professional development" [1]	3h.1 Students can develop domain specific knowledge without guidance (i.e. literature reviews, plant/facility tours, benchmarking, product evaluations, etc.) 3h.2 Students can locate information relevant to an engineering problem without guidance
3i.	"An understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity" [1]	3i.1 Students know the engineering code of ethics 3i.2 Students can evaluate the ethical aspects of an engineering problem
3j.	"A knowledge of the impact of engineering technology solutions in a societal and global context" [1]	3j.1 Students can ID critical issues relevant to a design problem (i.e. spatial, cost, environmental, etc.) 3j.2 Students can evaluate alternative design concepts considering critical issues and design constraints
3k.	"A commitment to quality, timeliness, and continuous improvement" [1]	3k.1 Students can develop work plans to achieve project deliverables 3k.2 Student can identify a project's critical path and compute the duration of project

Results

Table 3 shows the summative data for performance indicators 1-3 were collected in the FEA course. Students were asked to use Algor (FEA software) to construct an FEA model from the sketch of a truss and evaluate the results. A sample of 17 students (100% of the class) was assessed. The fraction of the sample of students that performed at a level of satisfactory or proficient on each indicator were 35% for indicator 1; 41% for indicator 2; and, 53% for indicator 3. In 2014, these assessment results were reviewed by the MET faculty member with expertise in CAE methods development. Based on the assessment results, students were unable to construct an FEA model of a structure that could have been evaluated using principles from mechanics of materials. It appears that they were unable to bridge the gap between FEA modeling and fundamental solid mechanics principles. For this reason, and because Algor is not a commonly used FEA software program, the course was redesigned to align it with current FEA modeling practices. The course was updated in 2015.

Table 5 shows the rubric used to score student performance on ABET outcome (3a). It articulates the expected FEA modeling skills of MET graduates. After completing the MET program, students should be able to use modern FEA modeling software to evaluate a mechanical component that is manufactured from a material with a linear stress/strain relationship and subjected to small displacements from contact with an adjacent body.

ABET Outcome (3a): Second Cycle Assessment Results—2015

To better align the FEA course content with current industry practice, the latest version of Siemens NX (10.0) was used to reflect industry expectations. Siemens NX is a modern, multi-purpose CAE modeling software suite. Similar to 2012, summative data for performance indicators 1-3 were collected in the FEA course (see Table 3). Students were asked to use NX to construct an FEA model from the sketch of a mechanical part. A sample of 20 students (100% of the class) was assessed. After redesigning the course, the frac-

Table 3. Summary of Assessment Results for Outcome (3a)

Performance Indicators	Method of Assessment	Where data were collected	Assessment interval (years)	When data were collected	Performance target
Students can construct a CAE model of a mechanical component to predict stress	Faculty-designed exam question	FEA	3 years	2012, 2015	80%
Students can analyze CAE data	Faculty-designed exam question	FEA	3 years	2012, 2015	80%
Students can evaluate CAE analysis results	Faculty-designed exam question	FEA	3 years	2012, 2015	80%

Table 4. Summary of Assessment Results for Outcome (3d)

Performance Indicators	Method(s) of Assessment	Where data were collected	Assessment interval (years)	When data were collected	Performance target
Students understand the function of kinematic diagrams for solving multibody dynamics (MBD) problems	Faculty-designed exam question	Kinematics of machines	3 years	2013, 2016	70%
Students can derive the velocity response of planar mechanisms	Faculty-designed exam question	Kinematics of machines	3 years	2013, 2016	70%
Students can derive the acceleration response of planar mechanisms	Faculty-designed exam question	Kinematics of machines	3 years	2013, 2016	70%

Table 5. Rubric Used for Outcome (3a)

(3a) "An ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly defined engineering technology activities" [1]				
Performance Indicators	Unsatisfactory	Novice	Satisfactory	Proficient
3a.1 Students can construct a CAE model of a mechanical component to predict stress	Lack of accuracy in 2 or more of the FEA model components: geometry, meshing, material or physical properties, and boundary conditions	Lack of accuracy in 1 of the FEA model components: geometry, meshing, material or physical properties, and boundary conditions	Accurately constructed the FEA model of a mechanical part: geometry, meshing, material or physical properties, and boundary conditions	Accurately constructed the FEA model of a mechanical part and computed the modeling error
3a.2 Students can analyze CAE data	FEA model did not converge (run error) or no attempt made to analyze the results	Analyzed the FEA results incorrectly, i.e. present stress results at user defined boundary conditions	Analyzed the FEA results correctly	Analyzed the FEA results correctly and verified the results with analytical calculations or the provided experimentally measured data
3a.3 Students can evaluate CAE analysis results	no attempt to evaluate the results, i.e. didn't present a conclusion	evaluated the results incorrectly, i.e. incorrect factor of safety calculation, wasn't able to ID that the stress results exceed the material yield strength stress	Evaluated the FEA results correctly	Evaluated the FEA results correctly and presented recommendations to improve the mechanical part, i.e. weight and cost reduction

tion of the sample of students that performed at a level of satisfactory or proficient on each indicator was 79% (44% improvement) for indicator 1; 37% (5% decline) for indicator 2; and, 43% (10% decline) for indicator 3.

Again, the assessment results were reviewed by the MET faculty member with expertise in CAE methods development. In general, students were able use CAE software to construct an FEA model of a mechanical component. However, the results also showed that they tended to be unable to determine the accuracy of the analysis results. Students also tended to be unable to evaluate the results. Based on these assessment evaluations, it was decided to continue to align the course with the latest industry practices and use the latest CAE software. However, in addition to focusing on FEA model construction using modern software, students would be provided with additional opportunities to apply mechanics of materials concepts to evaluate FEA results.

ABET Outcome (3f): Assessment Results—2013

For performance indicators 1-3, summative data were collected in the Kinematics of Machines course in 2013 (see Table 4). Using the polygon method, students were asked to analyze a slider-crank mechanism for a 2-cylinder engine. A sample of 27 students (100% of the class) was assessed. The fraction of the sample of students that performed at a level of satisfactory on each indicator was 50% for indicator 1; 42% for indicator 2; and, 23% for indicator 3. In 2014, the assessment results were reviewed by the MET faculty member with expertise in mechanism analysis. Based on the assessments results, MET students performed well below the expected performance target of 70%. The MET faculty were unsure of the root cause of this shortfall. Was it due to students being uninterested or pedagogical misalignment? Because of this uncertainty, it was decided to experiment with different pedagogical approaches (i.e., CAE and analytical delivery methods).

The rubric used to score student performance on ABET outcome (3f) is shown in Table 6. It communicates the expected engineering analysis skills in the thematic area of dynamics. For mechanisms subjected to planar motion, MET graduates should be able to construct complete and accurate kinematic diagrams and derive the corresponding velocity and acceleration responses.

ABET Outcome (3d): Second Cycle Assessment Results—2016

Similar to 2013, summative data were collected in the Kinematics of Machines course in 2016 (see Table 4). Since two sections of the course were offered, the MET faculty member with expertise in mechanism analysis experimented with various reinforcement strategies and teaching methods to improve student performance in one of the sections. Students were asked to analyze a 4-bar mechanism using the vector loop closure analytical method on a faculty-designed exam question. A sample of 18 students (100% of 1 of 2 sections) was assessed. Because of this pedagogical experiment, improvements were realized on each of the three performance indicators: 28% for Indicator 1, 47% for Indicator 2, and 49% for Indicator 3. The assessment results were reviewed by the MET faculty member with expertise in mechanism analysis. For the 2nd cycle assessment, the Kinematics of Machines course was taught using an approach that combined CAE modeling (multibody dynamics) labs and the analytical approach for analyzing kinematic linkages. The aim was to first align the course delivery methods with the learning style of the MET student body (as a whole) and current industry practice. In addition to presenting fundamental mechanism analysis concepts (analytical methods), the CAE labs provided students with opportunities to visualize the motion of various commonly used machines and mechanisms. The CAE labs also exposed students to the currently used industry practices to analyze and evaluate the motion of machines and mechanisms. Because of the significant improvements in student performance, the course will continue to be delivered using a combination of CAE modeling labs and analytical methods.

