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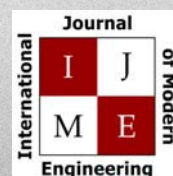
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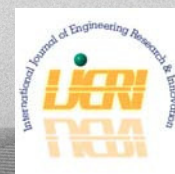
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# DESIGN OF A TELEOPERATED MOBILE ROBOTIC SYSTEM WITH A VIRTUAL REALITY INTERFACE

Wutthigrai Boonsuk, Eastern Illinois University

## Abstract

A teleoperated mobile robot—a robot that allows a human operator to remotely control it from a distance—has often been used in unsafe or unknown environments. Interfaces such as force feedback and video feed are commonly used to assist the operator in performing tasks with this type of robot. In order to accurately accomplish such tasks, it is important that these interfaces promote the operator's awareness of the environment surrounding the robot, also known as telepresence. In this paper, the author presents a design for a teleoperated mobile robot that incorporates a virtual reality (VR) interface. Virtual reality (VR) headsets have recently become popular in video game and entertainment industries, as they allow user immersion in an alternate environment. Robotic interface with VR headsets could be used to enhance the operator's telepresence while performing tasks remotely. The proposed design is intended to assist hobbyists, researchers, and developers in building teleoperated robotic systems.

## Introduction

In the early stages of development, teleoperated mobile robots used line-of-sight control via radio frequency (RF) communications, which once was represented by the term "remote control." With the advancement of internet networking and wireless technologies, robots can now be controlled from offsite locations and work in unsafe or unknown environments. This type of robot can be used in many applications, such as exploration, search and rescue, remote production, and remote service (Elhajj et al., 2003). When an operator takes control of the robot from a remote location, user interfaces such as force feedback or video feed have typically been used to enhance the operator's awareness of the environment surrounding the robot, and helped the operator to give correct instructions to the robot. This type of awareness is called telepresence (Kristoffersson et al., 2013).

Telepresence is vital for the operator to effectively control a robot in a remote environment by promoting feelings of being in a different place. The interface design for teleoperated activities plays a major role in encouraging the telepresence of the operator. Several types of interfaces that have been studied include force feedback and video feed. Force feedback, or haptic feedback, has been implemented in robotics systems that assist an operator in completing delicate tasks, such as surgical operations (Okamura, 2004; Reiley et al., 2008) and bomb disposal (Kron et al., 2004).

Similar to the vibration on a modern video game controller, haptic feedback felt by the operator is not a real force, but it is in fact simulated by an actuation system. This feedback helps the operator sense the presence or danger remotely. Another type of feedback, video feedback, is the most common interface that allows an operator to view the surrounding environment through a camera attached to the robot. Typical interfaces for video feedback can be built by attaching a single camera on the robot and displaying the camera view on a monitor back to the operator. This interface works to some extent but may not necessarily promote telepresence, due to the difference between the robot's environment and the operator's environment. With the advancement of computer and display technologies, virtual reality (VR) systems have been used to increase user immersion and sense of presence in virtual or alternate environments. Therefore, virtual reality interfaces could enhance operator telepresence while performing remote tasks with teleoperated mobile robots (Ackerman, 2015). In this paper, the author presents a design for a teleoperated mobile robot that incorporates a virtual reality interface. The system is intended for hobbyists, researchers, developers, and educators—technology and engineering-technology instructors and their students, who want to build their own teleoperated robotic systems, rather than for commercial use or consumer-finished products.

Virtual reality headsets, originally called head-mounted display (HMD) devices, have received a lot of attention, due to their rapid development and popularity in video game and entertainment industries. The VR headset consists of a stereoscopic display and positional tracking sensors that allow users to experience a virtual world with accurate movements. This has been widely used to enhance user immersion in alternate environments, not only for gaming purposes but also for training and simulation (Matsas & Vosniakos, 2015; Zhang, 2017). Several studies explored the uses of virtual reality headsets for teleoperation. For example, Baxter's Homunculus was a teleoperated robotic arm that allowed for operator control via VR headset and hand controller (Lipton et al., 2017). The main use of this robotic arm was for manufacturing movements such as pick, place, and assemble. Another example was a teleoperated mobile robot for virtual tours using a VR interface with 360-degree video streaming (Oh et al., 2018). This work demonstrated that a VR interface could improve user immersion in the remote environment. Finally, implementation of a VR interface on the camera arm of a surgical robot can be used to assist surgeons performing remote surgical procedures (Dardona et al., 2019). With a VR headset, surgeons can control the camera using their actual head movements and immerse themselves using a 3D stereoscopic view.

While a teleoperated robot with a VR interface was previously proposed and utilized in a variety of applications, details about how the system was constructed have not been fully described in previous literature, especially a system that is geared toward supporting the open source community. In this paper, the author fills this gap by providing the developmental steps of a teleoperated mobile robot, including the framework, system components, and software. Also discussed are key issues of the system design related to user telepresence.

## Design Framework for the Robotic System

The system of a teleoperated mobile robot developed in this study used open source and educational license software. Figure 1 shows that the system consisted of three main components: robotic system, computer system, and VR interface.

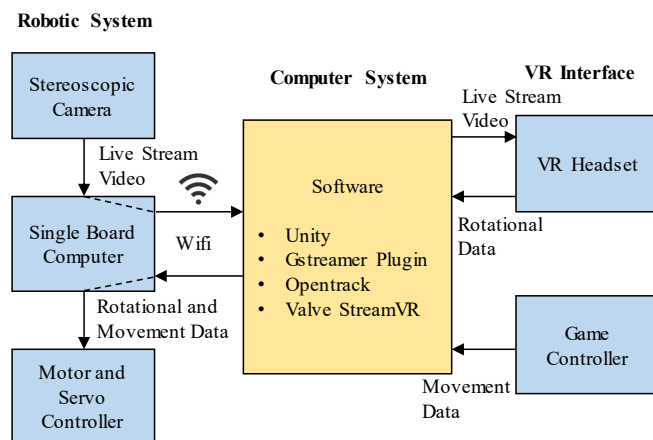


Figure 1. Three main components of the system.

The system was built using a tank mobile platform with two high-speed motors as powertrains. Figure 2 shows how a stereoscopic camera was mounted on two servo motors that allowed pan and tilt of the camera on top of the robot. Figure 3 shows how several circuit components were used for controlling the motors and the servo motors as well as for providing live stream video.

- The Stereoscopic camera used a CMOS AR0330 image sensor with a maximum resolution of 1920 (horizontal) x 1080 (vertical) per lens at 30 frames per second (fps). The camera had a dual non-distortion lens (100 degrees). In this project, a resolution of 1280 x 720 was used, as it provided better latency than the highest resolution.
- Raspberry Pi 3 (Model A+), a single board computer, was used for broadcasting live-streaming video captured by the stereoscopic camera to be sent to the computer system over a wireless network. The board also received rotational and movement data from the computer system and transferred this to the Arduino microcontroller board.

- An Arduino board (DFRobot Romeo BLE mini) utilized the data received from the Raspberry Pi to control pan and tilt servo motors as well as the movements of the robot (e.g., forward, backward, left, and right).
- A logic level shifter board was required because the Raspberry Pi and the Arduino board had different supply voltages, 3.3V and 5V respectively. Serial (UART) communication was established between these two boards (Jimblom, 2012).
- A voltage regulator was used for supplying 5V to the Raspberry Pi board.

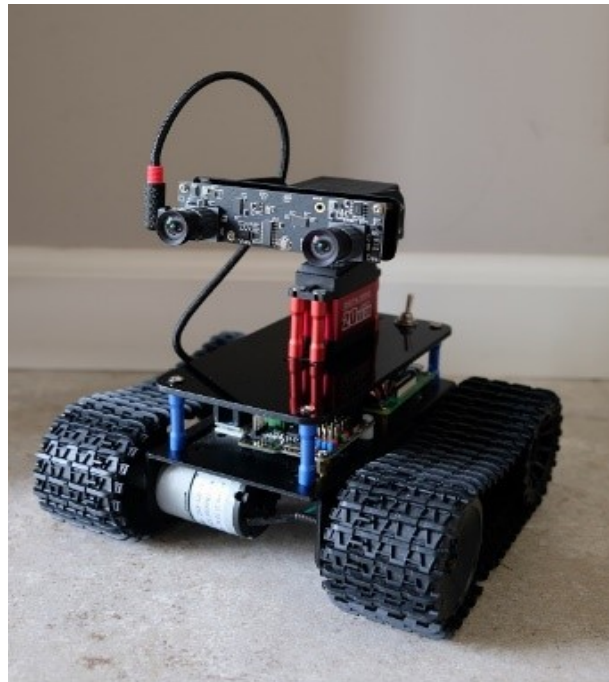


Figure 2. Mobile robotic system.

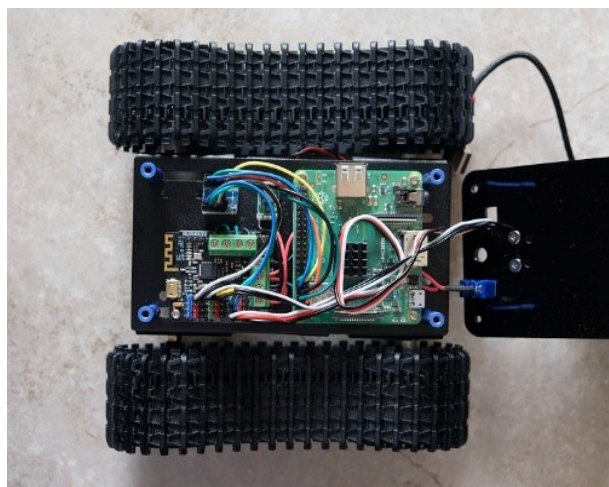


Figure 3. Circuit components.



When the teleoperated robot was powered up, two software applications ran on the Raspberry Pi. First, GStreamer, an open source multimedia framework (GStreamer, n.d.), was used to establish the video stream connection between the robotic system and the computer system over a wireless network. It allowed the stereoscopic camera to capture live video and transmit the feed to the computer. Figure 4 shows the pipelines of GStreamer running on the Raspberry Pi to broadcast the video via UDP protocol. The pipelines for the left and right cameras were virtually identical. The only differences were the video device numbers and the UDP ports.

```
gst-launch-1.0 v4l2src device=/dev/video0 ! videoflip
method=horizontal-flip ! video/x-raw, format=I420,
width=1280, height=720, framerate=30/1 ! queue !
omxh264enc target-bitrate=8000000 control-rate=3 ! vid-
eo/x-h264, profile=high ! rtph264pay config-interval=1
pt=96 ! udpsink host=192.168.1.100 port=5000
```

a) Pipeline for the left camera.

```
gst-launch-1.0 v4l2src device=/dev/video1 ! videoflip
method=horizontal-flip ! video/x-raw, format=I420,
width=1280, height=720, framerate=30/1 ! queue !
omxh264enc target-bitrate=8000000 control-rate=3 ! vid-
eo/x-h264, profile=high ! rtph264pay config-interval=1
pt=96 ! udpsink host=192.168.1.100 port=5001
```

b) Pipeline for the right camera.

Figure 4. GStreamer pipelines for left and right cameras.

A second application running on the Raspberry Pi was a C++ program used for establishing serial communication via a UDP socket between the teleoperated robotic system and the computer system. Source code for this program is available via Github (r57zone, 2017). The computer system sent rotational and movement data to the Raspberry Pi board. After data were received, the Raspberry Pi passed them through the serial port of the Arduino board. The data were then used for manipulating the camera's pan and tilt servo motors and movements of the robot platform.

## Computer System

The main purposes of computer system were to: 1) receive live-streaming video from the robotic system and display it on the VR headset; 2) retrieve rotational data from the headset (yaw, pitch, and roll) and detect movement data from the game controller (forward, backward, turn left, and turn right); and, 3) send data to the Raspberry Pi board via a wireless network. The following software applications were utilized in the computer system.

- Unity is a development platform used in this study for developing VR content in order to display the live-streaming video on the headset (Unity, n.d.).

- GStreamer Unity plugin is a H.264 UDP receiver texture that can be used as a receiver of GStreamer pipeline inside Unity to display video feed. This type of texture is commonly referred to as video texture, which is a plane object where the video feed is mapped on its surface.
- Opentrack is an open source application that can track a user's head movements and game controller input and transmitting this information to other applications, such as game or simulation software (Opentrack, n.d.).
- Valve StreamVR is a software program that connects support VR hardware, such as headset, controllers, and base stations, to VR content (Steam, n.d.).

VR content (application) for displaying the live-streaming video on the headset was developed in Unity. Figure 5 shows the Unity scene view that was constructed with Unity objects, including LeftCam (left camera), RightCam (right camera), CanvasLeft (left canvas), and CanvasRight (right canvas). The left and right cameras were positioned side by side and pointed to the centers of left and right canvases. These cameras represented positions where the user looked at the videos while the canvases displayed video feeds from the stereoscopic camera of the robot. The left video feed was displayed on the left canvas and the right video feed was displayed on the right canvas.

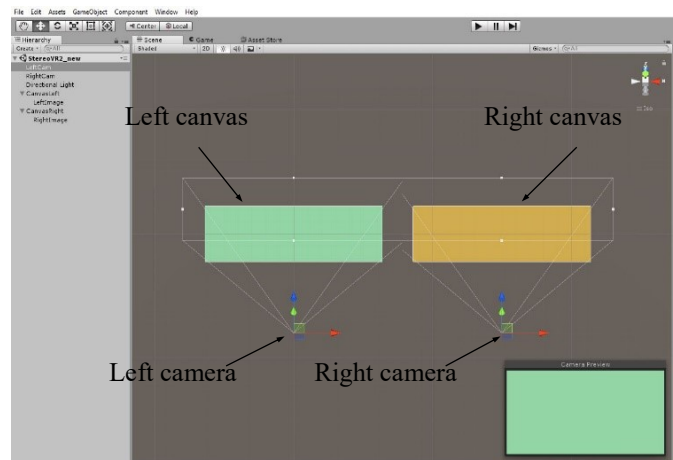


Figure 5. Unity scene view of left and right cameras that point to canvases.

The Unity plugin, mrayGStreamerUnity (2018), was used for receiver texture inside Unity in order to display video feeds on the canvases. The video feeds from stereoscopic cameras were received through UDP ports (5000, and 5001) and decoded with H.264 codec. Figure 6 illustrates the pipeline settings of GStreamer video textures on left and right canvases in Unity. Canvases were placed on two different layers, LeftEye and RightEye. The LeftEye layer was only visible to the left camera, while the RightEye layer was only visible to the right camera. This method allowed the video

from the left camera of the robot to display video only to the user’s left eye and video from the right camera of the robot to display only to user’s right eye.

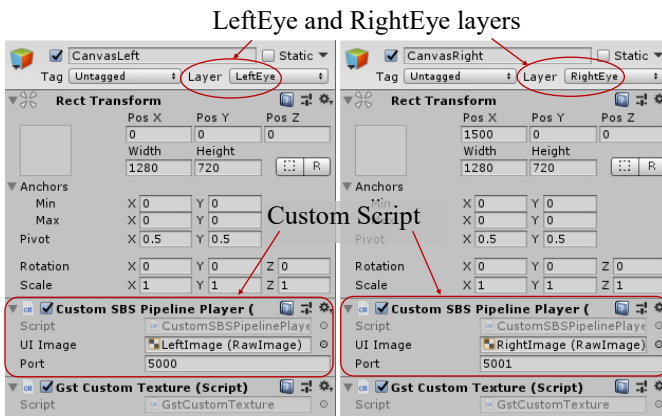


Figure 6. Settings of GStreamer video textures in Unity.

Custom Unity script (see Figure 6), referred to as the Custom SBS Pipeline Player (mrayGStreamerUnity, 2018), was used to construct the GStreamer pipeline and project video feeds of raw images that were placed inside the left and right canvases. Figure 7 shows the details of this script. When the user rotates the VR headset, the left and right cameras in the Unity scene view automatically follow the rotation of the VR headset. However, the GStreamer video textures (the canvases and raw images) do not follow the transformation of these cameras. Figure 8 shows the script that was used to enforce GStreamer video textures such that they would always be positioned in front of the user, and to maintain the distance between the video images and the user’s eyes. Opentrack was used in conjunction with Valve StreamVR to receive rotational data from the VR headset and detect movement data from the game controller input. Figure 9 shows the setting of the fusion input—the combination of rotation and position, and UDP output settings for relaying the data to the Raspberry Pi.

## VR Interface

The VR headset and game controller were utilized as the user interface. In this study, a Lenovo Windows Mixed Reality headset and generic Bluetooth game controller were used (see Figure 10). The idea for this interface was that the user inputs movements for the robot using the game controller (e.g. forward, backward, turn left, and turn right), while the live video feedback was available on the display of the VR headset. Since the left and right video feeds provided slightly different views that were captured from a stereoscopic lens, the user could experience stereo effects (i.e., depth perception) through the VR headset (Lebreton et al., 2012). This is a similar effect to what can be seen in 3D movies. When the user looks up or down, or turns left or right, the VR headset sends rotational data (yaw, pitch, and roll) to the computer system. As mentioned previously,

Opentrack in the computer system then sends these data to the robotic system to control the pan and tilt servo motors. Thus, the head movement of the user syncs with the movements of the two servo motors.

```
using UnityEngine;
using UnityEngine.UI;

[RequireComponent(typeof(GstCustomTexture))]
public class CustomSBSPipelinePlayer : MonoBehaviour {
    private GstCustomTexture m_Texture;
    protected Texture2D blittedImage;
    public Texture2D Eye {
        get { return blittedImage; }
    }

    public RawImage UIImage;
    public int Port = 1337;
    private GstImageInfo _img;
    private bool _newFrame = false;

    void Start()
    {
        m_Texture = gameObject.GetComponent<GstCustomTexture>();
        m_Texture.Initialize();
        string pipelineLeft = "udpsrc port=" + Port.ToString() + " ! application/x-rtp, " +
            "encoding-name=H264, payload=26 ! rtp264depay ! avdec_h264";
        m_Texture.SetPipeline(pipelineLeft + " ! video/x-raw,format=f420 ! " +
            "videomark ! appsink name=videoSink");
        m_Texture.Player.CreateStream();
        m_Texture.Player.Play();
        m_Texture.OnFrameBlitted += OnFrameBlitted;

        _img = new GstImageInfo();
        _img.Create(1, 1, GstImageInfo.EPixelFormat.EPixelFormat_R8G8B8);

        blittedImage = new Texture2D(1, 1);
        blittedImage.filterMode = FilterMode.Bilinear;
        blittedImage.anisoLevel = 0;
        blittedImage.wrapMode = TextureWrapMode.Clamp;

        if (UIImage != null) {
            UIImage.texture = blittedImage;
        }

        void OnFrameBlitted(GstBaseTexture src, int index) {
            m_Texture.Player.CopyFrame(_img);
            float w = m_Texture.Player.FrameSizeImage.x;
            float h = m_Texture.Player.FrameSizeImage.y;
            m_Texture.Player.CopyFrameCropped(_img, 0, 0, (int)(w), (int)(h));
            _newFrame = true;

            if (_newFrame) {
                _img.BlitToTexture(blittedImage);
                _newFrame = false;
            }

        void OnDestroy() {
            if (_img != null)
                _img.Destroy();
        }

        void Update()
        {
        }
    }
}
```

Figure 7. Unity script for a custom SBS pipeline player.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class TransformRawImage : MonoBehaviour {
    public Camera TargetCam;
    public float distanceFromCamera;