Conclusions

To ensure sustainability, the ABET assessment process used by the MET program at EMU was redesigned to improve efficiency. This was accomplished by leveraging existing faculty resources. Specifically, the data collection plan was based on currently used assessment methods. Besides existing assessment data and methods, the following process design requirements were considered: MET PEOs, ABET a-k outcomes, ASME program criteria, and the contractual teaching responsibilities of the MET faculty. The resulting assessment process was more efficient and it did not significantly increase the workload of the MET faculty, which was an enabler for a sustainable assessment process. Aside from ABET accreditation, the proposed assessment methodology is beneficial to program assessment in general. For example, the results from student outcome (f) were used as part of the university's 2017 self-study report to the Higher Learning Commission (HLC).

Table 6. Rubric Used for Outcome (3f)

(3f) "An ability to identify, analyze, and solve broadly-defined engineering technology problems" [1]			
Performance Indicators	Unsatisfactory	Novice	Satisfactory
3f.1 Students understand the function of kinematic diagrams for solving multibody dynamics (MBD) problems	Lack of accuracy in 2 or more of the vectors and/or rigid body symbols that define the motion of planar mechanisms	Lack of accuracy in 1 of the vectors and/or rigid body symbols that define the motion of planar mechanisms	Can accurately construct kinematic diagrams that define the motion of planar mechanisms
3f.2 Students can derive the velocity response of planar mechanisms	No attempt to derive the velocity response from the kinematic diagram of a planar mechanism	Attempted to derive the velocity response from the kinematic diagram of a planar mechanism (significant errors)	Can accurately write the velocity response from the kinematic diagram of planar mechanisms
3f.3 Students can derive the acceleration response of planar mechanisms	No attempt to derive the acceleration response from the kinematic diagram of a planar mechanism	Attempted to derive the acceleration response from the kinematic diagram of a planar mechanism (significant errors)	Can accurately write the acceleration response from the kinematic diagram mechanisms

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Biography

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BIORUBEBOT: A MULTI-DISCIPLINE APPROACH TO CAPSTONE PROJECTS IN BIOLOGY AND COMPUTER SCIENCE

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Abstract

BioRubeBot is a teaching tool for a computer science (CS) capstone project that promotes interdisciplinary learning and team building. In addition, evidence is provided that the CS students are creating an understandable and sticky molecular biology game. The result is a Serious Educational Game (SEG) that has obvious relevancy to the traditional classroom through gameplay based upon common molecular biology motifs. Finally, this game has been tested both formally and semi-formally, strengthening its potential use as a learning tool that can connect school to play and vice versa.

Introduction

In today's twenty-first-century classroom, the traditionalist teaching philosophies, which posit the teacher as the content authority that will impart needed knowledge to the "blank slate" student, is the antithesis of what is essential for modern science students. Instead, science teachers are encouraged to embrace the more inquiry-based and student-centered constructivist philosophy for effective teaching and learning. Historically grounded in the beliefs of John Dewey, Jean Piaget, and Lev Vygotsky, the constructivist theory affirms a holistic idea of learning, where knowledge is gained by meaning making through interaction and association of prior knowledge and experiences. Constructivists consider individuals not as absorbers of disconnected information, but as "constructors" and "re-constructors" of knowledge as they negotiate understanding. In a student-centered, inquiry-based, constructivist science classroom, lessons will involve a variety of strategies and techniques. These can include problem solving, simulations, and various technologies [1]. Consequently, the BioRubeBot (<u>Bio</u>logy <u>Rube</u> Goldberg Ro<u>bot</u>) educational game embraces the constructivist approach in the teaching of molecular biology to twenty-first-century science students.

BioRubeBot is a necessary advancement for molecular biology teaching in a today's biology classroom. Traditional molecular biology instruction uses pictures, plain text, and static models for teaching subcellular activities within cells. These immobile representations do not require the user to engage in concept manipulation, nor do they accurately depict the dynamic nature of the cell. BioRubeBot is a Serious Educational Game (SEG) that enhances learning by encouraging the user to visualize and manipulate proteins through time, with text-based definitions accessible at hot-points within the game. To develop this game, interested CS students were recruited to participate in an interdisciplinary game development project. Interdisciplinary projects are also an excellent constructivist teaching strategy that can improve retention, increase student satisfaction, improve student ability to interact on an interdisciplinary team, and aid in the development of real-world job skills. The primary goal of the BioRubeBot project is to fulfill these needs for CS students, while producing an effective molecular biology game.

In this paper, the authors provide preliminary evidence that the project team is achieving the three sub-goals of this project, which include: 1) expose undergraduate computer science majors to interdisciplinary teamwork; 2) develop an SEG that is an effective classroom learning tool; and, 3) engage children 8 to 15 years of age in a molecular biology game that exposes them to protein interactions and terminology. CS students at Athens State University have voiced a great deal of engagement and satisfaction with the development of this biology-based game. In addition, evidence indicates that their perception of the team often changed over time and they were aware of the delegation of duties. Furthermore, this evidence shows that both the game development and the game itself increased the CS students' awareness of biological concepts, is playable by biology students aware of the concepts within the game, and can engage children aged 8-15 in a semi-structured environment.

Background and Prior Work

The American Time Use Survey [2] notes that persons 15-19 years of age spend 52 minutes playing video games or in recreational computer use on weekends. By comparison, the same group spent only four minutes reading. Furthermore, Young et al. [3] noted that, in 2009, 60% of those in the age range between 8 and 18 were playing video games on an average day. These trends clearly indicate that video games, particularly on mobile devices, are an opportunity for informal STEM (Science, Technology, Engineering, and Mathematics) learning. Despite interest in this area, few examples of such games can be found in the application stores for mobile device platforms.

Within the games that can be found, content knowledge is primarily found in the storyline [4]. The result is TL; DR (too long; didn't read) syndrome. This is because the typical game player is more interested in the gameplay, rather than spending extensive time reading information provided in the storyline. Players will gloss over written content, especially when it contains information that is difficult to understand or irrelevant to gameplay [5, 6]. Furthermore, in educational games that, for example, have a first-person shooter style, gameplay rules typically have little relevancy to developing STEM problem-solving skills [7-9]. The result is that the player feels that the game is a bit like "Chocolate covered broccoli" [7] and the reality is that it is possible for the player to proceed through games by button mashing [9] without using critical-thinking skills.

While the biological concepts and terminology described here as being used in BioRubeBot gameplay may seem advanced for users aged 8-15, Gee [10] argues that, if a child is able to understand the complex, fantastical terminology in games such as YuGiOh, why not technical terminology that is relevant to future learning? A smattering of research supports this argument in the context of a classroom [6], but little analysis has been performed in an informal setting, where a lesson plan is not provided. It is expected that, with an appropriately paced tutorial, players in this age range should be fully capable of mastering game rules regardless of the terms used. Furthermore, the use of invented terms may create an unnecessary barrier for future learning, as students are required to forget game terminology and relearn the correct terminology [11].

Flow

The game design is based upon three basic game development principles: flow, stickiness, and sandboxing. Flow is defined as the state of deep absorption that is intrinsically enjoyable [12]. In gameplay, a player experiencing a flow state is deeply focused upon the gameplay and unconsciously loses awareness of the world. Csikzentmihalyi [13] suggests that three conditions are required in order to achieve a state of flow: 1) one must be involved in an activity with a clear set of goals and progress; 2) the task at hand must have clear and immediate feedback; and, 3) players must have an effective balance between the perceived challenges of the task and their own perceived skills. Establishing these conditions in gameplay fosters an enjoyable experience that motivates the player to continue to play the game. Motivated players in a state of flow is in a state of concentration and eagerness that places them into a state that aids in the learning process [14].