    void Start() {
    }

    void Update() {
        transform.position = TargetCam.transform.position +
            TargetCam.transform.forward * distanceFromCamera;
        transform.rotation = new Quaternion(TargetCam.transform.rotation.x,
            TargetCam.transform.rotation.y,
            TargetCam.transform.rotation.z,
            TargetCam.transform.rotation.w);
        transform.rotation *= Quaternion.Euler(0, 0, 180f);
    }
}
```

Figure 8. Unity script for GStreamer video textures.

Users can also control robot maneuvers by moving the thumb stick on the game controller. Similar to rotational data, movement data are detected by Opentrack software in the computer system. Opentrack then sends these data to the robotic system via UDP protocol. All data communications between the computer system and robotic system were transferred via wireless network.

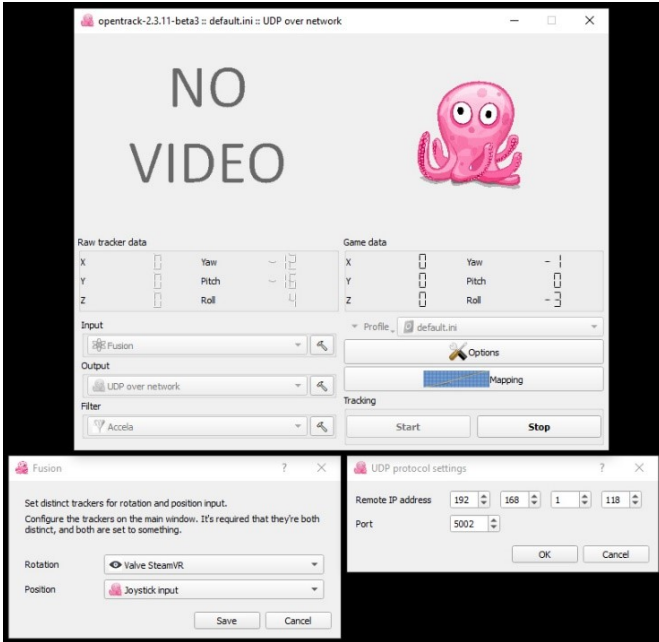


Figure 9. OpenTrack setting with rotational data from the VR headset and movement data from game controller.



Figure 10. Lenovo windows mixed reality headset and Bluetooth game controller.

## Discussion and Future Work

During the development of the teleoperated robot, several lessons were learned from observation and evaluation of the prototype. The following discussion depicts decisions that were made to balance the efficacy and actual performance of the design robot, so that user telepresence could be upheld. Methods of showing live video on a VR headset to enhance user telepresence need to be carefully considered. In this current project, a decision needed to be made between using 360 video or stereoscopic video with a non-distortion lens. Recently, 360 video has become a trend for filming video. As Unity provides support for displaying this type of video format, 360 video can be used in the design of teleoperated robots. The main benefit of using this approach is that the user is surrounded by the 360 video and able to

move freely in the scene. However, because the video is shot through a distortion lens, unfolding the 360 video into user view is far from perfect. The object can be significantly distorted and misrepresented in scale, especially when it is located close to the camera. Thus, the design for this study used non-distortion lens and two servo motors to support pan and tilt of the camera. A potential downside was when the user performed fast movements on the headset, which resulted in slower response times due to the speed of the servo motors.

Latency is a common problem of video streaming applications that can significantly interrupt user telepresence while using a VR headset. In this case, latency can be caused by several factors: network bandwidth, video resolution, and streaming software. For network bandwidth, 802.11ac (5 GHz band) is recommended for broadcasting live video streaming. Although 802.11n (2.4 GHz band) can be used, occasional video stuttering can occur while streaming video unless low video resolution (640 x 480) is used. It is a limitation of 2.4 GHz that has a standard bandwidth of 150 Mbps versus 433 Mbps or higher over 5 GHz. Video resolution is another factor that can affect both latency of the system and user telepresence. While higher resolutions—such as 1080p, 2k, or even 4k—can greatly improve user immersion and telepresence, the bandwidth can be filled up quickly, resulting in increased latency of the system. The current system displayed a video resolution of 1280 x 720 per eye. From several pilot tests, this resolution seemed to provide an optimal setting balancing latency and user telepresence. Streaming software can be one of the bottlenecks that can affect latency of the system. According to several experiments on the streaming software in this study, GStreamer was chosen, along with other video streaming software including VLC (VideoLan, n.d.), FFmpeg (FFmpeg, n.d.), and UV4L (UV4L, n.d.), in order to live stream a video resolution of 1280 x 720 per eye (2560 x 720 combined) using UDP protocol. The main reasons for choosing GStreamer were its real-time capability and streaming quality as well as the availability of plugin with Unity. Since optimizing the streaming tool was not the main purpose of this paper, this topic may be explored in detail in the future.

The tracking system is a technology in VR that allows precise location detection of the headset in real space. The three degrees of freedom (3DOF) that recognize rotations (yaw, pitch, and roll) of the VR headset were implemented in the proposed system. Only yaw and pitch data were used to control the servo motors that rotated the stereoscopic camera. For this setting, it was assumed that the user was in a seated position with the headset and used a game controller to control movements of the robot. In future work, room-scale tracking (6DOF) can be implemented to improve user telepresence, allowing the user to freely walk in the real world, while translational data (x, y, and z) from the headset are applied to control the robot's movements the game controller.

---

## Conclusions

Teleoperated mobile robots allow human operators to control the robots from a distance. A VR interface can be used to assist operators in improving telepresence while performing tasks with the robots. In this paper, the design of a teleoperated mobile robot with VR interface was presented in detail to benefit anyone from hobbyists to developers, who want to build teleoperated systems of their own. The proposed system was implemented based on open source and educational license software. It consisted of three main components: a robotics system, a computer system, and a VR interface. Individuals can replace and rebuild any of these components using their own hardware configurations. Several key issues discussed in this paper may lead to future efforts to reduce latency and improve positional tracking of the system.

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# ARTIFICIAL INTELLIGENCE AT THE EDGE OF THE CLOUD FOR SMART IOT

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## Abstract

In the next few years, businesses, large or small, will have to use some form of data analytics to make business decisions. As the Internet of Things (IoT) becomes more widespread, high-speed data processing, analytics, and reduced response times are becoming more important than ever. To enhance and complement the current centralized, cloud-based model, fog computing was established. However, in order for businesses to deal with current and future challenges of big data in IoT, there is a need for computing at the edge of networks, specifically at the fog nodes. In this paper, the authors propose adding an adaptive set of filter banks to dramatically reduce network load in terms of processing, volume, velocity, and variety of datasets.

## Introduction

Cloud computing involves delivering data, applications, photos, videos, and more over the internet to data centers. The Internet of Things refers to the connection of devices, other than devices such as computers and smartphones, to the internet (i.e., cars, kitchen appliances, and heart monitors). As the IoT surges in the coming years, more devices will be interconnected. Cloud computing and the IoT have a complimentary relationship. The IoT generates massive amounts of data, and cloud computing provides a pathway for those data to travel to their destination. In recent years, the IoT has been generating an unprecedented amount of data, which has put a tremendous strain on the infrastructure of the internet. With such growth of data, companies are seeking to find ways to meet the challenge of data management. Hence, fog computing, also known as edge computing, has soared in the last few years. Fog computing is an intermediate layer that extends the cloud layer. Simply put, fog is a cloud that is closer to the ground. Fog architecture moves part of the computing to the edges, away from centralized data centers and cloud solutions. It is a highly virtualized platform that provides computing, storage, and networking services between end devices and traditional cloud-computing data centers. Fog services are typically, but not exclusively, located at the edge of the network (Bonomi et al., 2012). Therefore, data can be processed locally on smart devices rather than being sent to the cloud for processing.

## Adaptive Computing Using Filter Banks

Datasets at any layer suffer from the effects of noise, as well as large volumes of data, missing data, and discontinu-

ties. Detecting information, anomalies, patterns, and trends from such data requires special processing techniques beyond traditional statistical approaches. With the advent of advanced data analysis tools, the authors have developed computational low-power, low-bandwidth, and low-cost filter banks capable of removing the noise and compressing, decomposing, and finding the patterns and new information in the datasets. This method is guaranteed to converge to a stationary point for both uncorrelated and correlated datasets. The proposed technique, otherwise known as adaptive filter banks, uses spectral estimation and data pre- and post-processing techniques to process data. Multi-resolution filters and advanced spectral estimation techniques have proven to be efficient solutions to network node processing (Sheybani et al., 2012). In this paper, the authors propose innovative filter banks designed to enhance the analysis of network (fog, cloud, etc.) data using parametric spectral and data classification methods, pattern recognition, and trending algorithms.

Among the major parameters that govern creation of an efficient data-processing tool, realizing the order (scale, dimension, or size) and orthogonality (separation) of datasets are two of the most important ones. There have been many attempts to improve the process of extracting information from data by manipulating these parameters. Dimensionality reduction is one of the basic operations in the toolbox of image data analysts and designers of machine-learning and pattern-recognition systems. Given a large set of data with few observations, an obvious idea is to reduce the degrees of freedom in the measurements by representing them with a smaller set of more “condensed” variables. This amounts to reducing the dimensionality of the dataset in order to reduce the computational load in further processing (Sheybani et al., 2010).

In computational analysis of network domains, data are often processed based on their features (e.g., size, depth, and other domain-specific aspects), such as trends and patterns of data. Certain features may be more significant than others while computing the datasets and drawing corresponding inferences for specific applications. Though domain experts may have subjective notions of similarity for computing, they seldom have a distance function that ranks the dataset features based on their relative importance. The proposed method ranks features for learning, such a distance function, in order to capture the semantics of the dataset (Varde et al., 2007). For cloud and fog computing, a special set of filter banks have been proposed to suppress the effects of noise and data order. One of the advantages of this approach is that the same algorithm serves to reduce the

data order, remove noise, and decompose the data into different layers for information extraction, component analysis, and trend/pattern recognition. The proposed technique uses orthogonal decomposition to decompose the dataset into spaces of coarse and detailed signals in order to show the most dominant patterns of information in the dataset. With the filter banks being designed from special bases for this specific application, the output signal in this case would be components of the original signal represented at different time and frequency scales and translations. Detailed mathematical descriptions of the technique can be found in other studies (Sheybani et al., 2012; Sheybani et al., 2010; Varde et al., 2007; Sheybani & Sankar, 2002; Sheybani, 2011; Sheybani & Javidi, 2009; Sheybani & Javidi, 2012).

## Cloud or Fog Computing

Using the orthogonal decomposition feature of the Adaptive Filter Banks (AFB), the dataset can be decomposed into layers of independent points with each layer showing trends and behavior of the most dominant mode of data (Sheybani et al., 2012; Sheybani et al., 2010; Varde et al., 2007; Sheybani & Sankar, 2002; Sheybani, 2011; Sheybani & Javidi, 2009; Sheybani & Javidi, 2012) that have a proven track record of stability, efficiency, and performance (Sheybani et al., 2012; Sheybani et al., 2010; Varde et al., 2007; Sheybani & Sankar, 2002; Sheybani, 2011; Sheybani & Javidi, 2009; Sheybani & Javidi, 2012). While these layers represent the entire dataset collectively, individually they represent different modes of data from the most dominant (coarse information, major pattern) to the least dominant (detailed information, noise). Therefore, the beauty of the proposed technique compared to other analyses is that it accounts for all of the data points, while the general pattern of data (most dominant mode of information) is recognized.

Cisco provides the example of a jet engine that creates ten terabytes (TB) of data about its performance and conditions in 30 minutes (Nisha, 2015). Transmitting all of that data to the cloud and transmitting response data back requires high bandwidth and a great amount of time, and can increase latency. In the proposed approach, much of the processing would take place on a local router at the fog level (AFB Layer 1), rather than having to first transmit the data to the cloud. Hence, fog computing focuses on lifting part of the workload off the regular cloud services by using the proposed algorithm to provide a quicker, smoother, and more streamlined experience for end-users. Fog computing analyzes the most time-sensitive data at the network edge, close to where it is generated, instead of sending vast amounts of data to the cloud. Also, in addition to acting on data in milliseconds, it sends selected data to the cloud for historical analysis and longer-term storage. In the proposed plan, another layer of computing and data reduction happens at the interface of cloud and fog (AFB Layer 2), where data from different fog layers fuse together. At this stage, too, the unnecessary load is reduced and only dominant modes of data important for decision-making are transmitted to the cloud

layer. It is understood that if this process is implemented at every fog and cloud interface, the overall cloud traffic will be reduced exponentially. Figure 1 provides a representation of the proposed fog/cloud computing (Javidi et al., 2018; Javidi et al., 2017).

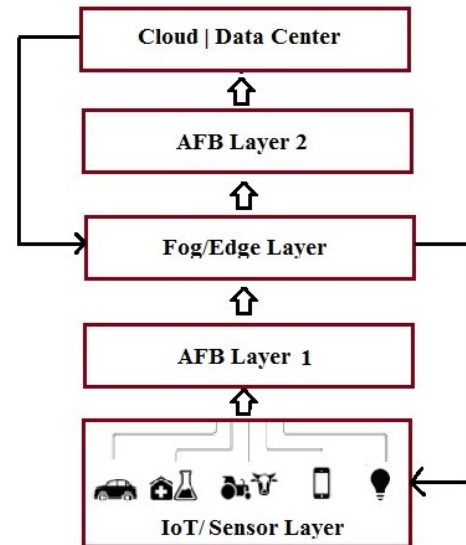


Figure 1. Overview of the proposed node-based computing.

## Results and Discussion

In the proposed fog/cloud-based AFB scheme, both cloud and fog provide data, computation, storage, and application services to end-users; however, the data stream in both cases will be streamlined such that it only transmits useful information from one layer to the next. To accommodate the services, and address the requirements of IoT systems, the proposed technique offers several advantages. It reduces the need for increased bandwidth by not sending every bit of data over transmission channels, but instead by aggregating data at a certain access point. It also eliminates latency and numerous hops, lowers costs, improves efficiency and supports mobile computing and data streaming. Network nodes can be deployed anywhere with a network connection close to the smart device where actual data generation or end outcome takes place (e.g., in a vehicle). One of the immediate benefits of the proposed approach is the proximity of the computation layer to the sensor layer. Moreover, the large-scale geographical distribution of the devices that make up the computation layer, combined with location awareness, ensures low communication latency. The combined benefits of location awareness and large-scale geographic distribution support the mobility requirements of devices or “things” at the sensor layer. The close proximity of the computation layer to the nodes provides real-time interaction with the sensors and actuators in the sensor layer. This way, concerns about scalability and trustworthiness can be also addressed. Node computing promises to ensure safe and trusted transitions, provide affordable

scaling under a shared infrastructure, offer real-time processing and cyber-physical system control, and increase efficiency by pooling unused local resources from participating end-user devices. Table 1 shows some differences.

Table 1. Cloud/fog/edge computing versus node/AFB computing.

Cloud/Fog/Edge Computing	Node/AFB Computing
Centralized	Decentralized
High delay jitter	Low delay jitter
High Latency	Low Latency
Servers are within Internet	Servers are on the edge of the network
There is no user-defined security	There is user-defined security
Multiple Hops	Single Hop
No location awareness	Location awareness

Security is another main reason that companies should turn to node/AFB computing. There are several fundamental ways that node/AFB computing is making the IoT more secure. AFB is built from the ground up and offers a new level of protection beyond IT security. It has the infrastructure to decompose data and extract useful parts. Therefore, it can detect and filter out attacks by hackers. It can also provide real-time incident-response services that enable IoT systems to respond to breaches without disruption of service to address a key vulnerability of physical location. Furthermore, the proposed method addresses the challenges in designing a secure storage system to achieve low-latency, support dynamic operation, and deal with interplay between fog and cloud. The existing security and privacy measurements for cloud/fog computing cannot be directly applied to node/AFB computing, due to features such as mobility, heterogeneity, and large-scale geo-distribution. Therefore, this research effort not only determines the impact of those security issues and possible solutions, but it also provides future security-relevant directions to those responsible for designing, developing, and maintaining node/AFB systems. In that regard, this approach also connects to other new permutations described in the literature: mist computing and fluid computing.

Mist computing is closer to the ground than fog, which in turn is closer to the ground than the cloud. It is about bringing computing, storage, and communication directly into the “things” of the IoT. Therefore, cloud infrastructure is high in the data center, fog infrastructure is between the devices and the cloud, and mist infrastructure is simply the things/devices. Fluid computing is an emerging network architecture that combines cloud, fog, and mist computing into a single abstraction. In other words, each of these three computing layers can be considered as an application of fluid computing in a specific, bounded context. Fluid architecture eliminates the technological separation created by cloud, fog, and mist tech-

nologies. As the IoT grows, a convergence of cloud, fog, and mist computing platforms toward a fluid computing platform is anticipated. This convergence will be necessary, if not essential, for accelerating the adoption of the IoT (Javidi et al., 2018; Javidi et al., 2017). The proposed approach is merely an implementation of mist computing in this context.

The proposed method will pave the way for the rapid growth of the IoT by providing businesses with faster and more efficient solutions, better security, and faster decision-making processes and lower operating costs. For many companies, relying on nodes on decentralized systems is a concern. For example, a major disaster could wipe out all of those individual processors in a city, resulting in catastrophic data losses. By storing data in the cloud/fog, businesses will be able to recover from disruptions much more quickly and efficiently. With node/AFB computing, local and remotely hosted data backups remain critical, as does ensuring that businesses can access stored data in the event of an emergency. Node/AFB computing remedies this issue by safely reducing and storing required data backups and allowing companies to schedule automated backups protected by military-grade encryption by decomposition. Node/AFB and cloud/fog complement each other in this scenario.

With the emergence of IoT applications, a real-time response can be “a matter of life or death” (Rasmussen, 2017). For example, reliable real-time data processing is crucial for medical wearables that monitor patient conditions. Node/AFB computing is especially advantageous for applications that require a response time of less than a second (Cisco, 2015). A good example is the airline industry. When a plane lands, data from its engines must be downloaded and analyzed. If any anomalies are discovered that could indicate trouble with the engine or any potential cause of failure, the problem must be remedied, usually by procuring and installing a new part. The entire process typically takes several hours. With node/AFB computing, airlines have the capability to do all of the analytics in-flight, on the plane, and transmit any anomalies to the destination airport while still in the air. Then, when the plane lands, the needed part can be waiting, reducing downtime to 15 to 30 minutes rather than hours.

A look at the transportation and manufacturing industries, with their need for preventive maintenance, shows how embracing node/AFB computing would enhance efficiency and safety across industries. As mentioned earlier, security concerns are also compelling companies to turn to node/AFB computing. Node applications can be used to monitor and analyze data from sensors and, if necessary, trigger an action or an alert. This could be used in many areas, changing equipment states—such as opening or closing a valve in response to flow or pressure readings—or security tasks like triggering automated locks or zooming a surveillance camera. It can also be used in predicting failures so that a technician can be alerted to carry out a repair before a problem becomes critical.

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## Conclusions and Future Work

Node/AFB computing can enhance computing, networking, and storage services for the IoT. Consider a system that processes data in order to learn patterns. The workload can be distributed in such a way that localized patterns are identified in the node/AFB layer, while generalized patterns are only available in the cloud/fog layer. This load sharing increases the amount of computing power available to process data. The proximity of the node/AFB layer to the sensors makes it an ideal way to react to events in real-time and enhance system reliability. Currently, industries such as healthcare, manufacturing, transportation systems, oil and gas production, and utilities are turning to cloud/fog computing. Nevertheless, more and more businesses that deal with a significant amount of data are learning about the potential of using node/AFB computing, with the understanding that it cannot entirely replace cloud/fog computing, since cloud/fog is still preferred for the high-end batch processing jobs that are very common in the business world. Hence, it can be concluded that node/AFB computing and cloud/fog computing will complement each other with their advantages and disadvantages. Node computing helps cloud/fog handle the significant amount of data generated daily from the IoT. It also enables a wide range of benefits, including enhanced security, decreased bandwidth, and reduced latency. These benefits make the node/AFB an appropriate paradigm for many IoT services in various applications such as connected vehicles and smart grids. Nevertheless, node devices obviously face several security threats, much the same as those faced by traditional data centers which must be addressed. As for many researchers and practitioners, it is recommended that individual businesses adopt a hybrid model, a combination of cloud, fog, and node/AFB on-site backup systems, to maintain efficiency while mitigating security risks.

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# HVAC MECHANICAL SYSTEMS SIMULATOR

Jeff Smith, Schneider Electric; Ben Zoghi, Texas A&M University; Jay Carney, Texas A&M University; Christopher Klaus, Texas A&M University; Jason Evard, Texas A&M University

## Abstract

The purpose of this study was to design and develop a low-cost scalable mechanical control simulator capable of interfacing with industry-grade heating, ventilation, and air conditioning (HVAC) automation controllers. The system would be used for training new engineers and customers. The simulator was designed by three senior students as a part of their undergraduate capstone project. The project sponsor, Schneider Electric, is a global company that develops connected technologies and solutions to manage energy and process it in ways that are safe, reliable, efficient, and sustainable. They manufacture heating, ventilation, and air conditioning (HVAC) control systems and program their control units to interact with physical hardware in order to control variables such as temperature, pressure, humidity, light, security, etc. Due to cost and other limitations of the existing system to train new employees, they are sponsoring this project. At present, in-class training is insufficient for properly preparing engineers and customers to use their control devices in the field. There is a need for a small form-factor simulation device to interface with the controllers and simulate the response of an actual HVAC system. This can be achieved by developing a mechanical control simulator capable of interfacing with Schneider Electric's HVAC automation controllers and simulating a range of devices associated with an actual HVAC system. The system also has to be scalable in order to support more complex system simulations in the future.