In terms of gameplay, achieving flow imposes four requirements on game design [14]: clear tasks, feedback, balanced and attainable goals, and concentration. A game with clear tasks must have clear and easily understandable goals. At the same time, feedback must be provided to the player so that she or he can determine if game choices are progressing towards game goals. It is also important that these goals be balanced and attainable: gameplay must be challenging but not unachievable or overly long. Finally, concentration means that gameplay must focus the player on the game and avoid distracting the player from important in-game tasks. In order to ensure that a game achieves these four requirements, it is essential that the game be tested by the target audience.

Stickiness

Physics-based puzzle games provide a series of simple rules that, on their own, are clear and attainable. Then, as rules are added, the game difficulty increases, leading to concentration. The result is a game that has what is termed stickiness: a form of psychological dependence behavior that leads a person to return to an activity. When it comes to game design, this leads to continued gameplay over time [15]. Sticky games exhibit greater engagement on the part of the player [16], and from greater engagement comes more opportunities for learning experiences.

Sandboxes

Sandbox levels, on the other hand, provide players with a level beyond a structured, goal-driven environment. It is important to provide a censure-free space in educational games, because, while learning through failure from increasingly difficult challenges is an advantage that games provide, failure can also be intimidating [17]. This is an important aspect of learning, maintaining flow, and sticky game design that current mobile, molecular biology SEGs fail to fill [4]. Along these lines, the sandbox has multiple benefits. It is important for 1) the retention of players uncomfortable with failure [18]; 2) encouraging advanced users to independently explore difficult concepts; and, 3) a teacher who wishes to adapt the game to the classroom [10]. Both fear of failure and boredom interrupt a state of flow [19, 20]. A sandbox level allows a weak player to engage with the game freely, creatively, and without fear [21, 22]. It also provides an opportunity for a strong player to explore when the normal levels become too rote. Finally, for BioRubeBot to be used as a link between play and school, it is important that the game be easy to implement in the dynamic nature of the classroom. The less adaptable the material, the less likely teachers will be able to use it effectively in their classrooms [17, 23, 24]. The sandbox will allow teachers to adapt BioRubeBot as a teaching tool for different textbooks and peer-reviewed literature.

Game Design

BioRubeBot is designed so that learning occurs through problem-based gameplay that is constructed upon principles of sub-cellular protein interactions. This has been accomplished in much the same way that physics puzzle games, such as The Incredible Machine or Mouse Trap, utilize the rules of physics on common objects to solve puzzles. The different props such as pipes, treadmills, light switches, mice, and dynamite—interact with each other using representations of the rules of physics, such as those for gravity, springs, levers, treadmills, bomb explosions, etc. The user places the props in the game field so that the props solve the puzzle through their interactions after the user selects the Start button. As the player progresses, she or he must solve increasingly complex puzzles. In an introductory cell biology course, protein interactions are often simplified. Current textbooks support the constructivist pedagogy that learning simple, generic rules about categories of proteins provides the student with a scaffold for learning about additional, more complex interactions. The first stage of BioRubeBot is a representation of a biological process called a cell signaling cascade that is typically taught in a cell biology classroom. In a stereotypical signaling cascade, information outside of the cell is transferred to the inside of the nucleus. Figure 1 provides a CS student-generated storyboard for this process. The set of terms and their definitions that are introduced to the user in the first five levels of BioRubeBot are as follows:

1. ATP (Adenosine Triphosphate): ATP has three phosphates. It can turn an object on by transferring one of these phosphates onto it, but it needs a kinase to help it.
2. Cell Membrane and Nucleus: Cell membranes define a cell by keeping the insides in and the outside out! The nucleus is one of many compartments inside of a cell. It holds DNA.
3. GDP (Guanosine Diphosphate): GDP has two phosphates. It has to be replaced by GTP for some proteins to work.
4. G-Protein (Guanine Nucleotide-Binding Protein): G-proteins bind GTP and GDP, but only one at a time!
5. GTP (Guanosine triphosphate): GTP is a lot like ATP. It has three phosphates and can lose one of them, but tends not to transfer that phosphate onto the protein.
6. Kinase: Kinases can transfer phosphates from ATP onto proteins.
7. Nuclear Pore Complex: Nuclear pore complexes allow for entry into and exit from the nucleus.
8. Phosphate: Phosphates are easy to transfer from one place to another, if you have things in their correct places!
9. Receptor: Receptors communicate signals between the cell and the outside world.
10. Signaling Molecule: Signaling molecules bind to receptors and can activate them.
11. Transcription Regulator: Transcription Regulators can turn on DNA transcription.

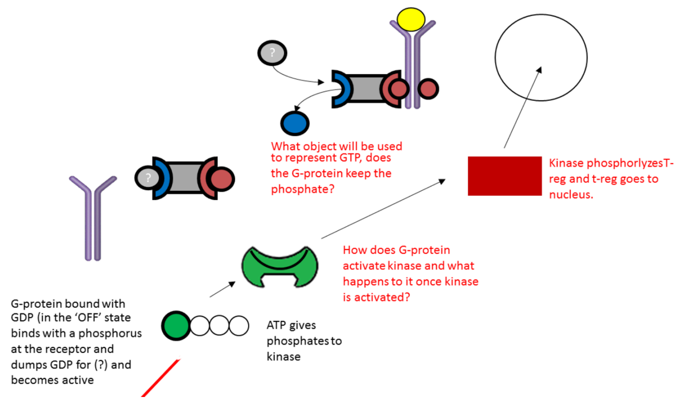

Figure 1. A CS Student's Workflow for Protein Interactions in BioRubeBot

In the interest of content knowledge transferability, it is desirable that the storyboard closely mimic textbook representations of proteins. This results in game piece design that is limited by predetermined canon. For example, most first-person shooters use the highly recognizable image of a gun to indicate to the player that they are able to shoot. Likewise, scientific illustrators tend to represent phosphates, very simply, as a ball. If the desire is to help game players understand static diagrams of protein interactions in textbooks, then it is important to use game pieces that mimic scientific illustrations. However, in the interest of designing an engaging game, object movements are being designed with unique approximations of the random motion seen in molecular movement. For instance, representations of ATP swim around the screen like tadpoles, while extracellular ligands swing in extravagant arcing motions. As one CS student noted during the development process, if the game used true random movement, the game pieces would potentially never come together.

In order to induce feelings of flow in the player, the levels in BioRubeBot quickly become more difficult as game pieces are added, much in the same way as the game Angry Birds progresses. For instance, the first level introduces the idea of a signaling molecule activating a receptor. In the next level, players have to combine their new knowledge of receptor activation with the idea of phosphorylation. Notably, these five levels are produced from the assembly of just one simplified protein-signaling cascade. By adding proteins and changes to protein interactions there is, as one CS student noted, nearly limitless possibilities for the development of higher game levels that can incorporate the multiplicative effects of protein signaling cascades working synergistically and/or antagonistically.

In order to allow for repeated and unique capstone projects, a start screen, where additional levels, such as those described above, can be added. Figure 2 shows the BioRubeBot start screen to the left, and to the right is the main screen for the "Free Play Level" referenced on the start screen. Tapping the Free Play Level button places the player into the sandbox level, where he or she can experiment with the different proteins and small molecules to test different solutions. Currently, each regular level introduces a new puzzle and begins at the same main screen as the sandbox with different objects displayed. At this point, the player can then attempt to solve the puzzle by placing the game pieces in and around the cell. The player's potential solution is tested when the play button on the main screen is selected. If the objects interact correctly, a reward screen appears and asks if the player would like to continue.

Methods

Three student teams from Athens State University's CS452 (Senior Software Engineering Project) course participated in the development of BioRubeBot, as of fall, 2015. This course is the capstone project experience for these students and is organized into self-managed teams that operate using principles of agile management and development.