## Introduction

Modern developments in the HVAC industry utilize the concept of predictive control, which uses a combination of measured data and a stochastic model (Loveday et al., 1995) to forecast the optimum control strategy and build more-efficient building energy management systems (Clarke et al., 2002). Attempts have been made to simulate zone conditions using fuzzy logic (Huang & Nelson, 1994) control and neural networks (So et al., 1995), but these methods do not take into consideration the external environment, while predicting the elements of the controlled systems. Recently, weather-responsive control systems have been designed (Ock et al., 2016) to adjust the HVAC schedules in response to the surrounding weather, but these systems are limited to certain control features of lighting, heating, and cooling energy consumption. Hence, there is a need for developing a hardware-in-the-loop (HIL) simulation that interfaces with the controllers and simulates the behavior of an actual HVAC system. This equipment will not only increase the efficiency of a building's available energy management system, but also be used to train employees in the field.

Leading HVAC companies such as Siemens, Johnson Control, Schneider Electric, etc. can integrate these simulators with their existing building management technology to provide a comprehensive all-around training course for their employees. In this paper, the authors discuss the development of a simulator capable of interfacing with building management solutions that use the Schneider Electric SmartStruxure solution.

Schneider Electric, one of the leading companies involved in the HVAC industry, develops innovative building management solutions using technology and hardware to create desirable environmental conditions inside the buildings. Currently, they have a training process to train entry-level new hires and other employees on their control units. These training methods, however, do not effectively prepare such new employees to work in the field, resulting in poorly functioning systems or even damaged equipment. Schneider Electric has identified this issue and is looking for a solution that provides a better training process for their technicians and employees. This can be resolved by developing equipment that emulates the behavior of a simple HVAC system (Trcka & Hensen, 2010), which, in combination with the existing tools used by Schneider Electric, forms a very effective and more complete in-field training course for the employees. To accomplish this goal, the team developed the HVAC simulator, a device designed to imitate the behavior of a mechanical HVAC system (Huang et al., 2006), while simultaneously interfacing and communicating with the control unit already used by Schneider Electric—the SmartStruxure solution, an integrated building management system.

## Design Implementation Strategy

The goal of the HVAC simulator was to create a platform that acts as a framework for future development of a training tool. The HVAC simulator is a proof-of-concept machine that demonstrates the technology capable of both simulating an actual HVAC system and interfacing with pre-existing hardware. (Chen & Treado, 2014; Zhou et al., 2014; Kassas, 2015). The device has an expansion port and extra resources to allow future expansion and modification. Figure 1 depicts the conceptual block diagram and Figure 2 displays the detailed HVAC mechanical controls simulator. The instructor, through a TGML (TAC Graphics Markup Language) GUI, selects variables and configurations. These settings are sent to the simulator through HTTP GET messages ("Web Services") over Ethernet (IEEE 802.3). The simulator reads the control signals from the controller (in the form of digital and analog inputs), interprets them, and changes the necessary variables inside of the simulation. The controller is programmed through a student's computer.

Real-time values from the simulation (Clarke et al., 2002) are also visible with XML (eXtensible Markup Language) formatting via remote HTTP GET messages.

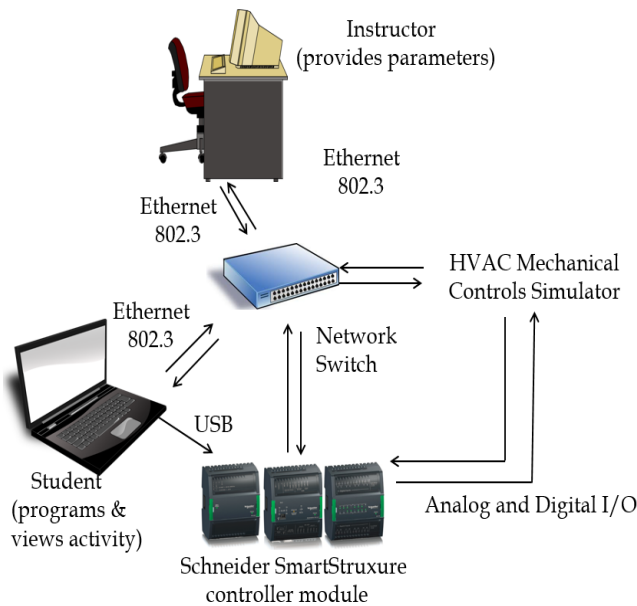


Figure 1. Conceptual block diagram.

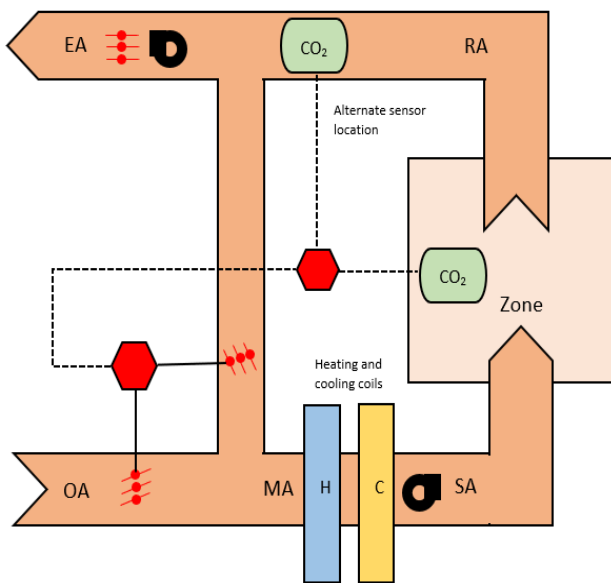


Figure 2. HVAC Mechanical controls simulator.

## System Requirements

The system has the following requirements set by the sponsor.

### Form Factor

- The HVAC simulator must meet a weight requirement of 3 lbs. or less.
- Enclosure size must meet a volume requirement of 10"x10"x4" or smaller.
- All terminals must have interfacing capability with the SmartStruxure I/O.

### Power

- The device should be placed in a fixed space near a conventional wall outlet.
- The board must be powered from a wall outlet using a DC power supply.

### Communication to Instructor

- The connection must be a wired Ethernet (IEEE 802.3) connection with addressing between an instructor and the device.
- The device must be able to receive variables and configuration data from the instructor's laptop.
- A graphical user interface (GUI) is used to pass these values through web-based XML format. This GUI is expected to operate only on the instructor's computer.

### Integrate with the Control Unit

- The simulator must interpret signals from the Schneider SmartStruxure controller:
  - 1 closed contact input (8 onboard)
  - 3 analog signal inputs (8 onboard)
- The simulator must pass signals to the Schneider SmartStruxure controller:
  - 5 thermistor outputs (12 onboard)
  - 1 Form A relay output (4 onboard)
  - 2 analog signal outputs (8 onboard)

### Simulation

- The device must interpret eight analog (0–10V) and eight closed-contact digital control signals from the Schneider Electric controller.
- It must simulate 12 thermistor outputs and have pins for eight more outputs, four Form A relays (fan status), and eight analog signals (0 – 10V, humidity conditions).
- The HVAC simulator must complete a full cycle of mechanical algorithm calculations and read/write to each I/O point no slower than once per second.
- One additional second is allowed for any cycle involving an Ethernet transmission between instructor and simulator.

## System Analysis

The final prototype had a number of areas requiring analysis and testing in order to completely understand the be-

havior of the system. The HVAC simulator had a number of standards and interfacing protocols used to communicate between devices. The PIC32 microcontroller communicates over the Ethernet Standard IEEE 802.3 to an external device on a local area network. The microcontroller’s Ethernet peripheral requires a physical chip and RJ-45 jack for communication. The PIC32 also uses the I2C, or Inter-integrated circuit, bus protocol to communicate with each of the six digital potentiometer ICs on the board. This is a 2-wire connection that uses a data and clocking pin from the microcontroller. This protocol was developed by the Philips semiconductor division (today NXP Semiconductor). The digital potentiometers allow addressing for four devices per I2C bus. Each I2C line (clock and data) is designed as an open-drain and requires pull-up resistors to 3.3 VDC.

Another interface used by the PIC32 is an SPI, or serial peripheral interface, to the ADC/DAC chip that handles all incoming and outgoing analog signals for the simulator. This SPI device requires a MISO (master-in slave-out) line, a MOSI (master-out slave-in) line, and a SCLK (clock) line. All of these are from the same microcontroller SPI module. It also utilizes three GPIO output pins (Chip Select, Load DAC, and Conversion Start), as well as one GPIO input (End of Conversion). These GPIO are used differently, depending on the clocking mode of the ADC/DAC. There are also twelve GPIO pins of the microcontroller for all required digital signals. However, the HVAC industry uses contact closures to sense and control digital points. To create this, eight of the GPIOs were designed to sense high voltage when the contact of two terminals was open, and shorted to ground when the two terminal contacts were closed. As for the required four digital outputs of the HVAC simulator, small relays were placed on the board, each being controlled by its own transistor network.

## Hardware Design

The HVAC simulator design includes all the necessary hardware for communicating analog, digital, and temperature reads and writes. Figure 3 shows the HVAC simulator’s functionality from a high level. The focal point of this diagram is the microcontroller, which is tasked with commanding each outward interface. It is shown split into four quadrants. The analog and digital outputs are connected to the SmartStruxure control unit, while the Ethernet jack is connected to the instructor’s workstation computer. The device is powered with an off-the-shelf external power supply equipped with a barrel plug. The system receives power from a power supply connected to the wall outlets. It will supply 12 VDC converted down from 120 VAC through a “wall wart” style external transformer that is then conditioned and regulated down to 5V and 3.3V in order to power all the necessary internal components such as the microcontroller and ADC/DAC chip. Figure 4 shows how the LED lights are controlled by each channel out from the power supply circuit (5V and 3.3V, respectively), three GPIO pins

of the microcontroller for debugging, and one status LED for the Ethernet chip. The “Power” LEDs are connected directly to the 5V and 3.3V channels, since each is independent of the other. In effect, these LEDs only turn on if all of the voltage levels are working. The GPIO pin LEDs are configured to show the looping time of the system and is calibrated to 1Hz. The “Ethernet Mode” LED is used to illustrate 10BaseT or 100BaseT communication. Outside of these custom board indicators, the RJ-45 jack houses two LEDs for indicating power and connectivity.

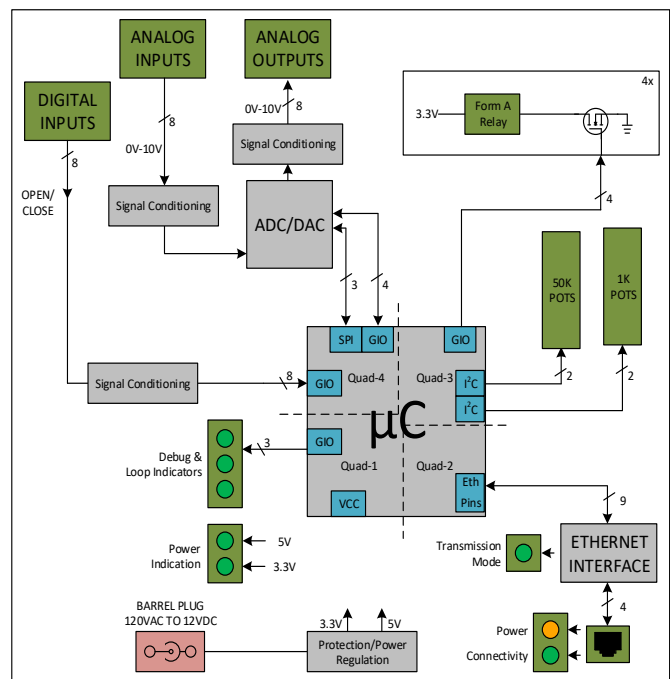


Figure 3. Functional block diagram.

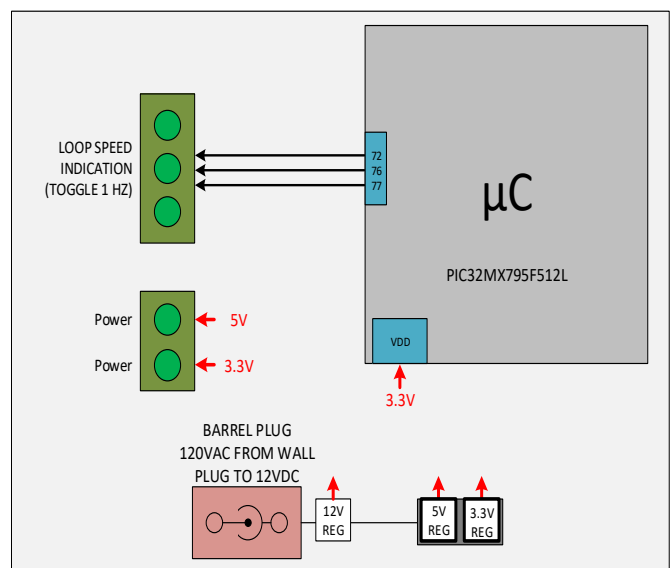


Figure 4. Voltage regulation and LEDs (Quad 1).

In order to create an RJ-45 connection (needed to connect over Ethernet and receive information from the instructor) using the built-in Ethernet capabilities of the microcontroller, an interfacing chip is needed. Figure 5 shows how the transceiver uses the Ethernet port of the microcontroller to communicate with the RJ-45 jack. This process is necessary in order to adapt the Ethernet pins on the microcontroller to work with a fully functional RJ-45 jack capable of plugging into rudimentary Ethernet cables.

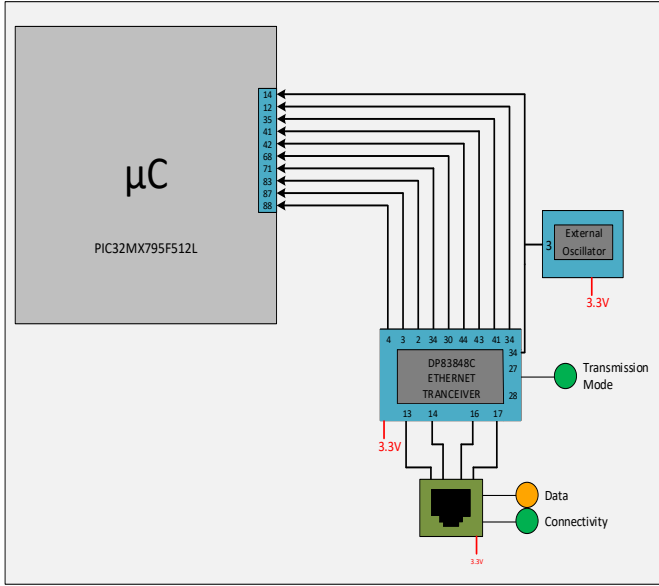


Figure 5. Ethernet (Quad 2).

Figure 5 shows how the microcontroller uses I2C ports in order to control a series of 1K $\Omega$  and 50K $\Omega$  digital potentiometers. In order to accurately simulate the behavior of the thermistor, there is a need for being able to finely adjust the resistance. Each 50K $\Omega$  potentiometer is connected in series with a 1K $\Omega$  potentiometer. This is done for very fine adjustment. Together, each pair of potentiometers simulated a thermistor. To control the relays, GIO pins and transistors are needed. The GIO pins supply a digital signal that controls the Gate pin of the transistor. Upon receiving a “high” signal, the MOSFET transistor allows a connection between the 3.3V and a Form A (single-pole, single-throw) relay. This is done to prevent the signals from the microcontroller from being directly coupled with the action of the relay. The board has accessibility to a stable 3.3V in order to power this circuit for each relay.

There are eight analog inputs for sensing 0–10V. To make them manageable for the ADC/DAC chip, they are conditioned down to 0–4.096V through a voltage divider. Figure 7 shows how the inputs are then connected to the specified pins on the ADC/DAC chip. The results of this process are sent back to the microcontroller through an SPI connection. To create eight analog outputs, the SPI port is used to communicate with the ADC/DAC chip. The outputs of the chip

are from 0–4.096V and are amplified to 0–10V using an op-amp circuit. There are also eight digital inputs sensed by a contact closure between a signal and ground terminal for each channel.

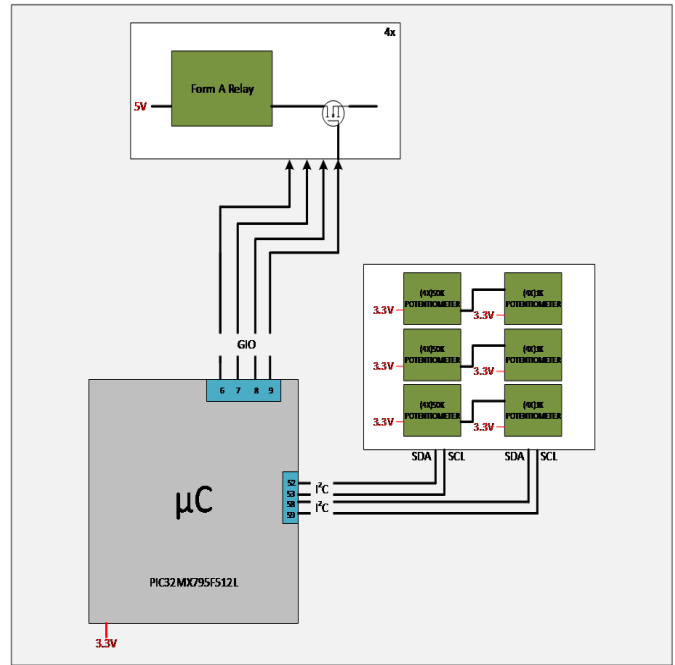


Figure 6. Potentiometers and relays (Quad 3).

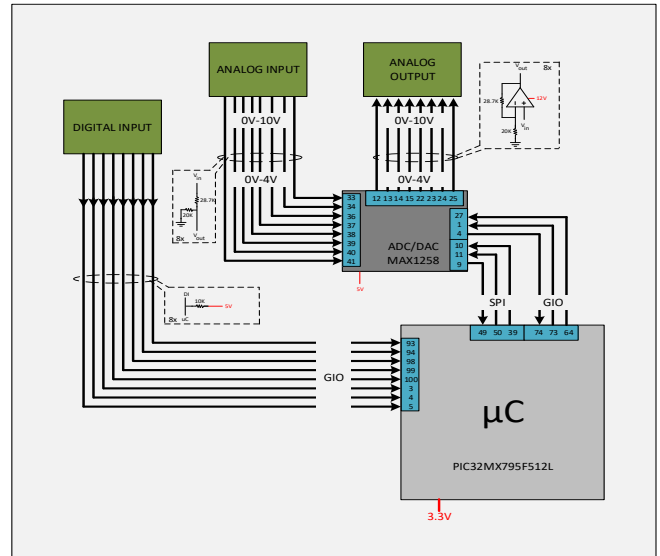


Figure 7. Analog circuit and digital inputs (Quad 4).

Each terminal and port of the HVAC simulator is controlled by the PIC32MX795F512L microcontroller, which handles the control of the entire circuit, hosts all Ethernet communications, and reads from or writes to the board’s respective analog, digital, and resistive interface.

The communications protocols used in this design included two I2C busses and one SPI. Ethernet and GPIO were also utilized from the PIC32. The schematic view of this microcontroller displays each outgoing physical connection of the design. It further illustrates the implementation of three green LEDs for the purposes of debugging as well as proper power decoupling and grounding. The PIC product line of microcontrollers utilizes the 6-pin “Pickit” header configuration (see Figure 8) for programming and debugging.

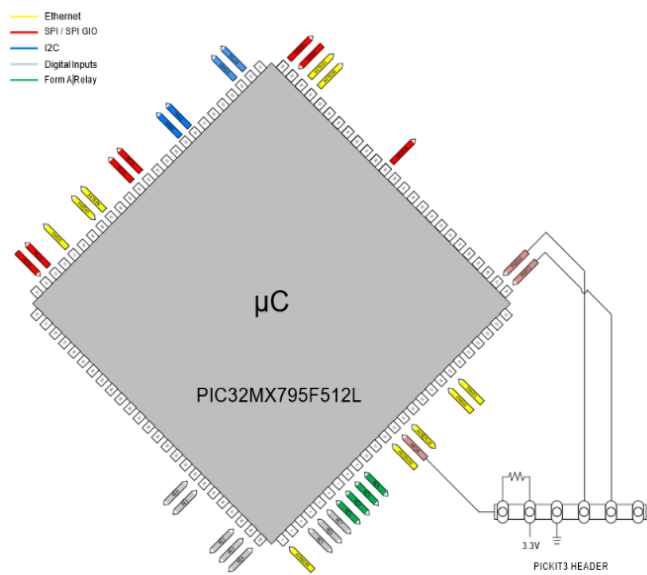


Figure 8. Microcontroller graphic.

Figure 9 shows the final PCB layout. This design uses a 4-layer board with a top component layer, a power layer, a ground layer, and a bottom trace layer. The parts were all placed on the top layer in order to save foreseen manufacturing costs. The final PCB layout measures 5.05"x 4". A custom enclosure was designed to enhance the ruggedness and durability of such a small device. In addition to protecting the internal components of the board, this enclosure gives a brand to the simulator and makes it attractive. The enclosure also serves as a fitting for each outgoing wire terminal and port used for Ethernet and power. Designed for use in an active electrical environment, this is crucial to keeping excess wires and tools away from live circuitry.

The three main functions driving the design of the enclosure included safety, durability, and branding. First, it separates the outside world from internal board voltage and current. This keeps the components safe from stray wiring, as well as protects the trainee using the device. Second, it reduces the chances of physical damage to the board if the device is dropped. Finally, the customer’s logo present on the enclosure gives them the exclusive ownership to the device. Figures 10 and 11 display the custom top and bottom enclosures for the simulator.



Figure 9. Full printed circuit board.



Figure 10. Top enclosure.

## Software Design Flowchart

In the HVAC simulator software design, the instructor uses the GET request method to send the system environment and load parameters. The GET method passes data through an appended portion that is placed at a chosen IP address. This method can supply any number of variables that will be needed for future expansion by Schneider Electric.

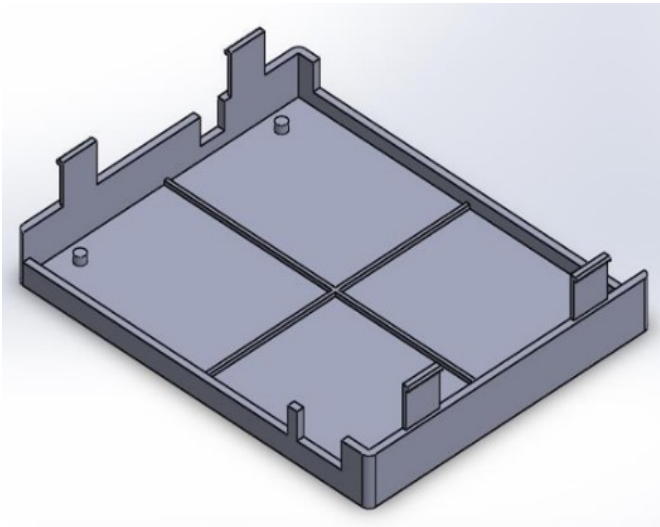


Figure 11. Bottom enclosure.

Figure 12 shows the main function of the embedded code of the HVAC simulator. When the board is powered, the simulator is idle and waits for an Ethernet transmission. Once this transmission is received, an algorithm is calculated from the initially passed values. It will then begin the simulation of the various I/O points, measuring appropriate points as needed for calculation. It will complete its loop and return to an Ethernet checker to ensure no loads have been changed that might affect calculations. This loop continues indefinitely until the instructor sends a GET request to the simulator to halt simulation. Regardless of this request, Ethernet continues to poll as long as power is supplied to the board.

The Initialize function is run as soon as the device is powered. It initializes the SPI and GIO pins necessary to control the ADC/DAC. Then it sends data bytes to clear the memory of the ADC/DAC. It sets up the DIO inputs and outputs and enables the I2C buses. The Ethernet function portion sets up the Ethernet functionality of the board and all its necessary components. The program keeps running the Ethernet functions until a GET request has been sent. At this point, all variables from the URL string are captured. These variables are used in the equations that predict the environment. Figure 13 shows the ADC/DAC, room temperature, and humidity functions. The ADC/DAC function first clears the memory of the ADC/DAC chip. The memory is then filled with a fresh set of analog readings. This is done by setting the CNVST pin low for a very brief time before pulling it back high. After waiting for the ADC/DAC to complete its conversions, the program sends 32 bytes of data and captures the ADC/DAC's 8-bit responses, saving each one of them into an array. After the data bytes are captured, every two consecutive bytes are converted into a single 12-bit voltage reading (keeping in mind that the four most-significant bits are always zeros) with calibration unique to each channel.

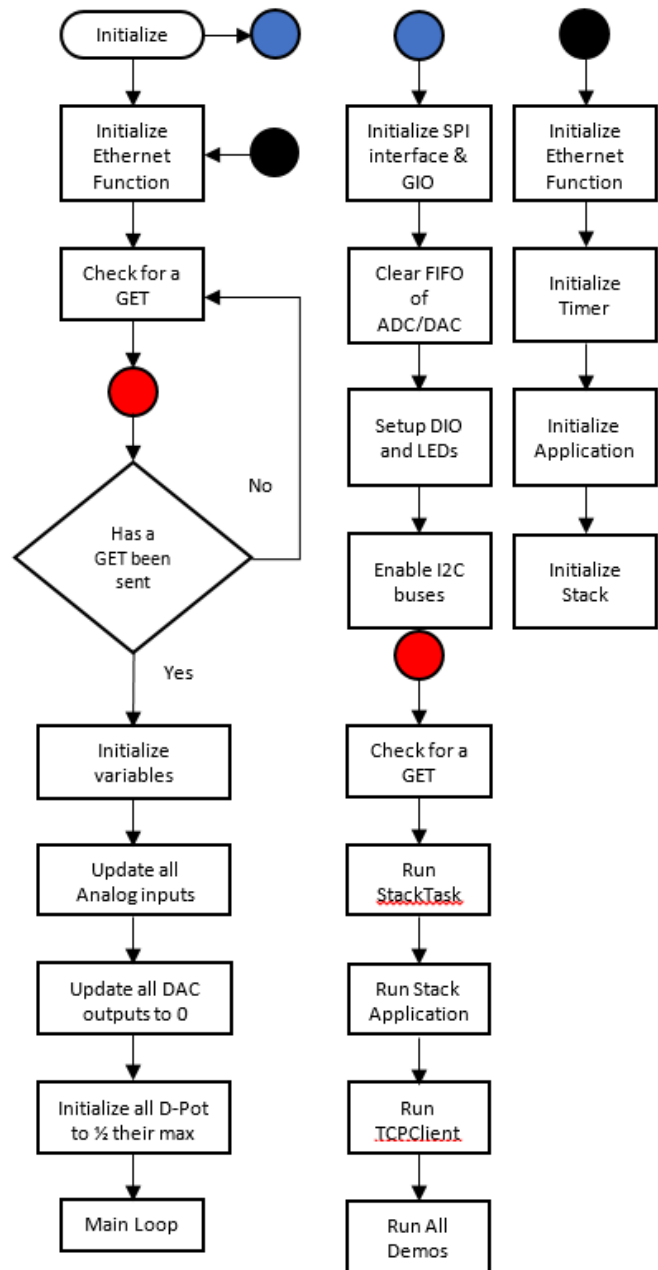


Figure 12. Main, Initialize and Ethernet functions.

To update the status of the digital inputs, which are on Port E of the microcontroller, a command is issued that returns all eight status bits of the port. Due to the nature of the circuit, these pins read a logic "HIGH" when the relay on the SmartStruxure is not closed. Therefore, the value must be inverted to show the status of the SmartStruxure relays. After the digital inputs are read, the simulator can determine if the fan is on or off. The output bit of the fan status is set equal to the bit that corresponds to the fan command from the SmartStruxure.

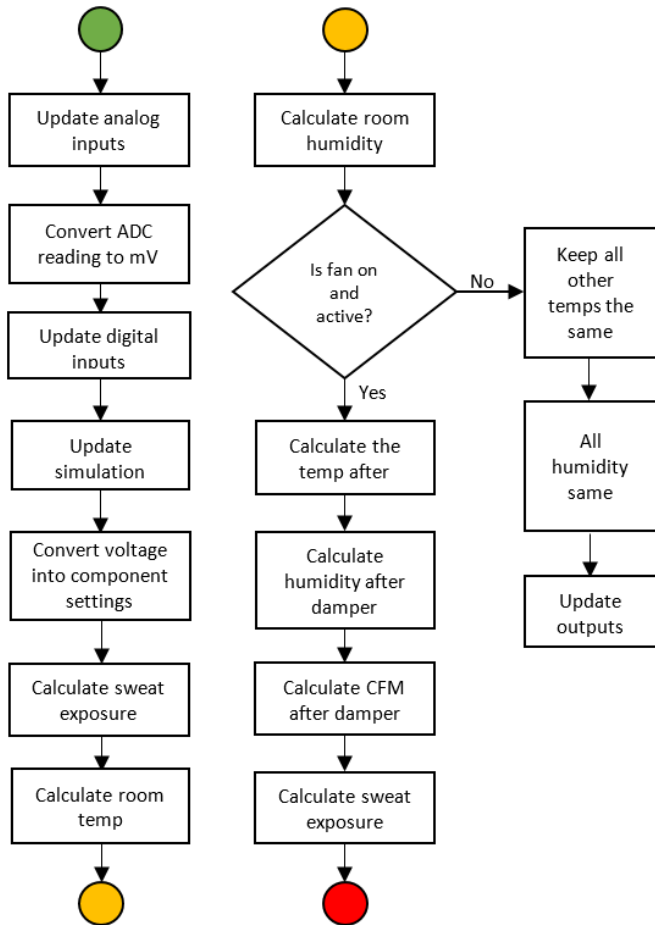


Figure 13. ADC/DAC, room temperature, and humidity functions.

The position of the heating coil valve and the cooling coil valve are set by analyzing the analog inputs and the initial GET message. At first, the GPM of the coils is set to the analog voltage (in mV) divided by 1000 times the maximum GPM. However, if the GET message indicates that a specific piece of hardware does not exist in the system, the effects of the component are set to zero (meaning the piece is effectively removed from the simulation). The sweat exposure is then calculated by taking into account the number of people in the room. The room temperature is calculated to ensure that the equations get their variables in the correct units. After the change in temperature after one second is calculated, it is added to the current temperature. The future humidity in one hour is calculated with a mechanical equation, the difference is calculated, divided by 3600 (which converts it into the change in one second), and then added to the current value. The simulator checks the fan status to see if it is on and calculates all other temperatures as scheduled when the fan status is on. If it is off, all other temperatures are kept the same. The next temperature and humidity values are calculated with mechanical equations as well as other aspects of the simulation.

Each temperature must be translated into its corresponding resistance. This is done by isolating the two points in the temperature-to-resistance array and performing a linear interpolation function between those two closest points. Once the resistance is calculated, 165 is subtracted from it (as it is the starting resistance). This is performed five times (once for each temperature to be outputted). The course and fine 8-bit values are calculated by finding the number of steps required to reach the desired resistance value (198Ω per step for the course adjustment and 4Ω per step for the fine). Each desired analog output is converted into two bytes. The four most-significant bits of the first byte are set to the address of the desired DAC channel, the CS pin is pulled low, the data are sent, and the CS is pulled back high. This process repeats until all eight channels have been updated. After this, the byte 0xEF is written to command the ADC/DAC to update all of its outputs. One potentiometer IC is updated at a time. It specifies which I2C bus the target is on, the address of the target, and the four data bytes to be written. To perform an I2C communication, the program must execute starting commands, transmitting commands, and stopping commands. Figure 14 depicts the mechanical and resistance calculations for the simulation.

## Test Results

Throughout the functional requirement verification process, a series of tests were conducted to check if the performance specifications had been met. Table 1 illustrates each test and the corresponding functional requirement being assessed.

Table 1. Test matrix.

Test Name	Functional Requirement	Form Factor	Instructor Interaction	SmartStruxure Interface	Real Time Simulation	120VAC/12VDC	Protocol Literacy	Output Accuracy
Weigh & Measure		X						
Ethernet Test			X					
I/O Connection Test				X				
Speed Test					X			
Power Test						X		
SmartStruxure I/OFormat				X			X	
Resolution Test								X
Simulation System Test			X	X	X		X	



The resolution test verified the ability of the HVAC simulator to mimic the behavior of a real thermistor, as per the standards of Schneider Electric, while the speed test verified its ability to complete a full cycle of mechanical algorithm calculations and read/write to each I/O point in a prescribed amount of time. The power test verified the HVAC simulator's power regulation supplied by a wall plug and the I/O connection test verified that the HVAC simulator had pins for future expansion (pins for 12 thermistor outputs, 8 analog inputs, 8 analog outputs, 8 digital inputs, and 4 digital outputs). The weigh and measure test verified various aspects of the board and enclosure for portability and storage, while the SmartStruxure I/O format test checked the compatibility of the HVAC simulator with the SmartStruxure I/O. In addition to these tests, a system simulation test was carried out to verify the communication between the different aspects of the HVAC simulator and SmartStruxure.

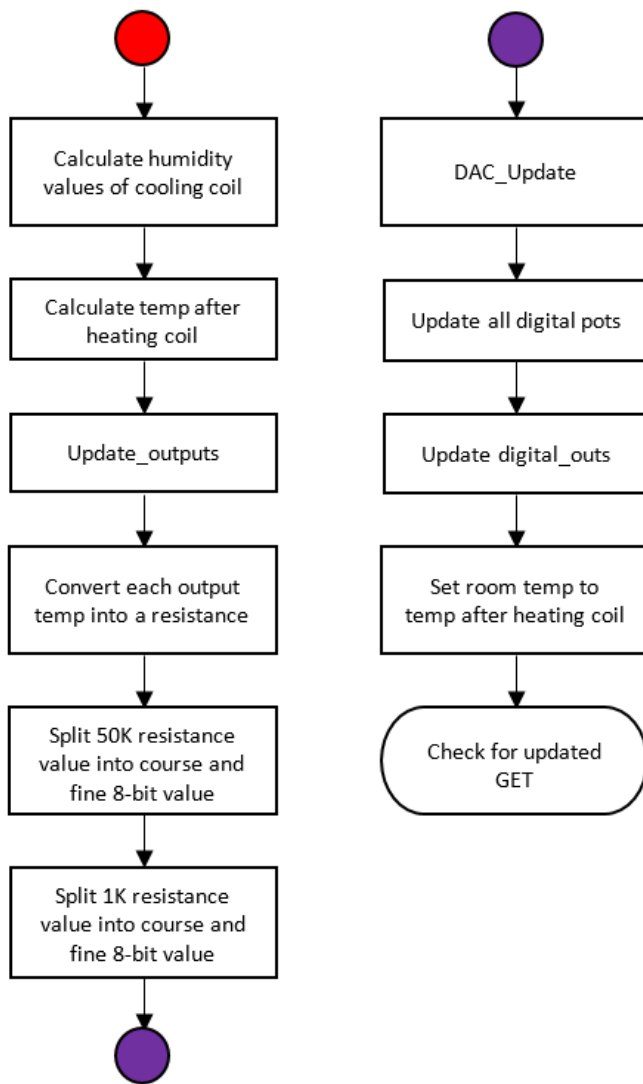


Figure 14. Mechanical and resistance calculations.

## Cost

Costs for development of the HVAC simulator included the cost for PCB revisions, parts, development kits, testing materials, etc. A total of \$1761.38 was calculated for all expenses for the development of the HVAC simulator. Table 2 shows the most expensive components of the HVAC simulator.

Table 2. Most expensive part list.

Description	QTY as of 4/15/2014	Single Part Price	QTY per Board	Cost	Board Label
Microcontroller	532	\$11.87	1	\$11.87	U1
Ethernet Physical Chip	3,798	\$5.42	1	\$5.42	U10
Ethernet Oscillator	1,069	\$2.04	1	\$2.04	QG2
50K Digital Potentiometer	0	\$5.81	3	\$17.43	U3,U5,U14
1K Digital Potentiometer	57	\$5.81	3	\$17.43	U2,U4,U11
ADC/DAC	184	\$23.07	1	\$23.07	U7
Power Supply	182	\$10.45	1	\$10.45	U9
Form A Relays	7,132	\$1.05	4	\$4.20	K5, K6, K7, K8
Op Amp	1,116	\$2.09	2	\$4.18	U6,U8
12VDC Wall Power Adapter	2,058	\$15.87	1	\$15.87	N/A

## Conclusions

As designed, the HVAC simulator is a fully functional device that meets all performance specifications listed by Schneider Electric. The main focus of the team was to provide a high-quality prototype, while not focusing entirely on reducing costs, which led the team to create the most efficient and robust simulator system. The value of the HVAC simulator's future expandability will warrant the upfront cost per board, which in turn will bring the board to fruition with Schneider's intended market.

## Acknowledgements

The project was accomplished by three senior students in the Electronic Systems Engineering Technology program, Jay Carney, Christopher Klaus, and Jason Evard as their capstone project. Many thanks to the Schneider Electric team lead by Jeff Morton for their technical and financial support of this project, and Jay Porter and Michael Johnson for helping students with daily supervision.

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## Biographies

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# MINI REMOTELY OPERATED VEHICLE

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## Abstract

Inspecting ship hulls, searching for items dropped in murky water, and exploration at depth or in contaminated water can be difficult, expensive, and hazardous to a diver. Remotely operated vehicles (ROVs) are traditionally meant for industrial functions, such as surveillance of pipeline networks, offshore platforms, and rail systems. Currently, however, ROVs are utilized for still other applications, including scientific functions and search-and-rescue operations. One of the most common applications is ocean exploration and aquarium development, where they establish a viable link between scientific voyage and live presentations through the Web. The oldest utilization of ROVs is in the Royal Navy, where they were deployed for recovering thrill torpedoes.

In the 1960s, the U.S. Navy designed the cable-controlled division between the center of buoyancy and center of gravity (CoG) to facilitate stability and operability under water. The intent of this project was to design and build a submersible ROV that would allow an operator to remain safely on shore, out of harm's way, as well as eliminate the cost and risk associated with having a diver in the water. This ROV was designed initially using hand sketches. Once an agreed-upon shape had been established from these sketches, a CAD model was developed using Autodesk Inventor to obtain a clearer picture of the overall design. Once these models were completed, the materials for the ROV were selected, formed, and assembled in order to create the ROV. In addition, a control box was created to house and transport the ROV and its components. Once these steps were completed, the ROV was tested to ensure that it met the required capabilities set by the team. In this paper, the authors present the design of a submersible vehicle that can be remotely operated for inspecting the hull of a ship.

## Introduction

Remotely operated vehicles (ROVs) are a class of manually operated or automated robots utilized in the maritime environment. Commercial ROVs are extremely maneuverable and operated by skilled operators aboard ships and other platforms. They are linked to the operator aboard ships and other vessels through cables that transmit electrical signals. The ROVs are traditionally equipped with cameras and lighting equipment to increase their usability. Other equipment that might be integrated with the ROVs includes magnetometers, sonar, graspers, water sampling devices, temperature sensors, light penetration devices, and water clarity measuring devices (Christ & Wernli, 2013).

ROVs are traditionally meant for industrial functions such as surveillance of pipeline networks, offshore platforms, and rail systems. However, ROVs are currently used for numerous other applications, including scientific functions and search-and-rescue operations. One of the most common applications is ocean exploration and aquarium development, where they establish a viable link between scientific voyages and live presentations through the Web. The oldest utilization of ROVs was in the Royal Navy, where they were deployed for recovering thrill torpedoes. In the 1960s, the U.S. Navy designed the cable-controlled division between the center of buoyancy and CoG to facilitate stability and operability under water. The reason for selecting an ROV for this design project stemmed directly from one of the team member's background working in the U.S. Navy and on offshore oil platforms. As a result, there was direct exposure to commercial and defense ROVs. Additionally, the same team member volunteered at Granby High School to help a group of 10-15 girls design and build ROVs for use in the Marine Advanced Technology Education (MATE) competition.

Some ROVs, such as the AQUA EXPLORER 2, are used to autonomously track underwater cables and measure their burial depth. This kind of vehicle can communicate with a mother vessel through an acoustic link. Only high-level commands are sent to the vehicle, and most of the control is done by an on-board computer. The vehicle can locate and track cables by detecting the magnetic field generated by the circuit current (Asakawa et al., 2002). Others, such as ROMEO, are specifically designed to work in harsh environments (Caccia et al., 2000). ROVs can also be used for surveying, inspection, and research purposes (Christ & Wernli, 2013).

The main purpose of the ROV designed during this project was to provide a way to eliminate the risk and costs associated with sending a person into potentially dangerous environments. ROVs can operate in toxic or irradiated water, fit into small areas, and operate at depths far too dangerous for a diver (Benthic, 2014). ROVs have a longer operating endurance than a diver has. As long as power is applied and an operator is present, a mission or recreational dive can continue. During this study on ROVs, a number of industry catalogs, hobby forums, textbooks, and videos were studied. While not every source has been cited in this paper, the research information helped guide considerations about the design and technology selection. The main objective of this project was to design an ROV capable of traveling up to 30 feet underwater, fully submerged, and transmit video back to a monitor located in a control box on shore. The main constraint was that the design had to be large enough in order to house the electronic components necessary for op-

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eration, have enough external space for a minimum of three motors, and be made from commercially available material. Several designs were considered before the final design was chosen.

## Propulsion Considerations

The main purpose of propulsion was to provide a desired motion to the ROV. The chosen voltage was 12 VDC. The following five motors were considered for this ROV:

1. A rim-driven thruster is the most reliable thruster available to date. It integrates an electric motor that engulfs the propeller to give a powerful thrust that provides a high torque. A properly designed rim-driver is comprised of a single moving element, the propeller that rotates between the rotor and the outer winding. The configuration provides a simplified and inexpensive mounting of the rim bearings. Some of the benefits of this design are minimal noise emissions, compact size, and no need for a center shaft. Some of the problems of using this specific motor are high energy costs and inefficiency due to friction losses.
2. A Voith Schneider propeller (VSP) is a specialized marine system for harbor tugs. The system is highly flexible and has the capability to alter the direction of the thrust. The capability allows deployment in ferries and tugs. The VSP consists of a circular plate that rotates around a vertical axis within circular arrays of vertical blades that protrude at the bottom of the vessel. Individual blades rotate around a vertical axis, facilitated by the internal gear that changes the angle of action of the blades in unison with the rotation of the blade. Each blade gives thrust in any direction, the same way a cyclic helicopter does (Hendershot & Miller, 1994). Cyclorotors can quickly vector thrust by altering the pattern of blade pitching. Benefits include a high degree of control, low noise emission, power, and efficiency. Some of the problems of using this specific motor are support spokes, causing added drag, cost, and poor hydrodynamics.
3. The brushless motor is made up of a rotor with multiple stationary magnets producing a DC magnetic field that interacts with the currents flowing through the stator core of thin and stacked laminations to generate torque between the motor and the stator. The rotation mechanism of the rotor necessitates a changing magnitude and polarity of the stator currents in a manner that preserves the torque and maximizes the electrical-to-mechanical energy conversion. Notably, the device that reigns over the current control is the inverter. Without the inverter, the brushless motor is inefficient (Hendershot & Miller, 1994). Two brushless motors types were purchased for use in the ROV.
4. An RC aircraft motor is a low-cost option most commonly used for quadcopters, often referred to as a “drone,” and requires modification to be used in a marine environment. Testing showed that this motor was able to deliver 0.8 lbf of thrust. Ultimately, this option was abandoned, due to the additional time required to prepare these motors for water, additional testing with different propeller sizes and pitch angles, and designing a shroud to protect the motor. The main benefit was very low cost, but one of the problems of using this specific motor was the additional engineering required to make it suitable for a water environment.
5. The T100 Thruster from Blue Robotics was designed specifically to operate in a marine environment (T100 Thruster Documentation, 2017). This motor is capable of operating in the ocean and delivering 5lb of thrust. It may be used to drive small boats, modified surfboards, and other personal propulsion devices. It is commonly used in robotics education and competition settings, such as the Marine Advanced Technology Education (MATE) competition. Benefits of this design include its design for ROV and saltwater environment use, its having a plug-and-play configuration, and incorporating a KORT nozzle as its shroud for added efficiency. Some of the problems associated with this specific motor include its cost and its noticeable operating delay.

## Power System Considerations

The main objective of the power system was to develop an adequate power supply to sustain all components of the ROV as well as provide power to the internal monitor contained inside the control box or inside the ROV (Wang et al., 2012). The main design considerations were to select a properly sized battery that could also be contained inside a control box or inside the ROV, deliver 12 VDC for at least 20 minutes, and be easily recharged. The second objective was to select a power supply wire large enough to carry the required current over a distance of 30 feet but not be oversized. The third objective was to ensure the placement of voltage regulators to reduce the risk of voltage drops at any point in the system. The most common batteries that are used in ROVs are lithium polymer, NiMh, and gel cells. There were two main power source location options were considered for the project.

Obtaining power from the surface is a very safe, easy, and common option that usually yields the best results if properly designed. The drawback is that the weight of the power wiring usually does not help the ROV in terms of neutral buoyancy and can in some cases reduce the flexibility of the tether. This option allows for the most sustained power, but because the power supply on the surface is effectively unlimited, the operating time of the ROV is potentially limitless. The amount of power supplied from the surface is greater as well, because there is no limitation on space or

weight, so more powerful motors, lights, and other accessories can be used, while still maintaining the size of the ROV.

Internal power is a very good option as well, but may be much more dangerous. There are two ways to generate internal power: small gel cells that are sealed lead-acid 12V batteries, and lithium polymer battery packs. Gel cells are not dangerous, but there is a limit to how much power can be used at once. For instance, a 6Ah battery cannot have 12A of current pulled from it for sustained periods of time, because it is not designed to have this high power rating. Lithium polymer battery packs, on the other hand, can handle many times their capacity in current; but if lithium is exposed to water, it reacts vigorously and produces hydrogen gas, which can cause an explosion if there is a spark or other source of flame. Voltage sources can be switching power supplies or 12V batteries. Switching power supplies can oftentimes be very costly, are generally not very portable, and typically require a connection to 110 VAC power. They can supply more than 1000W of power on a typical 15A single-phase household circuit, which would be about 20A at 48V. The other benefit of these power supplies is that they have been in use for a long time, so even power supplies that are a few years old are still a viable option for powering an ROV. A single 12V battery was the first option; the second was to use multiple batteries paired in either series or parallel. These are very common and range in capacity from roughly 6Ah up to 100+ Ah marine batteries, though of course prices vary greatly. The project team selected a 31 Ah, 12V battery.

The main objective of the motor control circuit (see Figure 1) was to design or provide an existing method for propulsion of the ROV that was simple, inexpensive, and easy to troubleshoot and repair. The component that allows the circuit card to drive the motors is an electronic speed controller (ESC). This circuit transforms the duty cycle of the pulse wave modulation (PWM) output from the ServoShock

2 card into a signal transmitted over three wires to rotate the DC motor. The specific ESC used was one from Blue Robotics, simply because the company has prefaced its ESCs for forward and reverse drive of DC motors. Some of the main benefits of this ESC are that it is simple and easy to use, offers plug-and-play components, and no programming is required if purchased pre-flashed.

## Microcontroller

The circuit card serves as the “brains” of the ROV. It converts commands given by the operator into a format that is understood by the ESCs, motors, and any additional outputs. Two technologies were considered for this role: the Arduino and ServoShock 2. Arduino is an open-source and simplified electronic platform encompassing both software and hardware. Arduino is a microcontroller company producing kits for designing and developing digital devices and interactive applications that can manipulate devices in the physical world. The software for implementing Arduino projects is the Arduino IDE that simplifies coding as well as the implementation of the Windows, Mac OS, or Linux board environments (Badamasi, 2014). It is possible to connect two Arduinos in order to establish communication between the two. This kind of communication is critical for numerous projects, including one Arduino running motors while the other senses the surrounding environment.

The appropriate configuration would be to use I2C and serial communication (Gibb, 2010). There are two types of serial communication: RX and TX port communication. I2C (inter-integrated circuit) is a protocol for communicating between the components and the motherboard in embedded electronics and cameras. Embedded electronics concerns the interlinking of circuits to generate a symbiotic system with a common protocol and information-swapping capability. The communication protocols, though varied, have a defined data exchange, either parallel or series, each having its own advantages and disadvantages. The parallel interface trans-

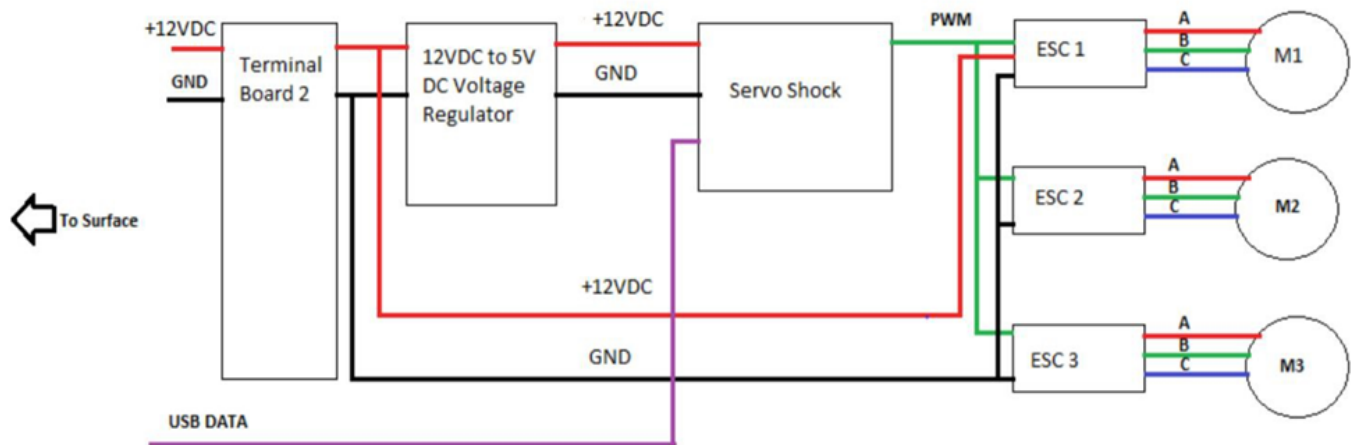


Figure 1. Block diagram of motor control circuit.

fers numerous bits at the same time and requires buses of data, usually within eight-, sixteen-, or thirty-two wire bundles. Data are characteristically transferred in huge but crashing waves of 1s and 0s.

In serial configuration, the data are usually transferred in a stream, bitwise at a time. Mainly, the interfaces employ a single wire but not more than four for data transmission. The benefits of parallel communication include speed, clarity, and ease of implementation. The disadvantage is the requirement for more input-output data channels. In moving data from one Arduino to the other, the limitation usually emerges in the number of I/O lines of the microprocessor. Therefore, serial communication is preferred for robust bin numbers rather than potential speed. For this current project, the Arduino was the first choice, due to prior experience with the card. Ultimately, though, the Arduino solution was abandoned, due to underestimating the degree of difficulty and the amount of time spent in attempting to program the card to work with PlayStation 1, 3, or 4 controllers. It is estimated that roughly 75% to 80% of the code had been worked out before switching to a simpler solution. Some of the main benefits of choosing this option were a large degree of capability, large open-source code community, low cost, and the option of multiple Arduinos working together in a master/slave configuration via I2C. The main problems with this configuration are that programming can be difficult and time consuming, and that lower-cost generic cards may not be as robust as genuine Arduino cards.

The ServoShock 2 card is a preprogrammed circuit card designed specifically for converting output commands from the Sony Dualshock 4 controller into PWM signals for use with ESCs or servos, as well as providing a digital output command for each pushbutton (Servo, n.d.). As of the time of this writing, the ServoShock 2 card is in a fundraising campaign via [www.kickstarter.co](http://www.kickstarter.co). The group was able to acquire the cards directly from the designer and bypass the fundraising efforts. The card has a 10-meter wireless range via a Bluetooth connection, 18 digital outputs, and 12 servo outputs. The card can also use an SPI bus data and control interface as well as interact with the Arduino to expand its capability. The circuit receives a 12V input to drive the card. Onboard, it has a regulator to drop the voltage down to 3.3V in order to drive the digital outputs on the side of the card and to 5V for the PWM outputs used by the ESCs. Power draw during testing of the card power at 12V was 0.418A. Some of the main benefits of this card are that it is already programmed for many outputs and has a user-modifiable program, flexible voltage inputs, and the ability to work with Arduino cards for expanded capability. The main disadvantage is that it is more expensive than the Arduino board. While testing the motors, two ServoShock cards were damaged. Both cards failed due to overheating of the onboard 5V regulator. This was caused by not having adequate circuit protection. Installing a 12 VDC voltage regulator before the ServoShock 2 card eliminated this problem.

## Lighting Subsystem

The main objective of the lighting system was to provide an external light system and control drive circuit to be waterproof and work with the 30-foot ROV tether. However, while the potential of the ROV is to reach that depth, all local areas for testing and planned operating areas are less than 30 feet. The research team considered two options: making a waterproof light and buying one off the shelf. The team chose to make a circuit with an LED and a resistor housed within a waterproof body. However, the right LEDs need special heat-shedding considerations that increase costs; thus, the DIY option was eliminated. This option was easy to build, but bright LEDs produced large amounts of heat that needed heat sinks, which again increased costs. Several off-the-shelf options were considered, from modifying a low-cost dive light to be driven off of a wired 12V line instead of batteries, to buying wired waterproof lights. Figure 2 shows the option selected for the ROV was an aftermarket LED designed as a daytime running light for use on automobiles and purchased from [theretrofitsource.com](http://theretrofitsource.com).



Figure 2. Morimoto Mini ModPod aftermarket LED (side and front views).

Discussions with the light manufacturer indicated that the light was not tested for IP6x rating. Figure 3 shows how the light can be switched between low- (300 lumen) and high-intensity (600 lumen) modes, allowing the operator to increase and decrease light as needed to ensure good video.

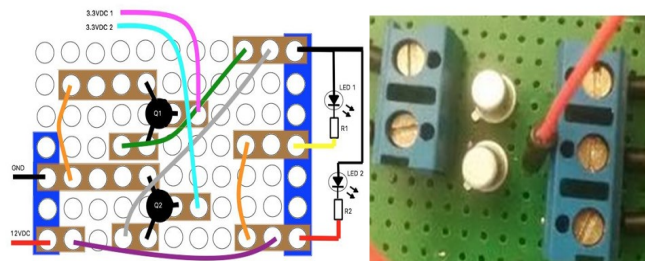


Figure 3. LED drive schematic and wiring layout sketch.

## Camera Subsystem

The main objective of the camera system (see Figure 4) was to provide a means of viewing objects underwater, while being compact and waterproof.



a) Camera.



b) Camera in PVC housing.



c) Potting material applied.



d) Acrylic lens in place with JB weld.

Figure 4. Parts of the camera assembly.

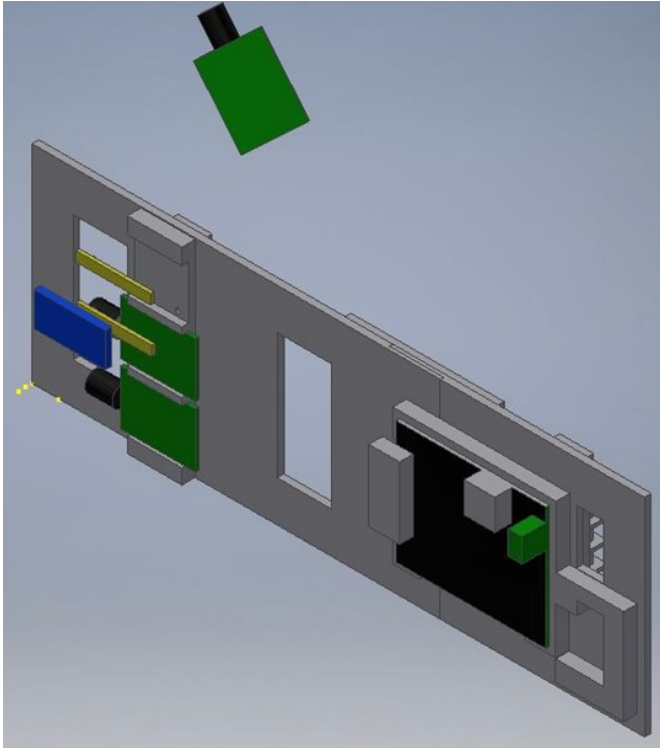
Considerations for the camera system were a low-cost bulk electronics option and an off-the-shelf camera such as a GoPro or a remote pilot view (RPV) camera system, also referred to as a first-person view (FPV), typically found on quadcopters. The RPV/FPV systems required extensive design work for waterproofing and modification from wireless radio transmission to a configuration that could transmit over a CAT5 or USB cable. The off-the-shelf cameras require less modification but are still prohibitively expensive. The camera system was selected based on simplicity and cost. It is a rear-view camera used in automotive applications. To view the video, the camera was mated to a similar low-cost bulk electronics monitor. These components were designed to be hard-wired via composite audio/video cables. This configuration proved to be suitable to the ROV application. The camera was housed internally to a 1" schedule 40 PVC tube. Waterproofing was provided by filling the rear and front with epoxy potting. Figure 4 shows how the front was also capped with a 1" clear acrylic lens secured in place with a JB weld.

## Electronics Mounting Platform

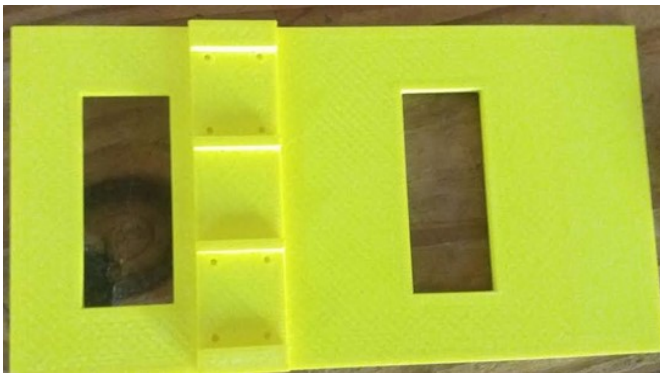
The main objective for designing an electronics mounting platform was to house all of the electronic hardware inside the ROV (Wadoo & Kachroo, 2011). The overall size was limited to the dimensions of the 4"-diameter PVC tube. Two platform materials were considered. The first option was to mount the electronics on the remaining HDPE that was left over from the ROV body to save money. The main problem of this design choice was that the standoffs would need to be purchased to allow the circuit cards to be mounted such that they would provide ample room for wires and components mounted on the bottom. The other option was to 3D print a custom platform so that final assembly would be easy, as all mounting positions would have been pre-measured and custom-formed for each component. To facilitate the custom configuration of the mounting plate, each component needed to be measured and rendered in CAD software. While testing the electronics, two ESCs and two ServoShock 2 cards were damaged at the same time. The vendor had changed its ESC design into a more compact form factor. As a result, the platform needed to be designed to be able to hold either the small (modeled in blue) or large (modeled in green) ESCs (see Figure 5). To accommodate the two sizes, spacers were made to fit into the gaps so that the ESC would be stationary. A 3D printer unable to print full size added complexity by having to print the part in two pieces.

## Control Box

The main objective of a control box was to design and create a box that would fully contain all components in the ROV (Whitcomb, 2000), establish positions for each of the dedicated systems, and could open at any time for deployment.



a) CAD design.



b) 3D-printed electronic platform.

Figure 5. Custom platform.

The team wired the internal components of the control box to allow the ROV to simply be plugged in, turned on, and sent on its way. The control box selection included a few principal ideas, the first being that the box needed to be large enough to contain the entire system, including the ROV itself. The second principle was that the box should have a latched lid to protect the internal components from weather damage (see Figure 6). The final principle was that the box should be portable to allow for easy travel to and from applicable sites. The inside of the box would house the monitor on the attached lid, a position for a removable battery, and a connection box to allow for easy connection of

the tether cable to the ROV. Additionally, enough room must be left for the ROV itself. This design included two options: custom built or commercially available. Building a custom box would entail full construction from wood with the need for finishing and waterproofing. Commercially, there were several options available from different companies that would be immediately ready for final assembly. Due to time constraints and the scope of the overall project, the commercial Pelican 1640 case was chosen to fit the design needs (see Figure 7). Figure 8 shows the ROV CAD design, while Figure 9 shows one of the assembly steps and an ROV final design.

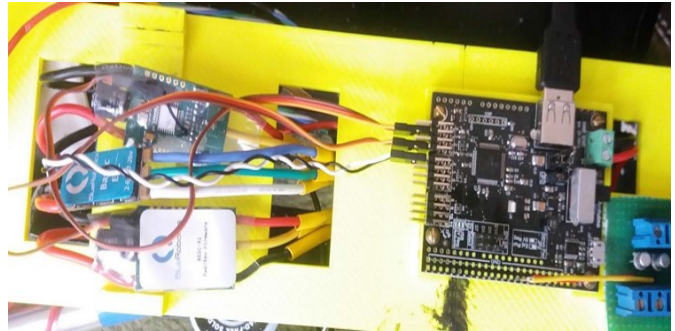


Figure 6. Assembled electronics platform.

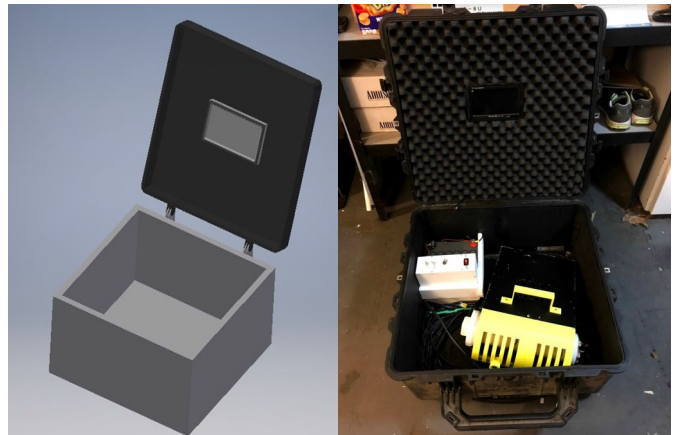


Figure 7. Electronics mounting platform and control box.

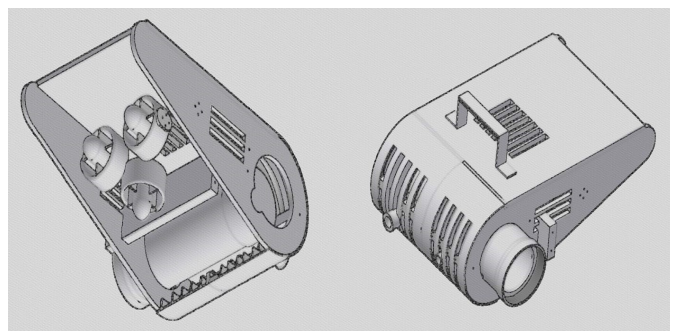


Figure 8. Isometric view of bottom-rear.





a) ROV housing.



b) PVC cap with cable penetrators and completed ROV.

Figure 9. ROV final design.

## Conclusions

The ROV presented in this paper is small, fully contained, and capable of transmitting video. It is a lightweight, hydrodynamic design to allow for enhanced maneuverability. The ROV for this project was designed during a senior project capstone course in Mechanical Engineering Technology at Old Dominion University. Students designed and fabricated an ROV that included a control box capable of carrying the ROV, receiving the video, and providing power. This ROV was capable of reaching up to 30 feet. The control board was a ServoShock card containing 18 digital outputs and 12 servo outputs, allowing for easy expansion of ROV capability.

## Acknowledgments

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## Biographies

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# WEARABLE HEADSET AND RFID TECHNOLOGY FOR SMART INVENTORY MANAGEMENT

Ben Zoghi, Texas A&M University

## Abstract

The provision of accurate, timely, and understandable information has the potential to revolutionize disaster management. The World Disasters Report (McClean, 2010) states that, over the last decade, more than 7000 disasters occurred worldwide, resulting in 1.1 million deaths, the displacement or disablement of 2.5 million people, and economic losses totaling nearly \$1 trillion. The Texas Task Force 1 (TX-TF1) is a Federal Emergency Management Agency (FEMA) Urban Search and Rescue Task Force, one of 28 teams that form the FEMA National Urban Search and Rescue System, and, as such, it is in rotation for deployment to national disasters and incidents of national significance (FEMA, 2006). TX-TF1 has a large warehouse with several shipping containers and expensive equipment. Before and after the team responds to a disaster, it focuses on training and inventory management. During TX-TF1's training period and non-response time, inventory is not a big issue. When the equipment is deployed in the field and returned to the warehouse, inventory management (Zhu et al., 2012) is a complicated and time-consuming task.

In this paper, the author describes a successful proof-of-concept project and lessons learned. The project scope was to design, implement, and test mission-critical asset tracking for the Texas Task Force 1 warehouse site, utilizing a voice-activated head-mount display unit (Kopin Golden-i) and RFID technology system. In addition, the system can help new employees responsible for warehouse management (Kelly & Erickson, 2005; Jones et al., 2005).