CS Interviews

Student participants from the Athens State University's CS452 class were asked if they would be willing to take part in an interview related to educational research and were reassured that the interview would have no impact on their final grade. The majority of the interviews were conducted prior to their final presentation for their CS452 class, although one took place afterward. The interviews lasted from 9 to 26 minutes, with the mean time being 15 minutes. At standard four-year institutions, five would be considered non-traditional students and four would be considered traditional. All were senior CS majors in their ultimate or penultimate semester at Athens State University. The number and types of courses that the students self-reported as having taken to fulfill their natural science lab requirements varied widely (see Table 1).

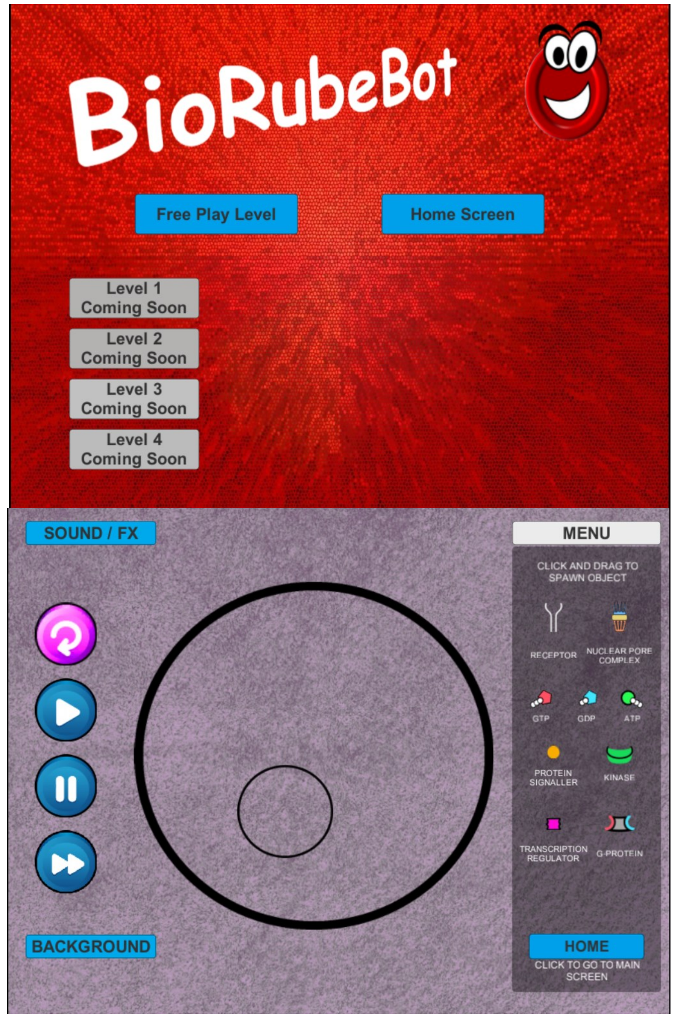

Figure 2. BioRubeBot Start Screen and Main Screen

Table 1. STEM Preparation of Student Participants

College Level Natural Science	Spring 2015	Summer 2015	Fall 2015
Introductory Biology I	2	1	0
Introductory Biology II	2	0	0
Astronomy	1	0	0
Physics I	1	1	2
Physics II	1	0	1
Non-Major's Chemistry I	2	2	1
Non-Major's Chemistry II	2	0	1
Physical Science	0	1	1
Environmental Science	0	1	1

During the first interview in the spring of 2015, the students were asked the following directive questions:

1) What classes have you taken in biology/science? Did you find that you applied the knowledge from these courses in designing this game?
2) What kinds of things did you do to help you better understand the biology content?
3) Do you feel confident in your ability to accurately design the game without knowing biology?
4) Are there differences in your approaches to learning the biology content of the game versus presenting the biology content in a way that would lead to learning? I.e. having correct content in the game vs. presenting the content to students.
5) Can you describe how you converted the biology concepts into executable code? How did this affect your understanding of those biology concepts?

In addition, each interview was initiated and concluded with a non-directive question: "*We can start with – what do you think of this project"?* and ended with "*Do you have anything else you wanted to add?"* After formative evaluation following the spring 2015 group, Question #3 was changed from "*Do you feel confident in your ability…*" to "*How did you feel about your ability… "* in order to avoid the interviewee being biased by the phrasing of the question. In addition, the following directive questions were included in summer 2015 and fall 2015:

6) What was your role in the project?
7) How did you feel about the group dynamics?

Biology Gameplay Interviews

The first beta test was completed on Version 1 with three randomly recruited Athens State senior biology students during the summer of 2015. Students were asked to sign an informed consent form and given no instructions on gameplay. As they explored the application for the first time, they were audio-recorded while they verbally described what they were doing. The educational backgrounds of the participants included one non-traditional student and two traditional students. The time since they had learned about cell signaling in a formal cell biology classroom ranged from one to two years.

YEA Gameplay Observations

Observations of children interacting with Version 4 of BioRubeBot occurred in a semi-controlled environment on April 9th, 2016 during the 2016 Athens-Limestone County (AL) Youth Education and Awareness (Y.E.A.) Conference. Attendees included families of all ages asked to sign a disclosure form upon participating. Tablets were placed out on a table and the observer sat behind the table. Children were allowed to approach the table without observer engagement. Children then either engaged the observer by asking to play or to color, or were asked by the observer if they wanted to play. No one was cajoled to play; the question was asked only once. If children said they wanted to color, they were allowed to color. If they then decided they wanted to play, they were allowed to play. The amount of time that the children engaged with the game was noted and, because of the variable nature of the engagement, those times were rounded up or down to the nearest whole minute. Their gender, as perceived by the observer, was also noted. In addition, observations were made regarding whether or not the player triggered the congratulations screen 0, 1, or multiple times, and if the child engaged in goal-driven gameplay or not.

Results and Discussion

CS Interviews: Student Interest

Every CS student interviewed described the project as fun or enjoyable at some point during the interview. In addition, when asked question #3, they generally noted something like: *'My ability to code it, yes. ... and my ability to mathematically model it, yes. My ability to understand the actual things that these objects are supposed to be doing together, probably not so much."* Also, some students did voice some concerns about the steep learning curve involved with learning the computing tools used to create BioRubeBot, for example: *"If I could get a better grip on the coding side of things, yes, I think I could do – […] I could probably offer a little more to the functionality of the success of the team."* This comment also reflects an opinion voiced by several of the team members, which was, they felt, that, at the end of the semester, they were now in a position to work in a more effective manner. They also voiced the opinion that, from their perspective, the project was an effective learning experience: "*I learned a lot and uh it was fun to actually get in there and learn the Unity engine and the gaming aspect as well as the biology part."* and *"As a, someone who aspires to be a game programmer, I enjoy the – learning how to work with different objects and tools such as Unity, its – because its one of the major platforms among the frostbite engine and a bunch of others that are in modern use."*

CS Interviews: Group Dynamics

At times, some of the students mentioned team member task allocation, solving group dynamic issues, and awareness of their biology contact's essential role in the project. Nearly every student mentioned the fact that having a biology expert involved with the team was essential for the project. On the other hand, group dynamics varied greatly from semester to semester. An example of task allocation is described by this student: *"I guess I was one of the, guess me and [another student] were basically the developers and - So I kind of went on my own and did the - Some of the aspects that you wanted in the program on the coding side of it."* Meanwhile, a student from a different group noted how the group had to change the way it was functioning in order to obtain their goals: *"...once you realize the limits of the group then you start taking your own initiative as to what you need to do to better the group and so at that point in time, you know, I started like 'Alright. I've got to start watching more videos; I've got to start reading...'"*