## Introduction

Golden-i Infinity is a voice-controlled and gesture-enabled smart screen, engineered for enterprise-level clients looking for a wearable computing solution (Ridgers et al., 2016; Schüll, 2016) that increases worker productivity, improves worker efficiency, and reduces work-related errors (Motti & Caine, 2014; Ledger & McCaffrey, 2014). The unit is designed and manufactured by the Kopin Corporation (2017). The Golden-i has basic Bluetooth and Wi-Fi connectivity, as well as a mini-USB port for connecting accessories. A Micro-SD card allows programs to be run and loaded without attaching a cable. Two microphones on the unit allow for noise-cancellation to be applied to the incoming voice commands. The built-in computer runs on Windows CE, and native applications are programmed in C. Programs can also be written in C++ to run in the Golden-i shell.

## Problem Statement

The project scope was to design a user-friendly, voice-activated system for employees to effectively manage inventory. The project focused on three parts. Part one was the Kopin Golden-i. Part two covered the Motorola MC9090 handheld RFID reader. Part three addressed the software. The software had two parts: one runs on the Golden-i, while the other part is loaded on the MC9090 to navigate the database of items. This program also has the ability to read RFID tags to confirm that the items have been found. The Golden-i unit has been used for many other applications, including hazmat training for first responders (Sartori et al., 2012). Figure 1 shows an overview of the Task Force 1 site.



Figure 1. Conceptual block diagram.

## Design Implementation Strategy

The MC9090 has been a key component of the solution to Texas Task Force 1's needs. It gives the user the ability to have the complete database of items readily available. Users are able to navigate easily through different categories of items, while giving them the ability to scan the actual items to see if they are located where they should be. This is all possible by using RFID tags. Each of these tags was scanned for a unique RFID identification number. This number was then assigned to a specific item in the database. The programming for the MC9090 was completed using Microsoft Visual Studio.

The Golden-i system was used to display maps and images to the user in order to find the items listed on the MC9090. The design had a voice-driven menu system that displays images to the user. All valid voice commands were featured in the Golden-i Help menu to allow users to know what they can do. The overhead image of the warehouse site was taken from Google Earth, while images of the items were taken on site with a digital camera. The layout of the warehouse was generated using Microsoft Visio. All images are saved in portable network graphics (PNG) form and edited with either Adobe Photoshop or GNU (an image manipulation program). The program was written in C++ and designed as a module for the Golden-i shell, which was completed using Microsoft Visual Studio 2008.

## System Requirements

The system requirements for the project are as follows:

- Fully functional C++ code for Golden-i
- Fully functional C# code for the MC9090
- A fully functional database of Texas Task Force 1 equipment
- Collection of images used in the step-by-step location process
- Prototype demo
  - Use the Golden-i to look for two or three specific items in the warehouse.
  - Use a step-by-step visual structure.
  - Employ a voice-activated .emo.

RFID tags were placed on boxes, tools, and any other items needed for inventory. These tags were then added to the database and scanned by the RFID reader on the MC9090. Low-cost passive radio frequency identification RFID tags were used for tagging equipment. On testing, these tags worked well on power tools, boxes, and other items except metals. The MC9090 device had the capability to read several tags from a short distance of about three feet.

## Software Design

Figure 2 shows the hierarchy chart for the Golden-i software design. A new class, WarehouseFind, was created for this project. The public functions for this class were all used by the Golden-i shell: GetMenuContainer, Paint, TakeControl, ReleaseControl, ButtonPressedEvent, and SelectDocument. Two new functions were created and added as private members to the class: AddButtons and RemoveButtons. The Golden-i shell was used to launch the C++ module, which called a number of pre-existing Golden-i functions. The GIDocumentViewer class was used to open the PNG images and display them on the screen. The GIDocumentMenu class displayed the menu options in the Golden-i help menu, with options such as zoom in, zoom out, headtracker on, headtracker off, and headtracker reset. Buttons were manually added to this menu using the GIMenuButton class, as the GIDocumentMenu class source was not available.

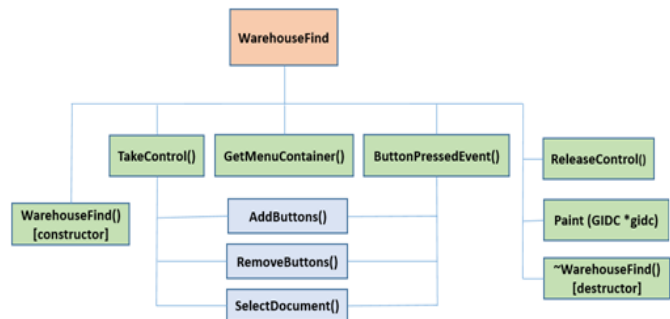


Figure 2. Hierarchy software design for Golden-i.

### WarehouseFind() [constructor]

This function was the class constructor, called when the Golden-i shell was first executed. The application directory and name were set here, as well as the language localization settings. The documentMenu and documentViewer variables were initialized to NULL. The screenView enumerated type was initialized to OVERVIEW\_VIEW, the itemView enumerated type was set to FLOORPLAN\_ITEM\_VIEW, and the numUsedButtons variable was set to 0.

### TakeControl()

TakeControl was the first function called when the user started the WarehouseFind application. It initialized the screenView and itemView variables to OVERVIEW\_VIEW and FLOORPLAN\_ITEM\_VIEW, respectively. It created a new document menu and told the speech recognizer to add those button names to its current vocabulary. A new document viewer was created to fill the entire screen with a 100% view scale, and the viewer was made invisible. Six buttons were created, each 150 pixels wide by 35 pixels tall with center-aligned 12-point font. The buttonxText strings were filled with the text to be displayed for each button. As this was the first screen, the text “Warehouse,” “Tool Can 1,” “Tool Can 2,” and “Tool Can 3” were the text fields for buttons 1 through 4. Buttons 5 and 6 had no text and were not displayed. AddButtons was called to add the newly created buttons to the Golden-i help menu. The overhead map view file was then loaded into imageFileName, and the SelectDocument() function was called to display that image on the screen.

### GetMenuContainer()

The GetMenuContainer() function was called when a menu was displayed on the screen. It was an overload function that matched a pre-existing Golden-i shell function. If no document viewer was created or if the document viewer was invisible, the function called the pre-existing GetMenuContainer function. However, if the document viewer had been created, then this function updated the Golden-i help menu.

### ButtonPressedEvent()

The ButtonPressedEvent function was called whenever an onscreen or off-screen button was activated, whether by voice command or by clicking with an external mouse. Each button had an associated action with it. Commands “level1,”

“level2,” and “level3” set the view scale (and therefore the zoom amount) in the document viewer to 100%, 200%, or 300%, respectively. The “zoomIn” and “zoomOut” commands added or subtracted 100 to the current view scale in the document viewer. The “trackerOn,” “trackerOff,” and “trackerReset” controlled the head tracker; the first enabled the tracker, the second disabled it, and the third reset the image so that it was centered in the front. The remaining button events were specific to the WarehouseFind class.

Figure 3 shows how the screenView variable was checked to see which screen was currently being shown. The overview level had actions for the buttons “Warehouse,” “Tool Can 1,” “Tool Can 2,” and “Tool Can 3.” If the Warehouse button was pressed, then the old buttons were removed and new buttons—Hard Hats, Hazmat Suits, PFD, Search Cameras, Show Floorplan, and Show Pictures) were added. The next picture then loaded, which was a Google Maps view of Disaster City with the warehouse circled. Finally, screenView was set to WAREHOUSE\_VIEW. If any of the tool can buttons were pressed on the first screen, all of the buttons were removed and the appropriate tool can was circled on the overhead map. In addition, the screenView was changed to TOOL\_CAN\_x\_VIEW.

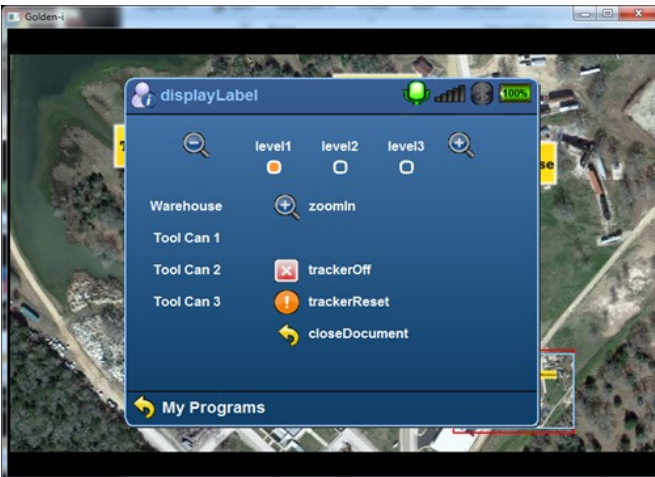


Figure 3. Main screen, Golden-i help menu.

The warehouse view had six buttons. The default (see Figure 4) showed a Google Maps view of the warehouse and the floorplans for each item in the warehouse. However, this could be changed with the “Show Pictures” button, which toggled itemView with PICTURE\_ITEM\_VIEW. When the pictures button was pressed for the first time, it changed the current image to the picture view as well as any future images. The “Show Floorplan” button changed this back to the floorplan view, toggling itemView with FLOORPLAN\_ITEM\_VIEW and redisplaying the current floorplan. Each item button (hard hats, hazmat suits, PFD, and Search Cameras) showed each item, either in an overhead floorplan view (FLOORPLAN\_ITEM\_VIEW mode) or as a picture in the warehouse with the item highlighted

(PICTURE\_ITEM\_VIEW). If the “closeDocument” button was pressed in any level, the program returned to the highest level overhead view.

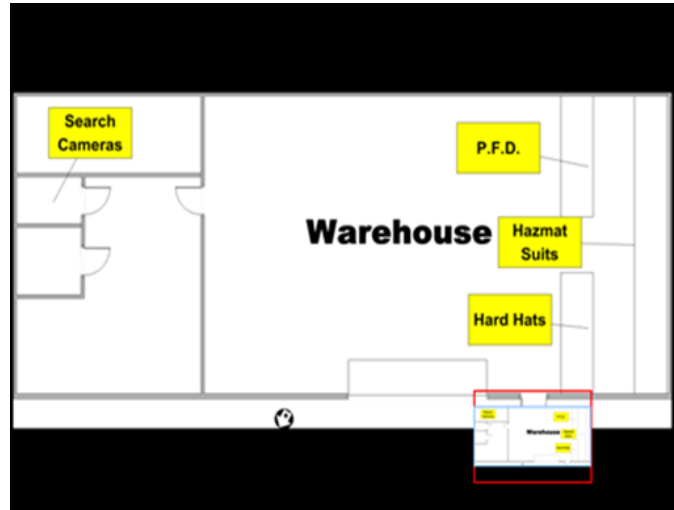


Figure 4. Warehouse floorplan view.

#### ReleaseControl()

This function was called when the application was exited and the user was returned to the Golden-i main application menu. The speech recognizer was first stopped before doing anything else. The document viewer was made invisible and all menu items were removed. Both the document viewer and document menu were set to null. The speech recognizer was restarted, which effectively took out the removed buttons from the vocabulary list.

#### Paint(GIDC \*gide)

This function was another overload function that was called by the Golden-i shell. If the document viewer existed and was visible, it was painted onto the screen. This meant that it was updated immediately.

#### AddButtons()

This function added buttons to the Golden-i help menu. First, the bounds of numUsedButtons were checked to make sure that they were not negative and not greater than the maximum number of buttons. If this was true, then the speech recognizer was stopped and the next loop entered. This loop iterated from 1 through the number of buttons used. In each iteration, the button’s name, text, and speech command was changed. The button listener added the speech command to the recognizer vocabulary, and the button was added to the menu. After the loop was completed, the speech recognizer was restarted; this reloaded the vocabulary list, adding the new buttons to the speech recognizer.

#### RemoveButtons()

This function removed buttons from the Golden-i help menu. First, the bounds of numUsedButtons were checked

to make sure that they were not negative and not greater than the maximum number of buttons. If this was true, then the speech recognizer was stopped and the next loop was entered. This loop iterated from 1 through the number of used buttons, removing each button in turn from the document menu. Once this was completed, the speech recognizer was restarted; this reloaded the vocabulary list, thereby removing the deleted buttons.

### SelectDocument()

This function was called from TakeControl or Button-PressedEvent when an image needed to be loaded onto the screen. The function first set the view scale to 100%. A new ImageDocument was then created with the file named in imageFileName, and the document viewer set to that file. The headtracker was started, the image was set to visible, and the screen was immediately repainted.

### ~WarehouseFind() [destructor]

This function was called when the Golden-i shell quit, releasing resources on the device. If the documentViewer or documentMenu variables were not null (meaning they had been used), each was deleted.

Figure 5 shows the MC9090 RFID reader hierarchy design. An easy graphical user interface (GUI) was created to provide access to the RFID Reader.

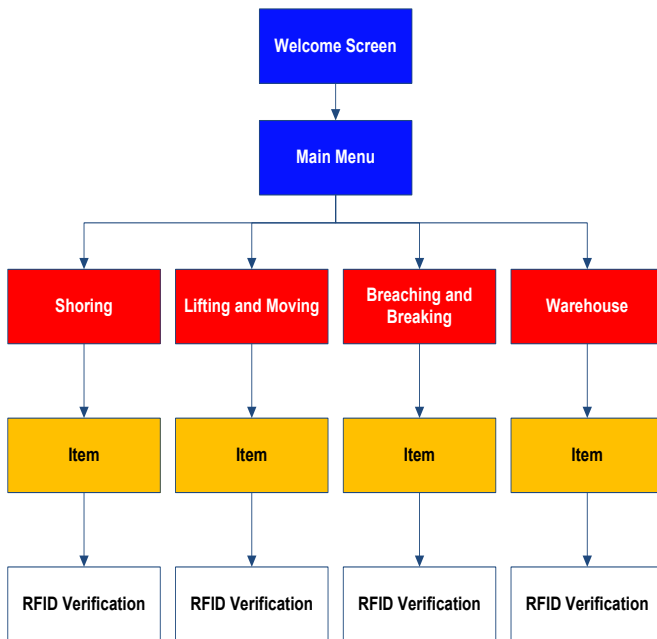


Figure 5. Hierarchy chart for MC9090.

The GUI was created into the key sections that were normally used by employees. Figure 6 shows the first screen presented to the user: the welcome screen. This screen just gave the user the ability to start the RFID Inventory program or to exit it.



Figure 6. RFID inventory program and welcome screen.

Once the user pressed Start, the program returned to the Main Menu (see Figure 7). The main menu consisted of three specific categories, used by the Texas Task Force 1, and also a generic category. The specific categories were Shoring, Lifting and Moving, and Breaching and Breaking. The generic category was the warehouse category. Each of these categories referred to actual spots where specific types of equipment were located. To access the items in any of these categories, the user clicked on the buttons. The Exit button existed the entire program.



Figure 7. RFID inventory program, main menu.

## Tool Categories

The Shoring category included several different types of tools.

- Circular saws
- Tool belts
- Senco nailers
- Palm nailers
- Miter saws
- Rescue chain saw

Figure 8 shows how each of these items led users to another screen that would give them the ability to use the RFID reader to verify the item. To do this, the user first selected the exact item from the dropdown menu. After choosing the item, the user then clicked the verify button to check the RFID tags with the RFID reader.

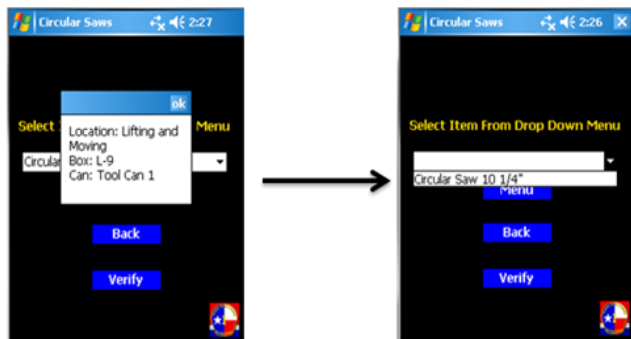


Figure 8. RFID tag verification process.

Once the verify button had been clicked, then the RFID reader screen popped up on the display. This display stayed up until the user scanned the correct item, and notified users if they successfully found the item with a message box. This process of selecting items and verifying them was the same for the rest of the items in the database. The categories were then broken down using the following outline.

#### Lifting and Moving (Figure 9)

- Slings
- Air bags
- Ropes
- Air hose yellow

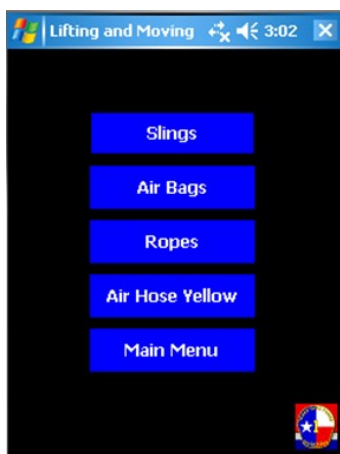


Figure 9. Lifting and moving.

#### Breaching and Breaking (Figure 10)

- Sawzalls
- Electric chipping hammers
- Rotary hammer drills

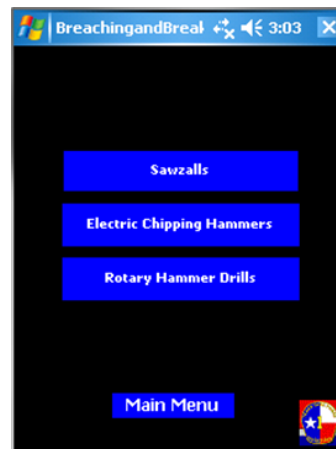


Figure 10. Breaching and breaking.

#### Warehouse Miscellany (Figure 11)

- Hardhats
- Personal floatation devices
- Extension cords
- Search cameras
- Thermal cameras
- Delsar listening devices

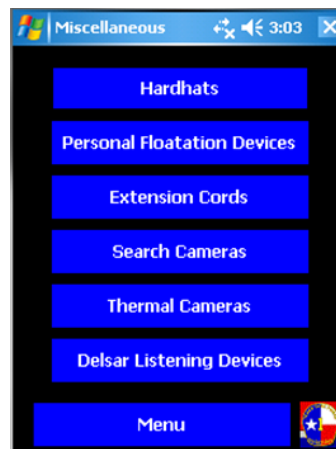


Figure 11. Warehouse Miscellany.

### Database Design

In this project, the purpose of a database was to store all of the data for each item in an organized form. An SQL database was designed with three datasets for cross reference. The first dataset contained item ID, which was the ID number of the RFID tags, and the item description, which allowed users to give a clear, descriptive name to each item. The second dataset consisted of item ID and box number, while the third dataset included box number and container number. All three datasets were connected so that users could cross reference the item ID in order to find the corresponding container number and box number.

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## Testing

During the process of coding the MC9090 GUI, each part was tested individually and collectively to make sure the operator navigated the program correctly. The coding was done in Visual Studio Project and then imported into the unit. After the code was proven to work in reading tags, the team had to check to ensure that the algorithm correctly distinguished the item the user was looking for. Multiple tests were performed for tag placement, environmental challenges, and accuracy. Because some of the equipment was metal, initial regular RFID tags did not work. In addition, if the equipment was submerged under water, the RFID tags were not read. A special metal RFID tag solved the initial problem of being able to read the tags on a metal surface. Humidity and very hot weather had minimal impact on the read rate. All tests were satisfactory. Task Force personnel used the system for three months and provided very useful feedback to the team for making minor changes in the software. The main challenge for Task Force personnel was to find time during less hectic days to conduct testing.

The Golden-i program was tested thoroughly in order to ensure that it worked properly. Every menu option was tested multiple times on every screen to ensure that all possibilities were accounted for. Also, menu options that should have been removed were tested by speaking the outdated commands. For example, on the Warehouse level, the phrase “Tool Can 1” was spoken to ensure that the command was no longer valid. Likewise, when the main screen was re-entered after speaking the “closeDocument” command, options from the last menu (such as “Hard Hats”) were spoken to ensure that this was not executed either. In addition, debug messages were sent to the Golden-i console to print the current speech command and see what command the Golden-i had heard.

## Challenges and Solutions

A number of problems that were identified and fixed involved the added buttons. When running the program a second time without restarting the Golden-i, text from previous runs would appear over the buttons in the menu. To fix this, the ReleaseControl function was modified to ensure that all menu items were removed on program exit. Also, new words would not be added and old words would not be removed from the speech recognizer vocabulary list when buttons were changed. To fix this, the speech recognizer was stopped when making any button changes and then restarted afterwards, reloading the vocabulary list. Finally, when the button text was updated, the speech command would not reflect those changes. To fix this, in the AddButtons function, the button name, button text, and button speech command were all changed at once.

Debugging was accomplished using different methods than a normal Windows-based program. Normal debugging,

such as stepping through code or using breakpoints, was impossible with the Golden-i. First, the Golden-i itself has no keyboard or other input method, other than speech, without wiring in something to the USB port. Second, because the module was a DLL file that was run in the Golden-i shell and not run directly, the code could not have breakpoints. Two methods were used to get around these problems. First, debugging messages were sent to the console, allowing the user to see what was going on in the program. Second, code running on the Win32 version of the Golden-i shell on a laptop could crash, but the Just-in-time Debugger allowed the programmer to jump to where the program crashed. This would go to the line in the .cpp file, which could be then corrected.

## Conclusions

The Golden-i RFID system was designed to be user friendly and to increase productivity by decreasing the time it takes to locate items in a warehouse. The system designed in this project was scalable in order to easily incorporate all of the items in the warehouse. Also, the software could be built upon to improve and expand the system. With further improvements and upgrades, the system could become a required piece of equipment for the TX-TF1. Overall, this project was successful and met all of the project requirements for the TX-TF1.

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## Biography

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# INTERDISCIPLINARY ENGINEERING TECHNOLOGY FRESHMAN EXPERIENCE: THE ROAD TO SUCCESS

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## Abstract

Vital skills necessary for achieving a high level of success, are introduced early in students' scholastic careers. Along with an increasing interest in experiential learning approaches to higher education, there have been proposals to introduce project-based learning into interdisciplinary programs in the engineering technology (ET) fields. The goal of this project was to assist faculty members in the design and implementation of an innovative instructional concept approach that focused on teaching students skills necessary to be successful in solving real-world problems and meeting future employer expectations. The instructional concept focused on placing students in an interdisciplinary group setting, taking them out of their comfort zones, exposing them to real problems, and ensuring that they work together toward a common goal using innovative technologies.

## Introduction

In this paper, the authors provide guidance to faculty members wanting to become involved in the creation and implementation of a successful course that integrates diverse components of various disciplines. The authors further discuss the critical dimensions of personal growth that better prepare students for success in their professions. The engineering technology (ET) interdisciplinary Freshman Experience places students of diverse backgrounds and interests into groups to work together toward a common goal. In achieving their specified goal, students learn teamwork, problem evaluation, problem solving, time management, creativity, innovation, and interpersonal communication. The Freshman Experience is highly experiential in nature and is intended to build bridges between diverse disciplines that do not traditionally interact in undergraduate ET curricula such as mechanical engineering technology, construction management, electrical engineering technology, agricultural technology, design and development, and computer science.

Group project-based learning is one of the most effective ways to get material and information across to students of all backgrounds, to keep those students motivated in their respective fields, and prepare them for their professional lives. The ability to work in an interdisciplinary group setting is a crucial skill for a college graduate. Professionals in almost every field are required to work in groups of people from varying backgrounds in order to achieve a common goal, and many have a difficult time adapting to this setting.

To prevent this, a program could be implemented early in the students' college careers to prepare them for challenges in the professional world and place them in the right mindset to work with people who are not necessarily like-minded.

## Group Project-Based Learning and Benefits of Working in an Interdisciplinary Setting

Project-based learning offers students an opportunity to apply and develop skills and knowledge to solve problems present in real life. There has been a strong emphasis on improving participation and retention in higher education, while providing students with important employability skills during their college careers (Herrera et al., 2015). Larmer and Mergendoller (2010) state that essential elements of project-based learning include: starting with a compelling question or challenge, creating a desire to acquire or create new knowledge, incorporating feedback and revision and rendering students' voice and choice. Project-based learning emphasizes the importance of learning by doing (Markham et al., 2003); therefore, the traditional lecture-test concept becomes less appealing.

Development of such a program requires recognition of the significance of different knowledge structures and practice of learning in different contexts and how they interrelate (Kinchin, 2011). It is supported by contemporary theories such as threshold concepts (Meyer & Land, 2003), semantic gravity (Maton, 2013), student-as-producer (Gamache, 2002), and meaningful learning (Huang et al., 2019). These concepts are emphasized in the integrated depiction of the theoretical basis of the programs that show how participants' perspectives can start and end with a focus on their own disciplinary expertise. Studies have found a correlation between development of specialist work-related skills and knowledge in the process of gaining confidence (Tierney & Kim, 2005; Knight et al., 2006; Snape & Finch, 2006; Dunne et al., 2009; Little & Greenwood, 2009). Especially with rising competition for jobs, transferable skills and an ability to perform assigned duties while continuing to professionally develop are in the spotlight (Simatele, 2015).

Other key elements that communities of practice (Wenger, 2010) bring into question are issues surrounding power and hierarchy, so students may not only struggle to find the appropriate language with which to make their thoughts explicit but may also have concerns about how

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their “contributions” are perceived by the teaching staff involved. If a student, or teacher, is seeking to strengthen that bond within the community of practice, and to adopt the role with which they are associated, they may act in such a way as to reinforce that individual role identity in order to develop respect, trust, and norms (Rudduck & Fielding, 2006). In this study, the proposed interdisciplinary project course helped to develop knowledge, insights, soft-skills, problem-solving competences, self-confidence, and a passion for learning, which are common goals of instructor-student interaction.

The intellectual merit of the Freshman Experience is the advancement of knowledge through a deeper understanding of how multiple disciplines work together to solve industrial and advanced societal challenges. The Freshman Experience program reflects a dawning recognition that strict specialization does not fully prepare students to respond knowledgeably and reflectively to the most important challenges in today’s society. The result will be graduates who value diversity and are prepared to solve problems through collaborative efforts—skills in high demand by employers. This program fosters a new generation of graduates who will have acquired critical-thinking and problem-solving skills, the ability to collaborate, as well as various forms of communication skills, often referred to as “21st Century Skills” to achieve their goals (Trilling & Fadel, 2012).