CS Interviews: CS and Biology

This last quote reflects the fact that having access to a biology professor did not stop most of the participants from accessing additional information about the topic. Very few of the students had taken biology as their natural science elective, tending more towards physics and chemistry (see again Table 1). Therefore, they reported independent investigation of both general audience information and, more rarely, peer-reviewed scientific literature to enhance their understanding of the biological interactions. Some examples are YouTube Videos, Google Image Search, and various websites, including references found in the EBSCOhost (Elton B. Stephens Co.) online research databases. As a result, some CS students displayed an excellent grasp of biology vocabulary usage. For example, (interviewer comments are bracketed): *"I'd just research online after I learned the signaling process. I looked it up and a lot of the - I noticed that there was research going on for the cancer and how that may play a role in it and there's actually some other studies going on that, things like Parkinson's, that I believe they help. Things of that nature. But trying to understand it, it was, it's not something that's simple. It is very complex. Learning the different molecules... I know there's proteins and you've got... I don't know ATP and ADP, I don't know what the A stands for, but I'm guessing its triphosphate and diphosphate. {Yes, good.} And the GTP and GDP are nucleotides. Don't ask me what those are, but I know they're not proteins."*

CS Interviews: Long-Term Engagement

As further evidence of their engagement with game design, participants displayed an intense interest in future directions. For instance, one student told the interviewer: *"I think the project is probably- after seeing what everyone else was doing I think this was by far the most important project we had. [...] how far I believe that it would be the sky's the limit on what you want to do."* Other comments related to future game development included more practical concerns, such as: *"the extracellular proteins would kind of float around, they were like – like they were on speed or something or where they would just like, you know, shake and - It was affecting the rest of the program but it looked right, but then we had to make a functional change where [...] you know, it looked odd. You know that was something that we couldn't do from a time standpoint, but that was something I would have corrected if I had been given more time."*

Biology Student Recorded Gameplay

All biology students involved in early testing were able to recognize relevant components of the game. It took them, on average, approximately 10 minutes to solve the puzzle. An example of a biology student describing gameplay demonstrates that the pieces were recognizable and that protein interactions were logical: *"I'm putting the ATP, the G-protein, the kinase, GTP, I mean GDP, and I'm putting the [...] GTP and transcription regulator all within the cell membrane. [...] And it's outside of the nucleus and now I'm going to hit play. So the signal protein comes. There's a conformational change, is that what it is? And now we're waiting for this. Oh so you can actually put more stuff in there to increase the likelihood of something attaching to the binding site. Just like a real cell. And then the cell wall actually contains everything. Yeah, this is cool! Now I get it! Nah, this is really cool. This'll help a lot. With uh, actually seeing how things really work with a bunch of random garble floating around and then they happen to attach in it bouncing around. The movement's clearly got that shaky, is that Brownian motion? I like it. [...]"*

Brownian Motion

The quote above also reveals an unexpected result from both the biology interviews and the CS interviews: the repeated theme of Brownian motion. In addition to the biology students noting the relevance of this type of random molecular motion to their understanding of protein interactions, the CS students seemed to agonize over this aspect of the game during their interviews. One of the more extreme examples of this type of consideration is shown below, as a student discusses the movement of ATP. The tail is referring to the phosphates on the ATP: *"... and that's fine but for instance, when we got the game it was really erratic. You know the tail was like this and just going crazy. So I made it to where it would be very smooth and fluid it looked more like a living organism rather than - It's kinda an erratic object. If you generate an object. But then I started thinking. Is that really what it looks like, Should it be more like the other, should it be more erratic, or..."*

This concern on the part of the CS students is obvious upon reflection of the investigators: the majority of the coding requires the students to make the objects move. Therefore, the question for the coder becomes: how does a protein move? When the students realize that the answer to this question is that proteins move randomly, they are left with the technical hurdle of designing a game where the pieces appear to move randomly and yet still come into contact with one another. Over time, they have developed several solutions and improvements to this problem. One student describes the math involved in coding the general movement of ATP: *"... it moves randomly, it varies in speed and direction. I actually had to plot a path around the nucleus, like if the Receptors over here, the nucleus is here and the ATP's here, then it can't get to the - to the receptor. I had to make it to where it would ray cast here, detect the nucleus, and then plot a path around the nucleus, and then calculate the vector from the ATP to the receptor leg. And then, when it gets here, calculates the incident angle between the receptor and the ATP so it knows how far to rotate."*

The movement of the objects also tied in with their desire for improving the game and future challenges. For instance, one student lamented the approach that former students had adopted, noting that it will cause future problems for the movement of two interacting objects: *"because C# doesn't have the concept of pointers […] you can't keep an aesthetic reference to a variable in memory. You're creating a copy, for the most part, […] and so, if you keep referencing this copy, but the original is changing, it becomes a problem when you're trying to dynamically go to where an object is. So when we get around to having objects actually moving while they are trying to interact, this will become a problem because they'll be referencing a copy of the original that was over here, but the original is actually moving towards another location. So it's going to be a problem once we get to that point, but we haven't actually had any objects that are moving while interacting, so that will be something for the next semester, I think."*

Another major theme in the student's concerns was improving the visual aspects of the game piece movement. This student also described improving the movement code of ATP: *"The code that was generated before, it was - was very static, it was - like for instance the ATP. It would just flip flip-flip-flip-flip. And what they were doing is they're just randomly generating a number telling it to move that far, move that far, move that far, and they were doing it all the time so it just - it didn't look - to me it just looked like it was freaking out all the time. What we did is we're like: OK, nothing looks like that. You know, all the things we saw online. Everything's very smooth. So we tried to give algorithms that would not be, uh, the ranges were smaller, the movements, so they couldn't do a one-eighty just like that, it would have to slowly turn itself."*

YEA Conference Observations

Conference attendees, who solved the game, averaged twelve minutes of playtime with BioRubeBot, which is comparable to the time that biology students required for solving the game. Notably, this average does not include individuals that did not solve the game nor does it account for the amount of time that individuals who played the game multiple times took to solve the game the first time. Furthermore, there appears to be no perceived gender disparity among the number of players, the amount of time played, or number of times the player solved the puzzle (see Table 2). One interesting difference that may even out as more participants are observed was that two of the female participants appeared to be more interested in decorating the cell in a non-goal-directed engagement with the game, rather than solving the puzzle.

Table 2. Play Times and Solve Rates for Perceived Gender

	Males		Females	
Result	Minutes Played	Average Minutes	Minutes Played	Average Minutes
Did not solve	3		11	
	2	2.5	3	7
Solved	7		6	
	5	6	4	
			20	10
Solved multiple	26		10	
	13	19.5	20	15
Mean		9.3		10.6
Median		6		10
Mode		N/A		20
Range		2 to 26		3 to 20

Preliminary Evidence for Informal Learning and Game Stickiness

Throughout the interview and observational processes involved with testing preliminary versions of this game, participants volunteered information related to sharing the game with family and friends. For instance, one CS student developer noted: "*I work with someone who his first degree was in biology and I was explaining the project and he just got excited. He started talking about all these concepts. I'm* *like, yes, exactly, that's what we're trying to do. It was really neat. […] I think it's a great thing."* Furthermore, informal discussions with beta testers led to one nontraditional student noting that he suspected his son would figure out the game faster than he would. Perhaps most encouraging was the fact that Y.E.A. conference participants asked if it were possible to download the game to their personal devices. These comments indicate that the Athens State University researchers and student software developers have created a sticky product that students want to share.

Conclusions

The student development team successfully built a cell biology game that is understood by biology undergraduates, who have already had a course in cell biology, indicating that the biological concepts in the game are taught in a general cell biology course. In addition, BioRubeBot has demonstrated game stickiness, since both males and females between the ages of 8 and 16 will, on average, engage with BioRubeBot as long as undergraduate biology students. Furthermore, one out of thirteen young participants actively used advanced biology terminology, indicating that the technical terminology was not a barrier to gameplay. While the sample size is small, this still suggests a potential future success rate of 5-10% for biology vocabulary learning in truant students using an app in an informal environment. Finally, results from game testing support evidence in the literature showing that sandbox levels are important in the production of a sticky molecular biology game, as the participants engaged with the game in both goal-directed and non-goal-directed ways.

Development of the BioRubeBot game as a CS capstone project worked as a method to encourage students to integrate computer science concepts with concepts from a new subject area. The CS students demonstrated engagement with the project by seeking out additional information, voiced enjoyment of the project, and displayed awareness of the project's future development. They also demonstrated their ability to problem solve a solution to a novel problem, that of how to ensure that the game remained educational by coding proteins to move as if they were randomly floating in a cellular environment without losing the stickiness of gameplay. This indicates that the BioRubeBot project provides an opportunity for CS students to learn the skill of integrating computer science and new subject areas, an important aspect for capstone courses, since it helps students transition to the continuous learning mindset required for software developers in industry [25]. From here, the next step is to test for learning gains in a formal classroom environment. In addition, CS students from Athens State continue to develop the game, focusing on wider dissemination of this product through mobile gaming stores and building the infrastructure to encourage other CS and biology departments to adopt BioRubeBot game-level development and classroom utilization.

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IMPLEMENTING LEAN IN HIGHER EDUCATION: DOES IT WORK?

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Abstract

Lean systems' roots are tied to the Toyota Production System (TPS). The primary focus of lean is eliminating waste in a system and which adds no value to the customer through continuous improvement. Higher education may be the newest sector to enter the lean race in an effort to modernize its operations and, as a part of strategic planning, to do more with existing resources. Lean is vital for public institutions in the higher education sector, due to the current cycle of decreasing state and federal assistance. A review of the literature revealed that lean has had mostly a positive impact in its relatively short run in higher education institutions (HEI). The author's professional experience as a lean consultant for a prominent HEI supports this finding. However, a common theme of challenges appeared across these institutions, while attempting to change their traditional settings, thinking, and way of operating. In this paper, the author attempts to consolidate challenges faced when attempting to implement lean in an institution of higher learning.

History

Lean system has its roots tied to the Toyota Production System (TPS). In 1984, an international conference at the Massachusetts Institute of Technology (MIT) concluded that North America and Europe had changed little from Henry Ford's mass production system, and they were not competitive with the ideas conceived and pioneered by Japanese automakers. Thus, in 1985, the International Motor Vehicle Program (IMVP) was launched by MIT to study the fundamental forces of industrial change. In 1990, Womack et al. [1] presented the results of a five-year study of the automotive industry in their book, "The Machine That Changed the World." John Krafcik, a factory specialist at IMVP coined the phrase "lean" to describe the new Japanese weapon. The manufacturing sector was revolutionized with the introduction of lean practices. Lean is a way of managing an enterprise that continually reduces operating costs, while maximizing returns [2].

Lean: A Value- and Flow-Based System

Womack et al. [1] label lean as a way of producing more and more with less and less [1]. The primary focus of lean is eliminating waste in a system that adds no value for the customer. Therefore, lean practices include strategic methods of reducing waste throughout the entire organizational process. Womack and Jones [3] stated the following about lean:

> ….provides a way to specify value, line up value-creating action in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more effectively. In short, lean thinking is 'lean' because it provides a way to do more with less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with what they really want. (p.15)

The main focus of most lean initiatives is operational improvement. According to Balzer et al. [4], the key steps in lean are: identify the end-users and stakeholders; perceive what the end-users consider value; identify key measurable metrics to measure process performance; identify how the process is currently being done; and, collect performance metrics. The next step is redesigning the process with the help of lean tools and implementing the revised process that removes waste, collects updated performance metrics data to evaluate the feasibility of new design, and continuously cycles as a closed-loop feedback mechanism towards achieving perfection. The lean project makers must align with the five fundamental traits of lean, which are value, value stream, flow, pull, and continuously striving to achieve perfection. If these principals are neglected, the effectiveness of the institution will not improve and cause the execution attempt to fail [5]. Therefore, lean principles are value based and intended to continuously improve a process to create flow (minimal interruptions such as waiting, reworking errors, and excess motion). Lean methodologies help an enterprise to select and apply resources in such a way that will result in high levels of efficiency and effectiveness. A number of tools and techniques have been developed to support lean and enable organizations to apply the ideas and implement change. Examples include but are not limited to A3 (a problem-solving story board), the Five Why's (an analysis tool to get to the root cause of a problem), Five S's (utilized to create a workplace suited for visual control and lean production), and Kaizen (a process function to plan and support a set of breakthrough activities).

Background

In the current scenario of globalization and organizations striving to streamline their operations for better yield, implementing lean has crossed the border between the manufacturing arena and becoming popular in most organizational sectors, including services, government, and education. Higher education could be the newest sector to adapt lean in an effort to modernize its operations and, as a part of strategic planning, to do more with existing resources. The financial impact of this sector both in U.S. and world economies is significant, as are non-financial aspects. According to the National Center for Education Statistics, in 2014-15, postsecondary institutions in the U.S. alone spent $536 billion, which included $336 billion at public institutions, $182 billion at private nonprofit institutions, and $18 billion at private for-profit institutions [6]. The lean strategy has been vital more than ever in the current scenario of decreasing trends towards state and federal assistance, especially for public institutions in the higher education sector. Many HEIs across the nation and around the world have turned towards lean as an operational strategy for continuous improvement and to do more with less. In addition, nationwide, statewide, and even internal competition has forced higher education institutions to do more with less. According to Isakson et al. [7], the assessed level of waste in higher educational sector processes is approximately 90%.

The current author is an internal lean consultant in a prominent Midwestern HEI, serving as primary investigator for lean projects and training senior leadership with lean methods and tools. A review of the literature revealed that lean has had mostly a positive impact in its relatively short run in HEIs [4]. Common areas of reported improvement included, but were not limited to, student services, admissions, student and faculty hiring processes, mail services, and facilities operation [8]. These have been reported from HEIs worldwide in the form of journal articles, technical reports, and other sorts of publications. However, a common theme of challenges appeared across these publications as well as from this author's professional experience. This current paper consolidates those challenges based on this author's know-how in implementing lean in higher education along with what is reflected in the review of the literature. The author is hopeful that the findings presented at the conclusion section of this manuscript will serve as a guide to future researchers wishing to implement lean in institutions of higher learning.

Cultural Change

Given the fact that this traditional method of operation for most HEIs has evolved over several decades, and in some instances centuries, makes lean convoluted, reluctant to change, and, hence, seemingly challenging to implement. In addition, the presence of academic and nonacademic departments as well as value and flow of the processes spread across different units with unique workforce of varied backgrounds and skill sets poses added hurdles. Lean implementation could have the biggest impact or change in three of HEIs' important segments: people, process, and technology. The people segment is not just about the employees but also about the social aspect of an organization (such as culture and adaptability to change), whereas a process is a set of sequential steps needed to execute a task, and technology generally relates to tools used by people to execute a process. From a change in management perspective, people have an overarching effect compared to process and technology, because day-to-day operations (including instruction, student services, academic support, and institutional support) of HEIs depend heavily on workforce.

An institutional culture of openness to change is required to successfully embrace and proliferate lean. Lean requires a mindset to view work as a process in order to expose waste in a system; for example, non-value-added steps involved in a student loan approval or purchasing equipment process. It will be difficult to observe hidden wastes in an HEI's business until you see work as a process and map its flow across different functional units. That poses a challenge in convincing senior leadership and senior managers to see the cross-functional improvement lean could make. Humans are generally reluctant to change, and it is very common that functional units tend to operate in their own silos, especially in HEI settings such as universities. In a traditional labor-intensive HEI setting such as a university, it is not surprising that there is a lack of enthusiasm to adapt to a new way of thinking [9].

Management Commitment

Management commitment and buy in is also key to lean success. One of the challenges is to prove to leadership that the transition to lean will be paid back in dividends, whether in profitability or prestige added to the institution. Many senior executives in HEIs are not clear on a good strategy to reach leanness, mostly due to not knowing the benefits of lean in a non-manufacturing atmosphere [10]. Lack of success stories of lean in academia has added to the hesitation to commit. According to Antony [11], the challenge is to get leadership to see the opportunity and believe in it. In addition, critics of lean and those wanting a roadblock to change could argue that lean may be an infringement into academic freedom and autonomy, which are integral parts of higher learning institutional culture.