Constructivism is a crucial component of project and research and project-based curricula, because it aids students in building their own understanding of certain topics. It can help students engage in their work and make sense of the material (Taylor et al., 2015) and reflect on their inquiries (Barron & Darling-Hammond, 2008; Thomas, 2000). Project-based teams allow students to work in interdisciplinary groups, which teaches them to learn in a more meaningful way (Kean & Kwe, 2014). Students become more interested and motivated if presented with hands-on research opportunities, decreasing the probability of dropping out (Xu, 2015). Constructivist and project-based learning allows students to bring forward their prior knowledge as well as absorb that of their peers for an enhanced classroom learning experience when compared to traditional lecture-based curricula. This type of instruction promotes lifelong learning by asking questions (Taylor et al., 2015).

Courses that implement project-based learning must be carefully organized. In 1995 and 1996, an innovative freshman-level statistics course was offered at the University of Wisconsin – Madison centered on “mentored, small-group, collaborative activities that simulated complex, real-life problem-solving.” The class included freshmen from very different backgrounds possessing different interests and concentrated on developing the students’ “inquiry and decision-making” skills, as opposed to simply providing information and formulaic material that the students could memorize and repeat. While this study was successful in terms of improving the students’ critical-thinking abilities and soft

skills, it resulted in the students being displeased with how demanding the class was for the number of hours, showing that an appropriate number of hours must be carefully planned out and allocated (Derry et al., 2000).

A primary reason for developing a project-based course is not only to increase the overall quality of education but also to increase student retention. Student retention at the university level depends on many factors, including the students’ interaction with their courses and the university, the learning environment, the quality of education, and levels of motivation. To maintain high retention, academic programs must be high in quality and encourage a sense of individuality in the students; therefore, things like class size and quality of education play a major role in making sure students do not drop out (Xu, 2015). It is important to focus on the students, especially freshmen, and enact effective retention programs to aid in their development. These students need clear expectations, helpful advice and support, and ties to peers and faculty in order to be successful and see the relevance of what is being presented to them (Belcher, 2010). Instructors who demonstrate an ethic of care and are able to establish a safe learning environment are most likely to be considered good teachers by the students. It is important for teachers and students to communicate with one another and to rise to the challenges present in the relationship, individual control, and overall goals (Scott, 2015).

A freshman-level course focused on interdisciplinary project groups would provide several benefits in the long run. A study that observed the organizational processes of elementary school girls doing a project concluded that this process of research at such a young age helped the girls to picture themselves as “leaders who could make changes.” The girls formed meaningful connections with the adults who advised them through the process as well as with their peers. They also learned the crucial skills of data presentation, time management, and public speaking (Mittra & Serriere, 2012). Another study that focused on new curricular ideas in a middle school mathematics class recognized the merit of a challenging, inquiry-focused classroom. “In particular, teachers need to engage students in more challenging tasks and facilitate opportunities for rich mathematical discussions of those tasks” (Wilhelm et al., 2016). An introductory course aimed toward new students at a university would allow them to see what they will be getting into in their professional lives from the very beginning. A course such as this should put a major focus on hands-on learning for the new students and should encourage the creativity, problem-solving, and mindset that they will need when going into their careers after college (Vallim et al., 2006).

Universities have acknowledged the increasing significance of producing college graduates with the skills to meet the challenges of today’s society (Porter et al., 2015). Instructors struggle with difficulties in teaching technical courses to freshmen who have not experienced similar courses at the high school level (Verginis et al., 2011). To

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help students overcome deficiencies and experience success, faculty members are modifying teaching strategies to make instruction relevant and meaningful. Students are given more flexibility in scheduling, assignments, and pacing (Keefe, 2007). Universities failing to recognize and adapt to student needs may suffer declining enrollment, as students seek excellence in education elsewhere (Aktas et al., 2015).

First-year programs have been shown to be effective in retaining students (Hoit & Ohland, 1998; Prendergast, 2013; Richardson & Dantzler, 2002), increasing GPA (Richardson & Dantzler, 2002), and providing a broader understanding of the engineering discipline (Schauss & Peuker, 2014). Olds and Miller (2004) report that an integrated seminar course benefited students in several ways, including their academic major selection. Budny (2001) reports on a successful first-year engineering seminar that utilized peer mentors as contact points that provided encouragement and guidance. Cuseo (2010) studied the outcomes of many first-year engineering seminar programs at different institutions and concluded that, in general, many of the programs produced higher retention rates, higher graduation rates, shorter degree completion times, and higher GPA. Padgett et al. (2013) found that first-year overview courses can enhance students' lifelong learning orientation and positively impact complex learning processes. Franchetti (2011) showed that integrating case studies and discussion topics into first-year courses improved student retention rates, GPA, higher cognitive learning, self-efficacy, and overall satisfaction of the course. Hands-on project-based activities integrated into freshman curricula have also been shown to positively impact student performance. Kalkani et al. (2005) reported that hands-on projects make students appreciate the values of cooperation, the performance of tasks, quality of results, and reporting effectiveness. Behrens et al. (2010) reported that freshmen hands-on projects can improve programming skills, enhance motivation, and enable the peer-learning process. Pecan et al. (2012) reported an interdisciplinary partnership, called "Math-Science-Engineering Technology in Iowa on Applied Renewable Energy Areas" (MSETI-AREA), bringing high school and middle school teachers together for the improvement of students' mathematical and scientific skill sets using renewable energy technologies such as energy-bike (e-bike), small-scale model wind generators, a variety of PV panels, and energy efficiency modules.

In response to the effectiveness of the first-year experiential curricula cited by research, the authors of this current study propose the Interdisciplinary Freshman Experience. Universities should strive to teach students how to cultivate innovative knowledge so that they can thrive among the intense competition in today's workplace (Chen & Tsai, 2013). The Interdisciplinary Freshman Experience addresses the deficiencies and spans the chasm to create an ideal project-based course aimed specifically at freshmen. Research and methodologies have enabled the development of this course with relative confidence and ease.

## Challenges

A number of other problems often arise when organizing lessons focused on team-based projects. Some of these difficulties include grading, fairness, and group management. Creating an organized system for the teacher and student to use is imperative, as it allows for the majority of the focus to center on the project and the information learned by the student when working in a group. Peer reviews by the students in a group are a fantastic way to give all students incentive to pull their own weight, but these peer reviews must have certain rules and oversight in order to avoid the influence of conspiracy and politics within the group (Portz, 2014). In order to have a successful course, students require the necessary communication and social skills to work together toward a common goal. Meanwhile, teachers need to strive to create a suitable environment for their students to work effectively, while also being available for giving and receiving feedback (Fischl & Morin, 2015). With a certain flipped model of instruction, some studies found students to be more engaged than in the traditional delivery approach. In addition to active engagement and learning, the student participants often argued that this method efficiently used class time, improved the quality of instruction, promoted collaboration, and utilized better communication (Clark, 2015).

It is also important that the student groups that are assigned these projects be interdisciplinary. Creating interdisciplinary groups lowers dependence on the instructor and allows students to learn at their own pace while maintaining a cooperative and organized group. Students may also find areas of interest to them in any project they undertake by working in interdisciplinary groups (Kean & Kwe, 2014). Through project-based learning, students can find areas of interest to them in any project by working in interdisciplinary groups (Kean & Kwe, 2014; Hwang & Safa, 2016). One study analyzed multiple interdisciplinary programs at the middle and high school levels. In this study, teams of teachers worked together as a cohesive unit to create an interdisciplinary classroom. As an example, Madison High School experienced great success with such a program. Their program focused on American art, literature, and history and used some unconventional teaching methods that allowed students to draw upon their personal experiences in discussion. The program created bonds between the students by placing them in an interdisciplinary group and lowering their dependence on the instructor (Applebee et al., 2007).

## Course Overview

The proposed Interdisciplinary Freshman Experience is an immersive set of two courses, a 2-hour course followed by a 1-hour course, over two semesters using a hands-on curriculum built on a balanced program of studies drawn from a variety of disciplines. Each course module has its own learning objectives and varies from engineering content

to business and other sciences. However, all of these course modules were designed based on the experimental teaching concept. The experiential teaching method consists of an introductory concept or skillset, problem definition, discussion, team-focused problem resolution, and a derived solution or prototype presented to a panel of academic and industry experts as a report, presentation, or similar communication. An important aspect of the course is that students are able to see their solutions in order to receive immediate feedback. The first semester consists of a series of projects with increasing challenge and complexity designed to build expertise and gain exposure to a variety of topics, culminating in a proposal for a larger-scale project to be developed in the second semester. Each project reinforces and expands the introductory concept and the core skills of critical thinking, communication, and creativity. To ensure success, the initial target audience is incoming freshman students and high-achieving students recommended by their respective department chairs.

## Implementation

The instructional implementation is a process spanning a 4- to 6-week timeline and then repeating. Students are introduced to concepts such as awareness, project management, reporting, and technology including, but not limited to, 3D printing, virtual reality, software design, CAD, and photogrammetry. A variety of teaching strategies and tools are used to increase comprehension and understanding (Merrick, 2010; Safa, 2013; Safa et al., 2015; Tokgoz, et al., 2017). A hands-on approach brings instruction “off the paper,” improving academic performance and raising interest (Mukhopadhyay et al., 2014). Working in teams, students are given a challenge and are encouraged to find creative solutions by employing the technology and concepts previously introduced. Figure 1 shows how, at the end of each learning cycle, teams are asked to reflect on how the creative process worked and how they can improve in the next project.

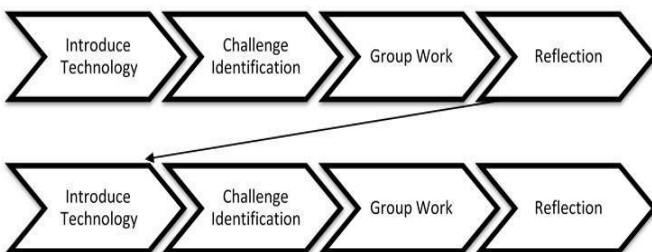


Figure 1. Learning cycles.

Learning outcomes extend beyond the primary goals of teamwork, problem evaluation, problem-solving, time management, creativity, innovation, and interpersonal skills to encompass evaluation of customer requirements, development of business proposals, and creation and delivery of effective presentations. Collaborative course development and the use of technology make the course more enjoyable

for freshmen and result in higher levels of student engagement and satisfaction (Gravel, 2014; Aiken et al., 2016). Enrichment activities, such as two guest speakers and three site visits, are incorporated to add relevance and significance to the challenges. The implementation strategy is to develop the course over the second half of the calendar year (summer and fall) and run a series of focus groups in the spring with the target audience to verify the projects and course structure. Upon successful validation through the end-of-the-semester student assessment, the program begins a two-semester pilot course series, starting in the fall of the second year for 25-30 selected students. The following fall (program year 3) will inaugurate the Freshman Experience across a broader range of incoming freshman students from the ET students selected by departments. Table 1 shows a breakdown of the implementation plan.

## Course Structure

The curriculum was designed as an immersion experience for students, directed by multiple instructors across a variety of disciplines and punctuated by guest speakers, including industry experts, entrepreneurs, and regional leaders. University faculty, in conjunction with industry experts and partner academics, developed instructional content. Instructors worked with upper-class Teaching Assistants (student mentors) from different colleges to assist in student learning. Students worked in interdisciplinary teams (engineering, science, business, fine arts, communication, social sciences, and humanities) on multiple project challenges with progressively higher complexity and decreasing structure (increasing degrees of freedom). Each project challenge had a different emphasis—technical challenges, economic issues, societal impact, policy decisions, etc. Guest speakers from industry were invited to present concepts and challenges to the cross-disciplinary student teams. Other activities included site visits and technology demonstrations.

As students advanced through the program, projects of increasing complexity and diminishing structure challenged the students and deepened the learning objectives of critical thinking, interdisciplinary teamwork, and communication. Potential projects could include the development of a bike trail on campus, methods for green energy utilization in the region, addressing the scarcity of water, or the introduction of new technologies to assist individuals with disabilities in experiencing everyday activities in a less-restrictive manner. In addition, external programs may be used to advance the goal of the Freshman Experience. Adobe Kickbox, for example, is a process that teaches innovation. Originally developed for Adobe’s internal use, Kickbox is now available for use by individuals and organizations. The premise is “innovation-in-a-box.” Recipients receive a “box” that contains everything an innovator needs to get started. The program guides individuals or groups through the six phases of development, from inception to implementation (Adobe Kickbox, 2016).

Table 1. Breakdown of the implementation plan.

<b>Summer (FY 1) Research</b>	<b>Fall (FY 1) Develop</b>	<b>Spring (FY 1) Focus Groups</b>
Gather projects & best practices	Order equipment and furniture	Install materials and equipment
Coordinate ET student	Recruit Faculty volunteers	Focus Group modules
Contact technology partners	Develop pilot modules	Learn & incorporate
Curriculum lineup	Develop online videos	Develop final lesson plans
	Recruit students - all disciplines	Contact guest speakers
	List in Freshman Orientation	Student Registration for Fall
<b>Summer (FY 2) Prep</b>	<b>Fall (FY 2) Pilot (2 Hr)</b>	<b>Spring (FY 2) Pilot (1 Hr)</b>
Fine-tune lessons	Pilot (2 Hour Credit Class)	Pilot (1 Hour Credit Class)
Prep for Pilot (20-25 students)	Incorporate Learning	Student Registration for Fall
<b>Summer (FY 3) Mentors</b>	<b>Fall (FY 3) Full Course (2 Hr)</b>	<b>Spring (FY 3) Full Course (1 Hr)</b>
Select Student Mentors (Sr/Jr/S)	Full 2 Hr Course (30-35 students)	Full 1 Hr Course (30-35 students)

Another example is the “Simulation Module: push system, pull system, inventory buffers, and kaizen and work cells.” Lego-bricks have been used as the educational tool to assist students in learning entrepreneurship, math, engineering, interpersonal and socio-emotional skills, and science. Lego-bricks are a great blend of hands-on education and entertainment class activities. This module assisted students with generating alternative solutions and working within a given set of constraints in order to arrive at new and better solutions. The module covered many lean concepts, including push system, pull system, inventory buffers, and kaizen and work cells. This session ran for two hours, equal to one session. Students watched the two assigned videos, 30 minutes each, through the online platform prior to class. Four phases of this session included: 1) the push system in which teams sort and build as fast as possible, inventory management, watch how chaos ensues then debrief, followed by a discussion of waste, inventory, push vs pull, and Kanban; 2) pull system in which they install buffer limits between stations and only build when buffers empty, followed again by debrief, discuss solving unlevelled process, and the concept of a work cell; 3) work-cell for simultaneous house construction in work cells, followed by debrief and discussion of the concept of kaizen; and, 4) Kaizen, where teams are allowed to perform any modification for improving the process, ending with a conclusion and final debrief. The instructor observes who is being silenced, controlling the group, or the loudest with regard to building a cohesive team concept. Since this simulation game is fast-paced, it helps students understand how to manage their stress in an actual workplace. The push and pull approaches between phase 1 and 2 help in understanding the benefits of lean. In phases 3 and 4, the work-cell concept and Kaizen are discussed and demonstrated.

## Methodology

Each institution of higher education that offers an undergraduate academic degree program in Texas must develop its core curriculum by using the Board-approved purpose, core objectives, and foundational component areas of the Texas Core Curriculum (TCC). If the institution is accredited by the Accreditation Board of Engineering and Technology (ABET), then ABET criteria should be considered. Through the TCC, students gain a foundational knowledge of human cultures and the natural world, develop principles of personal and social responsibility for living in a diverse world, and advance intellectual skills that are essential for all learning.

Through the Texas Core Curriculum, students prepare for contemporary challenges by developing and demonstrating the following core objectives:

- **Critical Thinking Skills:** to include creative thinking, innovation, inquiry and analysis, evaluation, and synthesis of information.
- **Communication Skills:** to include effective development, interpretation, and expression of ideas through written, oral, and visual communication.
- **Empirical and Quantitative Skills:** to include the manipulation and analysis of numerical data or observable facts, resulting in informed conclusions.
- **Teamwork:** to include the ability to consider different points of view and to work effectively with others to support a shared purpose or goal.

- **Personal Responsibility:** to include the ability to connect choices, actions, and consequences to ethical decision-making.
- **Social Responsibility:** to include intercultural competence, knowledge of civic responsibility, and the ability to engage effectively in regional, national, and global communities.

## Pilot Study

A recent pilot study was conducted with freshman ET students to serve as a starting point in developing a full-time course curriculum. The results were used as a framework for developing further modules. In the pilot study, the course was three hours and included students pursuing various concentrations within ET along with those taking the course in order to complete their minors, including construction management, mechanical engineering, electrical engineering, and physics. During this course, 25 participating students were given the opportunity to learn valuable skills concerning state-of-the-art technology and project management. Students were assigned projects based on the learning cycle and monitored during each stage of the process. It should be noted that this was the same group for the entire semester. At the beginning of the course, the students were divided into five groups of four to five members. Each team was responsible for planning and carrying out the creation of a unique, well-researched project. These projects demonstrated the students' ability to analyze and discuss the new technologies concerning their research. At the completion of the course, students were able to demonstrate the ability to present and discuss technology-based research through discussions and writing, and to formulate and develop critical perspectives.

Nearing the culmination of the course, the participating students were asked to complete a short, four-question survey. Figure 2 shows the first question asked: *Do you think a Project Management Course is beneficial to your major? Why or why not?* Most of the participants agreed that the course was beneficial. When asked why, the students stressed the importance of teamwork and leadership roles in completing projects. Also noted was the overall usefulness of the research and technical skills, along with the knowledge of modern technology and software. Experience gained through the course would also prove useful in future situations. Figure 3 shows the second question asked: *Do you think this course should remain a one-hour course or be extended to three? Why or why not?* Over half of the students agreed with the extension of the course. The current class was found to be too condensed and unorganized. One hour proved to be inadequate for the students to efficiently work on their projects and did not allow for meaningful discussions to take place. Extending the course would allow for more content to be introduced, better organization, and the overall improvement in the quality of work from the students. Figure 4 shows the third question asked: *Should*

*this course include site visits?* Students unanimously agreed with the incorporation of site visits. This presented an opportunity for students to observe the application of learned material, such as technology, project management, and teamwork, through the work of professionals in the industry. The visits would reinforce the students' understanding of class topics, while exposing them to different work environments. The students felt that site visits would keep them engaged and invested in the topics.

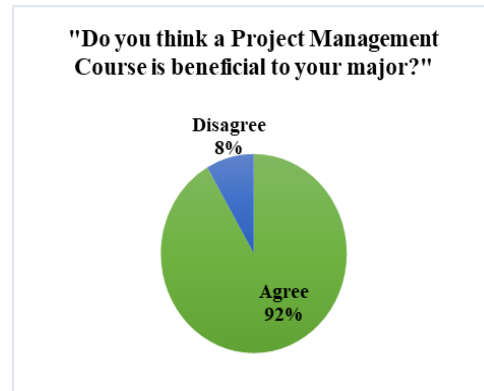


Figure 2. Results for the first question.

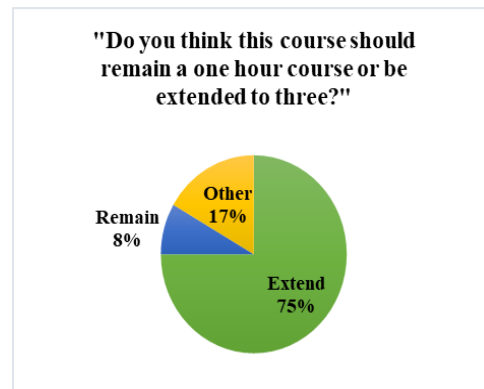


Figure 3. Results for the second question.

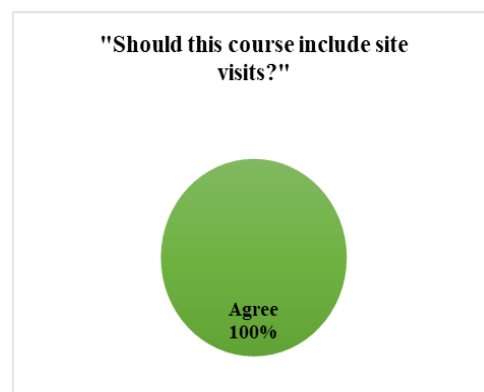


Figure 4. Results for the third question.

Figure 5 shows the last question asked: *Would you like to see more hands-on activity (project-based) in your other classes? If so, which classes?*. The majority of the participants were in favor of more hands-on activities. The general consensus was that hands-on-activities would be more mentally stimulating and provide more memorable learning experiences. Overall, the participants generally shared the same ideas. The course was very beneficial, and incorporating site visits and more hands-on activity would promote student engagement and interest, while allowing the observations of the learned material to be applied in real-world situations.

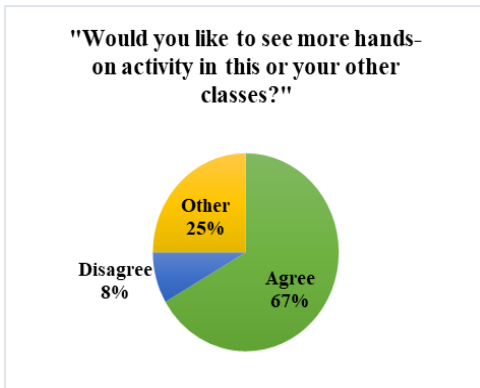


Figure 5. Results for the last question.

Eleven out of the twelve participating students found the course beneficial. The student that disagreed felt that the technology had too much focus throughout the course. Of the students, nine out of the twelve participating students desired an extension of the course. One student disagreed, due to schedule complications, while the remaining two students felt that the class could have been handled in the given hour if organized properly. All twelve of the students agreed with the incorporation of site visits and their benefit.