Higher educational institutions typically have a hierarchy, but for successful establishment of lean, employee involvement and willingness to listen regardless of rank is important [10]. A non-blaming approach is of utmost importance and must be emphasized as a prerequisite that allows a space for people to experiment freely [12]. The lack of being open to people's ideas is part of a culture of blame [8]. Also, in most HEIs, conversations over process improvement are usually initiated when a problem arises or there is a standstill. These processes could be spread across various functional units. A lean environment demands preemptive interaction between people from these different functional areas to identify opportunities of improvement and early detection of problems. Therefore, a commitment by management to provide a proactive platform for cross-functional interaction and collaboration towards identification and pursuance of lean projects is necessary.

Collective Decision Making

Another barrier to implementing lean is the general batch and que characteristics of processing. For example, a course change or introduction of a new course takes approximately two semesters in a typical university. This longer lead time is due to the fact that most of the decision making is done by committees at the college or university level that meets a limited number of times during a year. An aspect of lean that makes it unique is that decision making is quick and improvement decisions usually comes from an individual or easily gatherable team. This breaks the conventional thinking in the higher educational sector, where a university- or college-level committee meets only once a month. A lean culture would demand delegation of power and decision making to subcommittees or smaller groups in order to attain better flow of processes and avoid queued processing. One of the most frequently mentioned resistances to lean was the ability for the staff to accept such a drastic change in flow and culture compared to the established method they had been accustomed to. In a study done in the United Kingdom, lean was the first program to challenge the culture of a committee-based decision-making system to an individual level, causing resistance from differing levels of staff [13].

Communication

Communication is key to any organization but is critical if lean methods are to be acquired. Insufficient communication can be a real handicap to the success of lean [14]. Comm and Mathaisel [15] conducted a study and asked several higher education organizations why they believed initial attempts failed.

> The number one reason many respondents felt their organization was not successful with their initial change efforts was because of communication, or a lack of it. There were breakdowns in communicating the "why" or the sense of urgency. There was not enough attention paid initially to the communication of the vision, and where everyone fits into that vision. It was reported that it was a difficult task communicating and gaining buy-in from individuals in sub-communities within the larger organizations. (p.234)

The term "lean" had a negative impact on people and was intimidating to some, as people incorrectly perceived this as a way of reducing head count [16]. Often such misconceptions about the outcomes of lean contributed to the challenges in proliferating lean [15]. Such fears will lead to a lack of commitment, which is often a barrier that prevents an organization from starting lean in the first place [17]. Also, the misinterpretations created hesitance to the acceptance and commitment to lean and prevented it from spreading through the entire organization. Lack of total involvement stops lean from reaching its maximum potential when it must be an all-in effort. Often miscommunications about the success of lean initiatives lead to outcomes that are theoretically not due to lean caused fear among employees. In some cases, the fear was real because lean implementation managers failed to apply all aspects of lean in its truest and resulted in negative outcomes such as layoffs [15]. In reality, lean does not support employee reduction, except as a last resort to save an organization from going out of business, which in the case of HEIs is highly unlikely. Reducing staff as a means to cutting costs is considered in lean to be a short-term and short-sighted strategy [15]. Therefore, when this author's team started implementing lean, an alternate name of SmartWorks was chosen. Lean essentially teaches you to work smarter and more effectively so that cycle times of tasks can be reduced, and individuals can accommodate more work in a given time window.

Translation of Terminologies

One other reason that lean implementation became difficult is the translation from terminologies used in manufacturing to ones that matched HEIs [18]. According to Salewski and Klein [17], any reference to traditional manufacturing examples could turn a higher education audience off and reinforce the thinking that HEIs are different. Lack of unification around important terms is a culprit of failing implementation of lean in HEIs. If everyone is not working on the same page to reach the same goals, then efforts to make changes are guaranteed to fail. To people unfamiliar with lean principles, it can cause difficulty relating phrases that are meant for a product, or service and accurately interpret them into meaningful uses for higher education systems. For example, the concept of figuring out who the university's "customer" was, was not comfortable for some staff [19]. Is the customer the students, the staff, the society? In most of the traditional businesses such as manufacturing and services, it is usually apparent who the customer is. According to this author, the definition of customer in higher education depends on the value stream you are considering and could vary widely. Therefore, additional discussions on who the client is and reaching an agreement is imperative. Otherwise, the chances of lean projects moving out of scope are higher. According to Nadeau [8], there almost has to be a proper identification and definition of the client in order for lean implementation to be successful.

Since lean is such a new concept to HEIs, it is crucial that the team planning the transition needs to find a way to define terms that the community can understand and accept [14]. Sometimes the beneficiary or end user of a service, such as teaching (student), may not be the only customer. For example, employers sponsoring their employees to earn a specific certificate may have an interest in its content, because the ultimate objective is that the employees apply what they learned at work. So, in that case, both the student and sponsor could be equally important as clients or stakeholders and needs both of their involvement in value creation. The definition of the customer may change for a group of people who pay for the services and have the power to specify what they find as value or what they need. In essence, an effort must be made to create a new language that matches the HEI considering the change.

Measuring Institutional Effectiveness

Measurements are the best way to set a baseline to determine progress. And at times is the only way to tell how efficiently a plan is working or how effective the newly established changes are. If you consider the core mission of an HEI such as a university as teaching and research, there are no commonly agreed upon metrics for institutional efficiency. According to Comm and Mathaisel [15], student costs are the most generally accepted measure of efficiency, because it is one of the easiest measures; however, it may not be the most comprehensive one. Nevertheless, though financial effectiveness of instruction can be measured using internal metrics such as weighted student credit hours, there are limited metrics for student learning and teaching effectiveness. For these reasons, beliefs exist that the application of lean in instruction is almost impossible. The author agrees that institutions could be long way from having a standardized way of measuring institutional contributions to student learning, and it will be difficult to properly assess the effect of any particular effort on the quality of learning. However, that does not exclude instruction from being considered for continuous improvement.

There are many examples where lean process or tools are used to improve course content and delivery. One such example that intrigued this author was a case in Rensselaer Polytechnic's School of Management, where a professor used tools such as load smoothing (small assignments given more frequently), five 'S' organizational method (good sustainable course organization), visual controls (give examples of common mistakes that students make), standard work (standardized syllabus format), just in time (return graded papers at the next class meeting) to streamline business courses [16]. The study reported an approximately 25% improvement in course and instructor ratings after lean was utilized to improve the courses [16]. Such case studies are classic examples that can defy the common notion that lean cannot be applied in academic sectors.

Where to Start?

According to Netland and Powell [20], for organizations such as HEIs that have complicated and diverse goals, enhancing one aspect of performance may be detrimental to another. For example, in academia, research is key to bringing in money and prestige to the university and developing a new body of knowledge, as well as keeping faculty up to date in their relevant areas of study. It is not uncommon for research trials to fail, and any attempt to tie trial results to performance trials would be a tragic consequence and could suffer higher pushback from researchers [21]. Therefore, one of the challenges to keeping lean sustainable in a higher learning environment is the selection of projects that will align with the strategic objectives of the institution [22]. Having support for an idea to improve both the academic and nonacademic sides, the author is of the opinion that support or auxiliary services departments may be a good place to start lean implementation. Initial phases of lean implementation are steered more towards high-impact low-investment strategies that require operational changes that need out-of-the box thinking and quick implementation of operational changes. This may require digression from traditional ways of performing tasks and embracing change.

There is significant room on the operations side of these departments that can use easily identifiable projects with performance metrics to measure. Processes and metrics are easily comparable to the ones that exist in traditional sectors, such as manufacturing and services. For example, improvements can be made on internal processes such as mail delivery or health-center services and measurements such as cycle time and lead times could be taken to compare performance. In addition, the creation of a culture focused on value and performance, holding each step accountable and measurable may be easier to implement in nonacademic departments. The success from these experiences can be shared across the institution in an effort to encourage academic (mainly instructional) departments to embrace lean and make it an institutional theme. Therefore, it is critical to find those early adopters who have an initial interest in lean.

Training

One of the keys to lean success is proper training of the project participants with lean principles and tools. The trainers or coaches could be met with questions about what works in HEIs. A straightforward answer could be that it depends on the needs of the given organization. But it is more than that because of the uniqueness of the sector. This ties back to discussions in the previous section that the visibility of the value stream of the process under observation could be challenging for several reasons: process spread across various functional units; lack of cross-functional interaction; and, the stakeholders being from varied background. Considering the above facts, the author is of the opinion that two of the key lean tools, A3 and Value Stream Mapping (A3), may be the most powerful and the first tools to introduce to such populations [23]. An A3 can be introduced as a format of continuous improvement that eventually could become an institutionalized theme of problem-solving based on Plan, DO, Check, ACT (PDCA) methodology [24]. It can also act as a precise and concise report that the team can agree to regarding project plan (problem statement, goals, charter, countermeasures, findings, follow-up, etc.) and status at various phases. A3 being a live document could be successful in bringing widely varying participants onto the same page. Value stream mapping allows participants to visualize process value better and provides a common platform that the team can agree to regarding process flow. It forces the team to understand the process deeply by investigating the system's details. Also, the author is of the opinion that new training tutorials be developed with examples and case studies that match the higher education sector.

Considering that the staff size of most HEIs is in the thousands, and the cost of external training may be cost prohibitive, it is important that there is a strategy to perpetuate internal training. A continuous central improvement office or center could be very important. In the case of the author's HEI, a team (SmartWorks) of eight, including faculty and staff, was established. The SmartWorks team is comprised of two lean experts who recruited the other six based on their expertise in topics such as change management, communications, instructional innovation, and training. The team then sought, and was awarded, an internal grant aimed at creating a set of lean champions and running a lean pilot project. Approximately 70% of the grant money was utilized for training the SmartWorks team and stakeholders of the chosen pilot project with lean tools and techniques. The pilot project was successfully completed and the success was shared with the university community. The idea was that the champions would return to their respective units to coach other individuals and initiate new continuous improvement projects to perpetuate the model. Specific details of the SmartWorks team, its projects, current status, and success stories will be published later.

Conclusions

Figure 1 is a depiction and summary of the fundamental challenges and their root causes while attempting to implement lean in HEIs. The author concludes that the majority of these conflicts can be resolved through the application of principles of change management, such as but not limited to total involvement, addressing cultural change, and providing inspiration and actionable communication in a timely manner. According to Comm and Mathaisel [15], lean is an organizational change strategy that needs an environment for change, leadership, culture, employee empowerment, training, communication, and measurement [24]. The migration of lean from nonacademic value streams to the academic side could be slow, but certainly evidence exists that it is possible [11, 16]. Acknowledging the fact that much work needs to be done in preparing the academic side of HEIs to implement lean, it is an operational strategy that has innumerable opportunities in higher learning. Lean is still in its infancy among HEIs and there definitely exists a need from the HEI community to share its experiences. Implementing lean would be instrumental in creating value and increasing the quality of outputs from HEI systems. Lean could certainly promote a culture of accountability and help in establishing controls and metrics to ensure continuous and sustainable improvement across the institution and its value stream. With the cost of higher education skyrocketing, and in the current scenario of decreased governmental funding, it could be time that HEIs pay more attention to utilizing lean as a paradigm shift towards improved efficiency and doing more with less.

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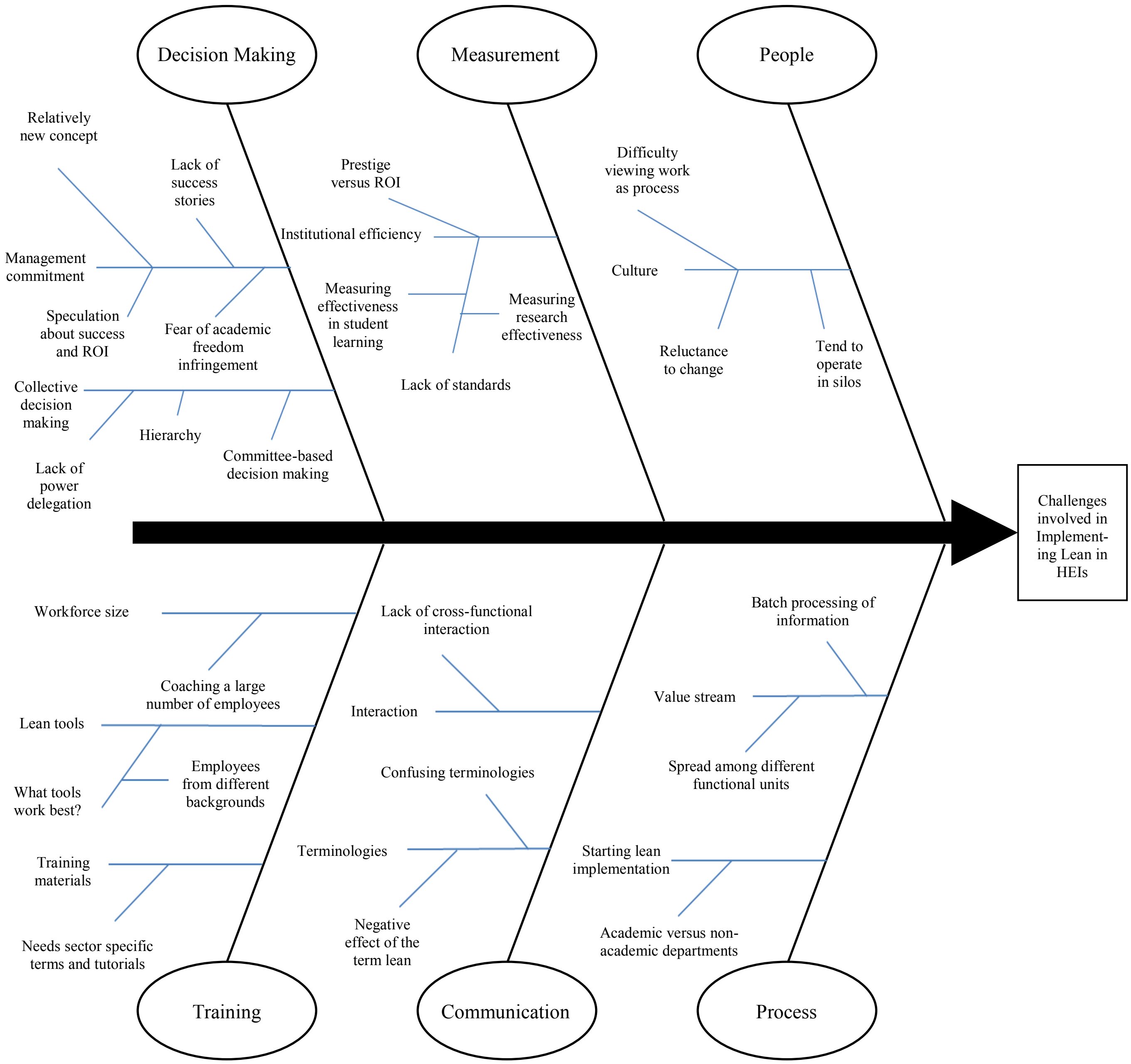

Figure 1. Challenges in Implementing Lean in HEIs

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Biography

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   T17-F-20 Figure 6

6. In-text referencing: List and number each reference when referring to them in the body of the document (e.g., [1]). In-text references must be in numerical order and follow entries in the References section. Again, see the sample Word document on our website for specifics. Please do not use the End-Page Reference utility in Microsoft Word.

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