Of the participants, eight of them agreed in wanting more hands-on activities. Two students disagreed and two stated that the answer varied depending on the students' individual majors. The students that disagreed preferred hands-on activities in their specific areas of study. Students are not alone in their support for the Interdisciplinary Freshman Experience concept. Experts from 10 different universities, representing different disciplines, were interviewed to obtain their professional opinions of an Interdisciplinary Freshman Experience course. The interview results were encouraging. When asked if they were in favor of a program such as this, one responded, "Absolutely! Getting outside your discipline is very important." The hands-on approach appealed to students as well as experts, "All the research shows, the more you have students be involved in hands-on learning experiences and interdisciplinary experiences... they're more likely to be motivated and stay in school." Perhaps one of the most compelling statements was, "...teaching them *how* to think not *what* to think is much bet-

ter." Overall, the participants generally shared the same ideas. The course was very beneficial, and many areas could be improved by following a similar method. Incorporating site visits and more hands-on activities would assist in maintaining student engagement, while also allowing the observations of the learned material to be applied in real-world situations. Few concerns were expressed, but the main issue was found in the number of hours the course was worth and how it directly influenced the quality of work the students would put in.

Through feedback from students, experts, and industry professionals, research revealed that the Interdisciplinary Freshman Experience is a unique program that is both desired and needed. The collaborative and hands-on approach to problem-solving will equip today's graduates with the ability to tackle the interdisciplinary problems they will face in the highly competitive and diverse workplace. The interdisciplinary nature of the course is designed to accelerate student performance, which can be identified and quantified through assessments. Assessment tools to evaluate critical areas (critical thinking, communication, teamwork, decision-making, etc.) will be used to measure the success of the course. The scores of students participating in the Freshman Experience will be compared to scores of traditional freshmen. The degree of success can be further evaluated by comparing scores with the upper-level class performance of sophomores, juniors, and seniors to assess personal development. In addition, qualitative data will be collected to assess how interdisciplinary and collaborative efforts diversify students' thought processes and affect their ideation, critical thinking, communication, and design skills.

The application of mixed methods to the formative stage of the intervention is characterized by quantitative and qualitative data collected through the piloting and implementation of the entrepreneurial-design course. The course will be piloted, generating data through teacher observations, self-assessments, peer-assessments, and student journals. Pilot results will be used to improve course curricula and pedagogy. During the implementation of the project, the courses will be formative and iterative in nature, using data collected to encourage student learning. Additionally, course evaluations as well as pre- and post-tests measuring collaborative teamwork, confidence, and entrepreneurial knowledge will be used.

## Example Modules Incorporated into the Freshman Experience Program

The modules used in the course covered a variety of disciplines, from business to engineering over design art to communication and are of regional, national, or global importance. The first module facing the students with introductory purposes was the nine-dot problem. In groups of two to three, students had to draw four straight lines, which went through the middle of all nine dots without taking the



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pencil off the paper. Start from any position and draw the lines one after the other. Students engaged in the project to develop skills in interpersonal communication, problem-solving, critical thinking, and creativity. The attraction of this nine-dot problem was that the students factually had to “think out of the box” to solve the problem. The pencil must go outside the box of the dots to be able to solve it. An important learning objective was the precise analyses of the definition. Students had to find out what was allowed and whether the boundaries were their own perceptions or were given. Furthermore, students engaged in a post-evaluation of the project. Based on their reflections, students reassessed their ideas and discussed what they might have done differently and why.

## International Markets Module – Global Game

Each group had to link important global companies, outstanding inventions, and the economic size to a country by pinning the cards on the world map at the accurate location. After the students were finished with the Global Game, each group had to prepare a 5-7 minute presentation for the next class period about the country they knew the least, or they were curious the most about. Students engaged in a team project to widen horizons, develop interpersonal communication, and critical thinking. Introducing the students through the Global Game to the world’s largest economies, companies, and important inventions, helped to teach and stimulate their global awareness. This module motivated students to widen their horizons by introducing and working with international economies and companies. This session ran for two hours, equal to two sessions. The Global Game was the content of the first session, and each group had to prepare a presentation for the second session over a country they knew the least about, or they were the most curious about. The module consisted of four phases:

1. Communication and critical thinking in which teams have to allocate each company and invention card to the country of origin;
2. Evaluation, where groups have to discuss their allocations and select a country for the presentation;
3. Presentation, where groups hold a presentation about a country of choice; and,
4. Listening, where every student has to actively listen to the presentation and participate in the discussion afterward.

This module enabled students to broaden their horizons, learn about other countries and global companies, and practice oral presentations as well as active listening. Students engaged in a post-evaluation of the Global Game. Based on their reflections, students were more engaged with companies that influenced their choice of country for the presentation. They considered questions related to companies and countries with economic and innovative influence.

## Ecological Considerations: Teaching Sustainable Environment

As environmental awareness increases, industries and businesses are assessing how their activities affect the environment. Society has become concerned about the issues of natural resource depletion, air quality, and environmental degradation. Complex global challenges require multidisciplinary sustainable solutions, so the next generation of students must be prepared to apply sustainability concepts to solve these challenges. This set of experiential activities teaches the fundamentals of Sustainable Environment by using learning strategies that can help students achieve the wide range of knowledge, skill, values, objectives, and practical applications of rhetorical knowledge by hands-on activities. Students will be introduced to several innovative technologies, such as unmanned aerial vehicles (UAVs) and air pollution meters (Safa et al., 2018).

A basic premise of education for environmental sustainability is that, just as there is wholeness and interdependence to life in all its forms, there is a unity and wholeness to efforts to understand it and ensure its continuation. This sustainability-themed module engages students in critical thinking, problem-solving, and decision making in ecological and environmental contexts that are personally relevant to them and regionally related. This approach to learning also involves opportunities for debriefing and consolidation of ideas and skills through relevant feedback and applying potential solutions to real-life. The 4-week module includes an introduction to the Sustainable Environment, Life Cycle Thinking (LCT) assessment, Air Pollution Measurement activity, UAV (drone) field day, and integrated-module project. Educators purposefully engage learners in direct experience and focused reflection to increase knowledge, develop skills, clarify values, and develop the students’ capacity to contribute to their local communities. This module’s project increases regional awareness by focusing on the recognition of and development of solutions for current environmental issues in the local area.

Lifecycle thinking (LCT) assessment serves as an introductory team-based exercise to stimulate the thinking process to define sustainability in regards to the environment. Lifecycle assessment involves the evaluation of environmental aspects of a product system through all stages of its lifecycle. A large number of companies, from Apple to Unilever, employ LCT in their sustainability work, often at substantial expense. Lifecycle assessment (LCA) is data-intensive and requires a team of diverse professionals working collaboratively across organizational functions. Each group of 4-5 students is given a product to take apart. Students then quantify total sustainability impact—like environmental damage—over the entire life of a product following the six stages of a lifecycle. This exercise is designed for a deeper understanding of sustainability narrative and possible ways of improving product design in order to lower

the negative impact on the environment in the long run without compromising the needs of future generations.

Product design, manufacture, and industry all contribute to air pollution levels. Students must accurately measure the levels of air pollution using air pollution meters and identify possible impacts of industrial waste and its contribution to the area's ecological state. By using UAVs (drones), students can map polluted areas and identify the main sources of pollution, such as chemical plants, construction sites, traffic, and lack of green space. This field day activity exposes students to innovative technology usage and photogrammetry techniques for mapping the desired area for the final project. Given levels of air pollution and an interactive 3D map, students are asked to generate ideas for a sustainable project that would positively influence the environment and well-being of a community and present it in groups. The use of a drone introduces students to new technology and teaches them how new technologies can facilitate tasks. This module assists students in generating alternative solutions and working within a given set of constraints to arrive at the most accurate solution. The three phases of this module are: 1) introduction to a new technology and sustainable development challenge in which teams learn about new technologies, new possibilities, and alternative options, but also restrictions, rules, and regulations that have to be observed; 2) observations such that each group has a given period to use the drone and an air pollution meter to monitor the given area; 3) comparative analysis and creativity, where students are asked to collaboratively work on a creative and sustainable solution for an environmental challenge without a given set of constraints. The groups have no limitations to finding solutions for their problems—free creation stimulates creativity.

Students also engage in a post-evaluation of the project, where they consider questions related to the projects in the areas of impact of new equipment (technology), construction (engineering), and decision making (management). Based on their reflections, students re-assess their ideas and discuss what they might have done differently and why. Furthermore, students are engaged in the use of drones in various ways to facilitate monitoring, especially in unclear and inaccessible situations such as environmental disasters.

## Expected Outcomes

Universities across the U.S. have implemented programs to target incoming freshmen. The primary goals of these programs are recruitment, retention, and academic success; however, most programs focus only on the transition to university life or provide special interests for freshman support. This unique Freshman Experience is a for-credit course that empowers freshman with an academic advantage early in their collegiate endeavors. The result is expected to be highly skilled professionals who can more effectively compete in today's competitive job market with the skill sets that employers demand.

The broader impacts of the Freshman Experience are recruiting, retention, reputation, and professional development. The challenge of student retention is one shared by all universities—as many as one-third to one-half of freshmen may not return for their sophomore year (US News & World Report, 2016). The Freshman Experience targets and attracts high-achieving students with a strong desire to excel in academic and professional arenas. Figure 6 shows how the appeal of the course addresses these impacts.

<b>RECRUITMENT</b> Quality of Students Uniqueness of Freshman Experience Positive Peer Influence	<b>RETENTION</b> Integration into University Community Desire to Build on Freshman Experience
<b>REPUTATION</b> Quality of Academic Programs Quality of Faculty & Staff Journal Papers Grants	<b>STUDENT DEVELOPMENT</b> Critical Skills Development Work Ethic Career Exposure

Figure 6. Essential impacts of the proposed program.

The proposed experience is designed to bring new students to the institution, and faculty from across colleges at the university come together in new ways. As new students are recruited and more students enroll to advance their professional preparation, revenue increases. Employers who observe a higher degree of skills and interpersonal effectiveness will consider scholarships and donations to support program operations and may ask for program expansion to all students. Other potential funding sources include:

- Alumni Donor Scholarships
- Technology Company Sponsorships
- Grants
- National Science Foundation Division of Undergraduate Education (DUE) – Improving Undergraduate Education: Education and Human Resources (Interdisciplinary)
- Texas Higher Education Coordinating Board: Research and Project Grant

The program will be a model that others will want to emulate and will have a broad and lasting impact on the university, its students, and the surrounding communities.

## Conclusions

The main scholarly impact of the proposed course is to provide ET students with an opportunity to experience interdisciplinary collaboration to solve real-world problems and to promote the value of diversity in a collaborative environment. In addition, the Freshman Experience provides a

means for faculty members in different disciplines to work together and with cross-disciplinary student teams, forming a catalyst for innovative ideas and new research opportunities. Generally, college graduates hold degrees and possess technical skills but are lacking in communication and interdisciplinary teamwork skills. Graduates often enter the workforce with significant deficiencies in interpersonal skills, problem-solving skills, oral communication, leadership, and written communication skills. The Freshman Experience targets and strengthens the skills that have been long-standing concerns of employers. The university and the region will benefit as graduates are better prepared for modern working environments.

Coursework results in improved experiential education. This experience is a unique opportunity to train a new generation of students. This course is a source for faculty learning and research by providing a team-learning environment, campus-wide collaboration, lab facilities, and educational best practices. As a result, the course is truly multidisciplinary and integrated into content and design. It is the authors' aim to continue studying and testing the program, providing reports in the future, and updating the progress and results of long-term implementation. Although initiated with ET students, a broader implementation will engage students and have a positive effect on retention across the university. Recruiting higher-quality students attracts even more high-achieving students, forcing better performance across campus. By emphasizing practical interdisciplinary behavior early in a student's academic career, the Freshman Experience will also reinforce the university's reputation in the industry.

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# USING A SMART POWER METER IN AC ELECTRONICS LAB ACTIVITIES

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## Abstract

Students tend to lose interest in some electronics classes for a number of reasons. Most labs, for example, are only related to theory, without any real-life examples. Moreover, some theories cannot be verified in the lab, due to limitations of lab equipment. Most meters used to test AC power systems are expensive and hardly used in the lab, due to safety concerns. There are, however, some new, low-cost electronic devices on the market that can be adopted for solving these problems. In this paper, the author describes an example of using a smart meter to verify the theory of a parallel resistive-capacitive (RC) circuit in an AC electronics class. The parallel RC circuit cannot be tested using an oscilloscope, which only shows signal voltage, as there is no difference between voltages in a parallel RC circuit. Most lab books change the parallel circuit a little bit in order to use an oscilloscope; this may confuse students, because the resulting circuit is no longer an RC parallel circuit. In this paper, a smart meter is used to show how it can measure a parallel RC circuit. The meter is an off-the-shelf power meter with functions for measuring AC voltage, current, frequency, real power, apparent power, and energy in kWh. All variables read from the meter can be used in solving real-world problems. The result also explains some theory about power factor as well as some considerations in power transmission. The method is safe for students to use 120 VAC power systems in the lab.

## Introduction

AC electronics is one of the most difficult, yet fun, basic classes in the electronics field for a number of reasons. Compared with a DC power supply, an AC power supply provides a changing voltage or current rather than a constant one. Sine waves are used in the theory to simplify the problem by using RMS values (constant value) rather than changing instantaneous values, which makes it hard for students to understand. Labs can provide good explanation and support for theories, which can motivate students in learning, especially labs that demonstrate real-life examples. The most commonly used equipment in an AC lab includes oscilloscopes, multimeters, and function generators. A function generator is used as a power supply, while an oscilloscope is used to measure voltage in a circuit. Although an oscilloscope provides a vivid picture to show how voltage changes in a circuit, there is no low-cost equipment for showing current and power in a similar way. A digital multimeter can measure AC current and voltage, but only at low frequencies. Power and power factor are calculated according

to theory and are seldom measured directly by using a meter in lab. Most times, students are excited when they see waves on the screen of an oscilloscope.

But oscilloscopes only show different voltages at different times. They can show the phase shift of voltages in an AC serial circuit. Figure 1 shows how an oscilloscope cannot be used to measure voltages in a parallel circuit, because they are the same. The current meter, such as a digital multimeter, cannot show the phase shift of current in a parallel circuit, either. In order to show the current phase shift, current sensing resistors with small resistances are added in the parallel circuit (see Figure 2) such that it is technically no longer a parallel circuit (Buchla, 2000). This method sometimes confuses students, because of the differences between the two circuits of Figures 1 and 2. Parallel AC circuits, such as power systems used in our home, are commonly used in our daily life. Most students are curious about the real parallel AC circuits rather than the modified ones with current sensor resistors.

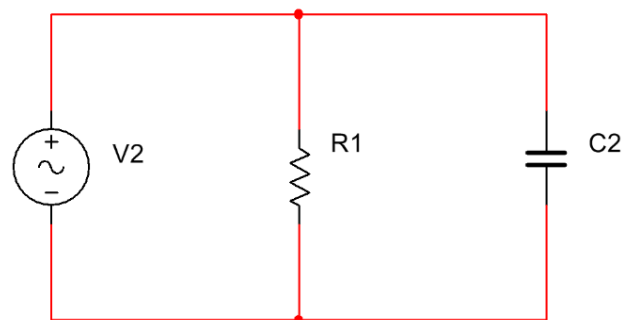


Figure 1. Real parallel RC circuit.

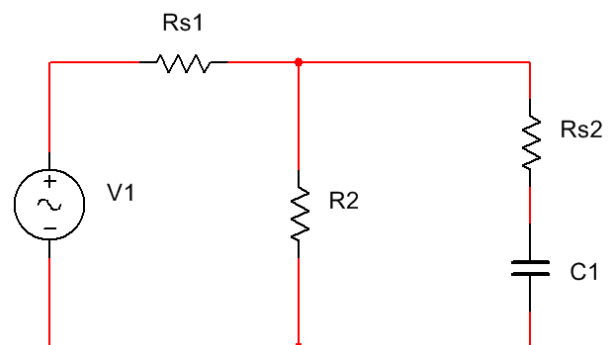


Figure 2. Parallel RC circuit with current-sensing resistors Rs1 and Rs2.

Most AC labs do not use 120 VAC as the power supply for safety reasons. A common question asked by students after a lab is, “Can we get the same result if 120 VAC power is used in this lab,” because everyone wants to see real-world applications rather than theory. Labs using a 120 VAC power supply can help students realize that all theories are used, in fact, in real life. Lab maintenance and upgrades can be expensive. An economic way might be buy some less-traditional equipment as supplementary to traditional lab equipment. Smart meter provide a possible economic solution to all of these problems. It can be used for a 120 VAC system, and the price is currently around \$30. It can measure voltage, current, real power, apparent power, and power factor (Power in Resistive and Reactive Circuits, n.d.). In this paper, the author gives an example using a smart meter to test a parallel AC circuit with a 120 VAC power supply as a supplemental AC lab for verifying parallel theory.

## Smart Meter

There are many kinds of smart meters on market; one example is the Kill a Watt smart meter (Kill a Watt, 2018). It is a cheap device that can be used to monitor how much power is used by a device, for example, energy consumed by a computer in sleep mode. The result will let people know which device uses more energy and how they can reduce their power bill, for example by turning off the computer rather than just leaving it in sleep mode. It is easily applicable and safe. The device under test (DUT) is simply plugged into the front socket and the smart meter will show voltage, current, real power, apparent power, frequency, power factor, and energy used by the DUT. In this paper, the author uses as an example a parallel resistive and capacitive circuit that uses a smart meter in an AC electronics lab class.

## A Parallel RC Circuit under Test

Figure 3 shows the lab setup, where a 120 VAC, 60W incandescent light bulb was used as a resistor (R1) and a 3.75  $\mu\text{F}$  AC motor as a capacitor (C1). The capacitance was about 3.83  $\mu\text{F}$ , which was read from a digital capacitance meter. Both components were connected to a power cord with a plug. A power strip was used to connect the lamp and the capacitor as a parallel circuit. The following test process was used in lab.

1. Discharge the capacitor and connect it with a power cord.
2. Connect a lamp-holder with a power cord and install the bulb.
3. Plug the capacitor and lamp’s power cords into the power strip.
4. Plug the power strip cord into a power socket to make sure the lamp is on, which means the connection of the circuit is good.

5. Unplug the power strip from the electrical outlet and plug it into the socket of the smart meter.
6. Plug the smart meter into the power socket and make sure the lamp is on again.
7. Press the related button on the smart meter and record all variables for the RC parallel circuit. The results are related to the variable from the AC power supply.
8. Unplug the power strip from the smart meter and remove the smart meter from the power socket. Plug the power strip into the power socket directly; the lamp should be on again.
9. Unplug the lamp’s power cord and plug it into the smart meter’s socket.
10. Plug the smart meter into the power strip. The lamp should be on again.
11. Press the related button on the smart meter and record all variables for the lamp (e.g., resistor R). All results are related to the resistor branch.
12. Unplug the smart meter from the power strip.
13. Unplug the lamp from the smart meter and plug it into the power strip.
14. Unplug the capacitor’s power cord and plug it into the smart meter socket.
15. Plug the smart meter into the power strip.
16. Press the related button on the smart meter and record all variables for the capacitor (C) branch.



Figure 3. A parallel RC circuit.

Table 1 shows the test results from one group.

Table 1. Measurements of a parallel RC circuit.

Smart Meter Position	Voltage (VAC)	Current (A)	Real Power (W)	Apparent Power (VA)	Frequency (Hz)	Power Factor
Power Socket	121.6	0.53	59.6	64.5	60	0.92
Capacitor	121.9	0.17	0.8	21	60	0.03
Lamp	121.8	0.49	59.8	59.8	60	1

## Analysis and Discussion

The test results were analyzed in two ways: 1) verify Ohm's law and 2) verify the parallel equations (Schultz, 2015).

Ohm's law verification for the AC power supply:

- $V_T = 121.6\text{V}$
- $I_T = 0.53\text{A}$
- Apparent power,  $P_T = V_T I_T = 64.4\text{ VA}$ , was close to the measured result of 64.5 VA.
- Total impedance (Equation 1) will be verified by the calculated results for the parallel circuit in the following section.

$$Z = \frac{V_T}{I_T} = 229.4\Omega \quad (1)$$

Ohm's law verification for the capacitor, C, (treated as an ideal capacitor):

- $V_C = 121.9\text{V}$
- $I_C = 0.17\text{A}$
- Capacitive reactance (Equation 2) was close to the results found using Equation 3, where  $C = 3.83\ \mu\text{F}$ .

$$X_C = \frac{V_C}{I_C} = 717\Omega \quad (2)$$

$$X_C = \frac{1}{2\pi fC} = 692.6\Omega \quad (3)$$

- Reactive power, where  $P_C = V_C I_C = 20.7\text{ VAR}$ , was close to the test value of 21 VA.
- According to AC circuit theory, power is not dissipated in a purely reactive load, such as an ideal capacitor; it is alternately absorbed from and returned to the source. The test results showed that there was 0.8W of power dissipated by the capacitor branch. A small amount of power was dissipated by the wire resistor (about  $1\Omega$ ) and leakage resistor capacitor. The real power of 0.8W was much smaller than the capacitor branch power of 21 VA, according to the test results, so the capacitor branch could be treated as an ideal capacitor. The power factor was about 3%, which was close to the ideal result of zero.

Ohm's law verification for the resistor (R) branch:

- $V_R = 121.8\text{V}$
- $I_R = 0.49\text{A}$
- The real power,  $P_R = V_R I_R = 58.7\text{W}$ , was closest to the measured result of 59.8W as well as the rated value of 60W.

- Resistance, R, was found using Equation 4. Because the resistance of an incandescent light bulb changes according to its temperature, it was hard to measure using a multimeter.
- Impedance, Z, (Equation 5) was close to the result according to Ohm's law from the previous calculation.

$$R = \frac{V_R}{I_R} = 248.6\Omega \quad (4)$$

$$Z = \frac{1}{\sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}} = 234.9\Omega \quad (5)$$

Verification for a parallel RC circuit.

- Voltage drops on a capacitor and resistor are almost the same as for the AC power supply voltage.
- The total current, I, (Equation 6) was close to the measured result of 0.53A.

$$I_T = \sqrt{I_R^2 + I_C^2} = 0.52\text{A} \quad (6)$$

- Apparent power, P, (Equation 7) was close to the measured result of 64.5 VA.

$$P_T = \sqrt{P_R^2 + P_C^2} = 63.2\text{VA} \quad (7)$$

- Power factor, PF = real power / apparent power =  $58.7\text{W} / 63.2\text{ VA} = 0.928$ , was close to the measured result of 0.92.

Different capacitors and lamps were used in class by different groups. Every group came up with a similar analysis. The test results closely matched the calculated results according to the theories. In this setup, it was safe to measure current because the circuit was not opened. Voltage, current, and real and apparent power could be measured after the power cord was plugged into the smart meter. Test results for the capacitor branch also showed real-world results rather than the theoretical results using the nonzero power factor. The ideal capacitor should not consume energy, and real power and power factor for the capacitor branch should be zero. Students were encouraged to discuss why the power factor of the capacitor branch was not zero, and which part dissipated the 0.8W of power. Power dissipated on transmission lines as well as the reason for adjusting power factor close to one in real life was also discussed.

## Conclusions

An example of using a smart meter in an AC lab was presented in this paper. This smart meter could also be used in other labs related to AC power applications. For example, it is easy to see the change of power factor after a running



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capacitor is added to an AC motor (Valentine, 1998). Compared to other AC equipment, this smart meter was cheaper and easier to use in a safe way. It can provide more information in AC circuits, especially in a 120 VAC power system. Some variables are hard to be measured using oscilloscopes or digital multimeters, such as real power and apparent power. All of these variables can be measured by the smart meter at the same time, making it a good test setup for an electronics lab.

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# REVISION OF ABET ACCREDITATION CRITERIA FOR TECHNOLOGY PROGRAMS (2019-2020): A ROADMAP FOR A SEAMLESS TRANSITION

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## Abstract

The Accreditation Board of Engineering and Technology (ABET), the leading accreditor for engineering and technology programs, recently revised its accreditation criteria for technology programs as part of its continuous-improvement initiative. The revision was centered around student learning outcomes, which primarily resulted in reduced assessment requirements for accreditation. There is no detailed roadmap available for adapting to the revision during an assessment cycle. In this paper, the authors propose such a roadmap for a seamless transition to the newly revised criteria for accreditation within the context of an Electrical Engineering Technology (EET) program.

## Introduction

Academic accreditation is a process of external review of the quality of education (Fergus, 2012). It is a voluntary peer-review process that academic programs or institutions undergo in order to sustain the quality of educational standards. This process demands compliance with a certain set of criteria by the accrediting body (Lehigh University, n.d.). The criteria for accreditation are developed by a peer-review board primarily consisting of faculty members from various accredited institutions. Typically, as per accreditation criteria, the institutions/programs are required to establish student outcomes (SOs), also known as student learning outcomes (SLOs) (CHEA, 2008), and demonstrate their systemic assessment (Hou, 2011). Accreditation is an important instrument of educational systems that offers a certain level of recognition of student work in reference to other institutions and employers (Eaton, 2015; Department of Education, n.d.; 50States, n.d.; ABET, n.d.-c). Additionally, in many cases, it is a condition for institutions to receive financial support from the government.

Accreditation consists of two major types: institutional level (known as regional accreditation) and program level (known as national accreditation) (Department of Education, n.d.). Institutional accreditation validates the entire institution and requires it to demonstrate the achievement of the institutional mission by means of various institutional apparatuses. On the other hand, program accreditation validates a specific program within an institution and mandates that it demonstrate effective student learning within the discipline by means of different mechanisms. There are a num-

ber of accreditors at the institutional and program levels; the Middle States Commission of Higher Education (MSCHE) and Accreditation Board of Engineering and Technology (ABET) are respective examples of such (MSCHE, n.d.; ABET, n.d.-b). This current study focused solely on ABET, which is the leading program accreditor for engineering and technology programs. ABET is a private entity involved in accreditation of post-secondary educational programs, specifically in the engineering, engineering technology, applied science, and computing disciplines. The Council for Higher Education Accreditation (CHEA), which oversees accrediting bodies, has recognized ABET since 1997 (ABET, n.d.-a). To date, ABET has accredited 4005 programs at 793 institutions in 32 countries, supporting approximately 85,000 students annually (ABET, n.d.-c).

ABET accreditation is an ongoing process, which takes place in a cyclic manner, where the accreditation cycle can be up to six years. The accreditation process includes defining SOs that are consistent with ABET requirements, designing courses that can support them, developing assessment instruments and schedules for assessing the SOs with a set attainment target, and establishing a documented process of assessment and evaluation and the systematic utilization of such results for continuous improvement of the program. This process is documented in a self-study report. Upon examination of the self-study report, ABET conducts a site visit for a first-hand evaluation of the program (ABET, 2017). This process is primarily guided by two current documents (2018-2019) established by ABET: "Criteria for Accreditation" and "Accreditation Policy and Procedure Manual (APPM)," mainly covering accreditation criteria and administrative issues, respectively (ABET, 2017; ABET, 2016).

Figure 1 shows that ABET consists of the following four commissions: Applied and Natural Science Accreditation Commission (ANSAC), Computing Accreditation Commission (CAC), Engineering Technology Accreditation Commission (ETAC), and Engineering Accreditation Commission (EAC) (ABET, 2019). ANSAC accredits applied science programs such as health physics; CAC accredits computing-related programs such as computer science; EAC accredits engineering programs such as electrical engineering; and, ETAC accredits engineering technology programs such as electrical engineering technology. While the APPM applies to all of the commissions, there are specific "Criteria for Accreditation" for each commission (see again Figure 1). In this paper, the authors limit the discussion of criteria-

related issues to ETAC only, and whose current criteria (2018-2019) (ABET, 2016) were revised recently, which is effective from the 2019-2020 cycle (ABET, 2018-b). The revision modifies primarily the SOs, leading to the reduction of assessment requirements. While the reduction of assessment requirements is a blessing, adapting to these criteria revisions during an assessment cycle can be a challenge. Therefore, the authors present a roadmap for a seamless transition to ETAC's newly revised criteria of accreditation within the context of Electrical Engineering Technology (EET) programs. The authors also present a brief overview of ETAC's accreditation criteria, the revised ETAC criteria, and a proposed roadmap for a seamless transition.

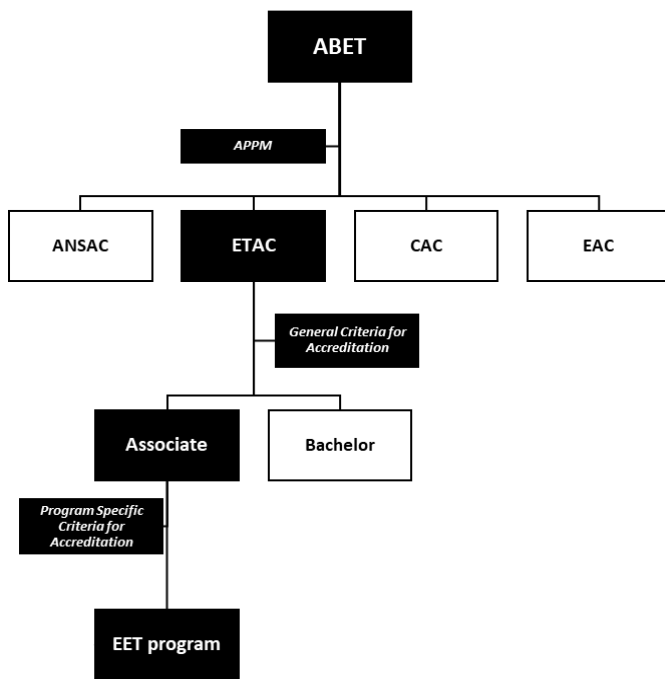


Figure 1. EET program accreditation and ABET hierarchy.

## ETAC's Accreditation Criteria

ETAC's current "Criteria for Accreditation" establishes the following eight general criteria that are the major requirements of accreditation for all programs: 1) students, 2) program educational objectives (PEOs), 3) student outcomes (SOs), 4) continuous improvement (CI), 5) curriculum, 6) faculty, 7) facilities, and 8) institutional support. Table 1 provides a short description of these general criteria. In addition to these eight general criteria, there are a small number of program criteria (PC) specific to each program (ABET, 2016). The PCs illustrate specific details needed for interpretation of the general criteria for a given program, such as the PCs for the EET program. The PC section starts with a preamble, which states the requirements applicable to all programs, followed by a small number of criteria specific to each program. Thus, the EET program

must comply with the eight general criteria along with a few specific EET PCs (see Figure 1). The general criteria are of two levels: the associate degree and bachelor's degree. While most of the general criteria are identical for both degrees, two criteria differ: criteria 3 and 5. For criterion 3, there are nine SOs (a-i) for the associate degree and eleven SOs (a-k) for the bachelor's degree. ABET 2016 provides a detailed description of the current criteria.

Table 1. A short description of the general criteria.

Criteria Title	Description
Students	Students are to be admitted, advised, and monitored to ensure graduation and attainment of student outcomes
Program Educational Objectives	PEOs exit that are aligned with the institutional mission and the needs of the constituencies
Student Outcomes	The associate degree program must have the following SLOs, the students are able to: apply knowledge, skills, and tools of engineering technology apply knowledge of mathematics and science to solve problems conduct experiments and analyze data function in teams analyze, and solve technical problems communicate effectively understand importance of life-long learning understand professional and ethical responsibilities commit to quality and improvement
Continuous Improvement	There must be a documented process that is utilized systematically and regularly to assess attainment of student outcomes for program improvement
Curriculum	The curriculum must be consistent with the student outcomes. Associate degree programs will include: college level mathematics (algebra and trigonometry) and physical or natural sciences technical content that is between 1/3 and 2/3 of the total credit hours
Faculty	There must have an adequate number of competent faculty with due authority to support the program
Facilities	The facilities and equipment associated with the program must be adequate and well-maintained to support the attainment of the student outcomes
Institutional Support	The support of leadership for and the allocated resources to the program must be adequate to maintain the quality of the program

The eight general criteria and the PCs revolve around criterion 3 (SO). Therefore, it is important to see how the SOs are linked to the other general criteria. Figure 2 illustrates this link between the SOs and the other criteria. Generally, the SOs evolve in stages from the institutional mission. Typically, the mission is initially mapped to broader PEOs (criterion 2), which reflect the need of the program's constituencies and describe what the graduates are expected to attain within a few years after graduation. The PEOs are then translated into specific, measurable SOs (criterion 3) that the students are taught and are expected to attain while enrolled in the program. The next criteria connected to the SOs that support their attainment are as follows: a well-designed curriculum (criterion 5), a qualified faculty (criterion 6), and appropriate facilities (criterion 7). The SOs relate to criterion 1 (students) and require that the institution/program admit and support qualified students who can attain such SOs. Finally, all of these activities take place under the umbrella of the institution, requiring institutional

support (criteria 8). It is important to note that the SOs and their assessments are at the center of the accreditation process. Therefore, any change to the SOs impacts a number of other criteria and their assessment activities.

## Revised ETAC Criteria

ETAC revised some of the general criteria and PCs for the 2019-2020 cycle as per its continuous improvement initiative (Fergus, 2016; ABET, n.d.-d). This revision better aligns the criteria with the needs of industry (Prados et al., 2001; Prados, 2001; ABET, 2001) and reduces the burden of assessment of the programs. The revision entails some major changes along with a number of fine details involving wording and scope. A detailed description of the revision along with the current criteria can be found in the 2016 ABET report (ABET, 2016). This current study focused only on the overall major changes of the revision in order to outline the major steps needed to adapt to the changes.

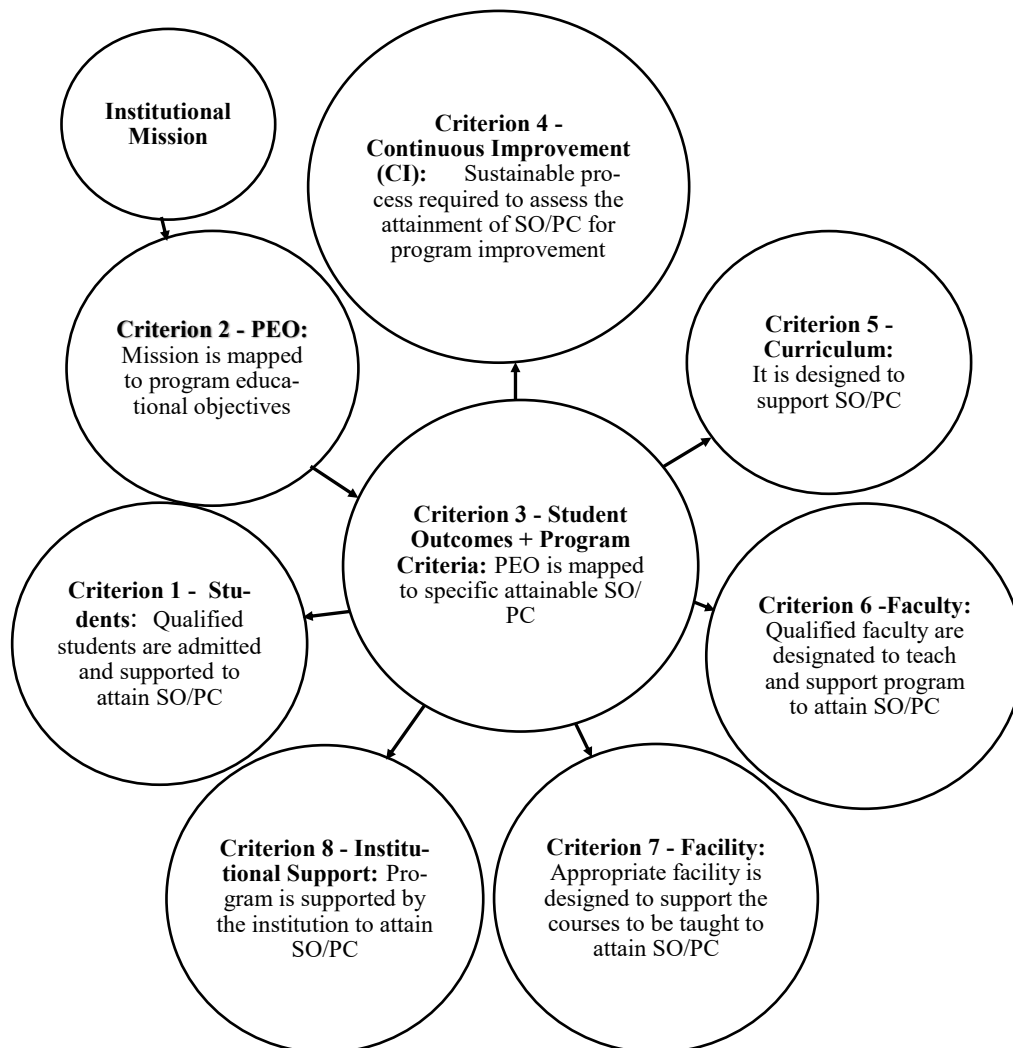


Figure 2. Overview of the relationship of the SOs to the other general criteria.

The revision mostly affects general criteria 3, 5 (corresponding to SOs and curriculum, respectively) and a few PCs. Specifically, it resulted in the reduction of the associate degree SOs from (a)-(i) to (1)-(5) and the bachelor's degree SOs from (a)-(k) to (1)-(5) (ABET, 2016). The associate-level SOs were reduced by merging a number of SOs and moving others (primarily soft skills) to the curriculum criterion. While the revision reduces the total number of SOs to five, it adds a new requirement in the SO, which mandates design activity for solving technical problems. Although the authors limit their discussion to the associate level, the same approach can be extended to revisions at the baccalaureate level. Table 2 illustrates the general mapping between the current and revised criterion 3 (SOs), while Table 3 provides details regarding the EET PCs.

Table 2. Mapping of the revised associate-level student outcomes.

Associate Degree SOs (2018-2019): (a-i)	Revised Associate Degree SOs (2019-2020): (1-5)	student outcomes
(a) an ability to apply the knowledge, techniques, skills, and modern tools of the discipline to narrowly defined engineering technology activities	(1)	an ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve well-defined engineering problems appropriate to the discipline
(b) an ability to apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require limited application of principles but extensive practical knowledge	(2)	an ability to design solutions for well-defined technical problems and "assist with the engineering design of systems, components, or processes appropriate to the discipline"
(c) an ability to conduct standard tests and measurements, and to conduct, analyze, and interpret experiments	(3)	an ability to apply written, oral, and graphical communication in well-defined technical and non-technical contexts and an ability to identify and use accurate technical literature
(d) an ability to function effectively as a member of a technical team	(4)	an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results
(e)** an ability to identify, analyze, and solve narrowly defined engineering technology problems	(5)	an ability to function effectively as a member of a technical team
(f) an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature		
(g) an understanding of the need for and an ability to engage in self-directed continuing professional development		
(h) an understanding of and a commitment to address professional and ethical responsibilities, including a respect for diversity		
(i) a commitment to quality, timeliness, and continuous improvement		

Table 3. Details of the associate-level PC for EET programs.

EET Associate Degree PCs (2018-2019) (ABET, 2016)	Revised EET Associate Degree PCs (2019-2020) (ABET, 2016)
(a) the application of circuit analysis and design, computer programming, associated software, analog and digital electronics, and microcomputers, and engineering standards to the building, testing, operation, and maintenance of electrical/electronic(s) systems	No changes in the numbering or content of the PCs. However, while they must remain in curriculum, they are not linked to the SOs anymore. Thus, the PCs are not required to be assessed like the SOs anymore
(b) the application of natural sciences and mathematics at or above the level of algebra and trigonometry to the building, testing, operation, and maintenance of electrical/electronic systems	

Since the criterion 3 revision moved some of the SOs to criterion 5 (curriculum), it resulted in more specification to criterion 5; more importantly, those SOs that were moved are no longer subject to assessment. It is important to note that there is no major task associated with any of the SOs that were moved to the curriculum criterion, as those SO topics were in the curriculum to begin with. Regarding the PC section, the preamble revision specifically states that all program-specific criteria listed under each program name are linked to the curriculum and faculty criteria. Since they are no longer linked to the SOs, they are not subject to assessment but must remain in the curriculum to be taught by competent faculty. Since it is a challenge to implement all of these revisions, the authors propose a roadmap for facilitating a seamless transition to these revised criteria.

It is important to note that the SOs are typically broken down into smaller, more easily measurable performance indicators (PIs). The SO assessment instruments (e.g., rubrics) were designed with those PIs to assess attainment, such as "ability to apply modern tools to solve well-defined engineering problems" (part of revised SO 1). One major focus of this roadmap is to maximize the reuse of PIs (from the current assessment instruments) for the revised SOs via mapping. ETAC's current "Criteria for Accreditation" establishes the following eight general criteria that are the major requirements of accreditation for all programs: 1) students, 2) program educational objectives (PEOs), 3) student outcomes (SOs), 4) continuous improvement (CI), 5) curriculum, 6) faculty, 7) facilities, and 8) institutional support.

## Proposed Roadmap

ABET periodically revises the criteria of the four commissions, and there are ample studies addressing those revisions (Turner et al., 2018; Estes et al., 2018; Karimi, 2017; Haddad et al., 2016; Leisher et al., 2015; Volkwein et al., 2004). These studies show that many of the existing accreditation processes and resources can be utilized to meet the revised accreditation criteria via modifications and mappings (Turner et al., 2018; Estes et al., 2018). Nevertheless, it requires a considerable number of logistical tasks. Table 4 provides a breakdown of the major tasks, and Figure 3 depicts the corresponding flow of the tasks. As indicated by Table 4, this process should start by mapping the new SOs (1-5) to the current SOs (a-f), as per Table 2. It should be noted that the new SO2 (design activity for solving technical problems) has to be added separately, since it cannot be mapped. Additionally, the PEOs must be revised and remapped to the new SOs, while remaining consistent with the mission statement of the institution. These revisions are required to be documented and approved by the appropriate bodies. Note that these changes must be reflected in all published and online materials in addition to any forthcoming self-study reports. As the new SOs are adopted, a realignment of the courses is needed in order to support/assess these SOs as well as for identifying or adding new course

Table 4. Overall breakdown of the major tasks for adapting to the newly revised criteria.

Criteria	Scope	Tasks
Criterion 3: SOs	Revised ABET SOs 2019-2020	-Update SOs (see Table I and ref (ABET, 2016)) -Constituents approval -Documentation of the approval process (minutes)
Criterion 2: PEOs	Consistency of PEOs to the revised SOs and institutional mission	Revise and remap the PEOs to the SOs and the institutional mission statement -Constituents approval -Documentation of the approval process (minutes)
Criterion 4: CI	Consistency of assessment activity with the updated SOs	Align the SOs assessment related elements: -revise assessment schedule for updated SOs (new SOs): five SOs vs nine SOs (a -i) -align courses with revised SOs (new SOs) -select courses with revised SOs for assessment -advise faculty with revised course SOs and assessment assignments -revise assessment instruments (rubrics, surveys, exams etc.) according to the updated SOs, such as: discard relevant assessment instruments for current SOs g, h and i rename assessment instruments for SOs c,d and f to revised SOs 3,4 and 5, respectively map current assessment instruments for SOs a,b and e to SOs 1 and 2 as applicable. Also, add an assessment component to SO 2 for “design activity” for solving technical problems
Criterion 5: Curriculum	Consistency of curriculum with the revised SOs	-Update curriculum mapping to show how it supports revised SOs -Indicate that the PC and soft skills (current SOs g,h and i, that are moved to curriculum) are supported by the curriculum -Add “design activity for solving technical problems” in the curriculum (SO 2)
PC Preamble	Authority	PCs (for all programs) are no longer linked to the SOs; they are linked to general criteria 5 and 6. It means that the program specific topics remain in the curriculum as in the past, however, they are <i>not</i> required to be assessed
Associate level EET PCs (a and b)	Requirements	The two PCs remain unchanged in the curriculum; this requirement can be satisfied by demonstrating student works in relation to the EET program specific topics (ABET, 2018-b).
Criterion 6: Faculty	Faculty qualification regarding Program-specific topics	-Provide evidence that the faculty qualifications match with program specific topics - Update CVs accordingly
All SOs	ABET SO references on course outlines	Update course outline references according to the revised ABET SO numbers
All SOs and PEOs	Published materials and websites displaying PEOs, SOs and PC	Update PEOs, SOs and PC everywhere
Overall revision process	Evidence	Involve appropriate parties in the revision process and retain evidence of consultation, such as meeting minutes

material that can support an SO2 that was not previously mapped to the current SOs. It is important to note that as some of the current SOs (g, h, and i) and the PCs are moved to curriculum, they are not required to be mapped and assessed, however, they must remain as part of the curriculum. In light of new SOs, faculty CVs must be reevaluated to ensure that their expertise matches the course material they teach in support of the new SOs. Finally, the SO assessment schedule (semester, course, faculty, etc.) and corresponding assessment instruments (rubrics, surveys, and exams) must be revised as per newly adopted SOs.

1. Assessment instrument revision (e.g., rubrics): three out of nine of the current SOs (g-i) were moved to the curriculum criterion and no longer have to be assessed. Hence, six of the current SOs (a-f) can contribute to the design of the assessment instruments for the five new SOs. Three of the current SOs (f, c, and d) directly map to the revised SOs (3, 4, and 5, re-

spectively); this allows those assessment instruments to be reused simply by updating the numbers of the SOs. Thus, two new SOs (1 and 2) are left to be addressed. The rubric for two of the current SOs (a and b) can be merged and edited to form the assessment instrument for the new SO1. Figure 4 shows such an approach of combining existing SO rubrics to generate new ones. For the new SO2, there is no direct mapping, because it includes a new assessment requirement (“engineering design”; see Table 2).

2. Assessment rubric for SO2: Table 5 shows a template of this rubric.
3. Assessment schedule adjustments: aligning the current assessment schedule to the new SOs is a fairly simple task. It requires that the current SOs on the schedule be substituted with the newly mapped SOs in addition to adding the new SO2 into the schedule.

4. Self-study report: the revision noted above necessitates a change to the self-study report format as well. It is important to follow ABET's template for the self-study report. And while it is not a requirement, it is convenient for program evaluators as well as for the overall accreditation process. A revised template for a self-study report is available from ABET (ABET, 2018-a).

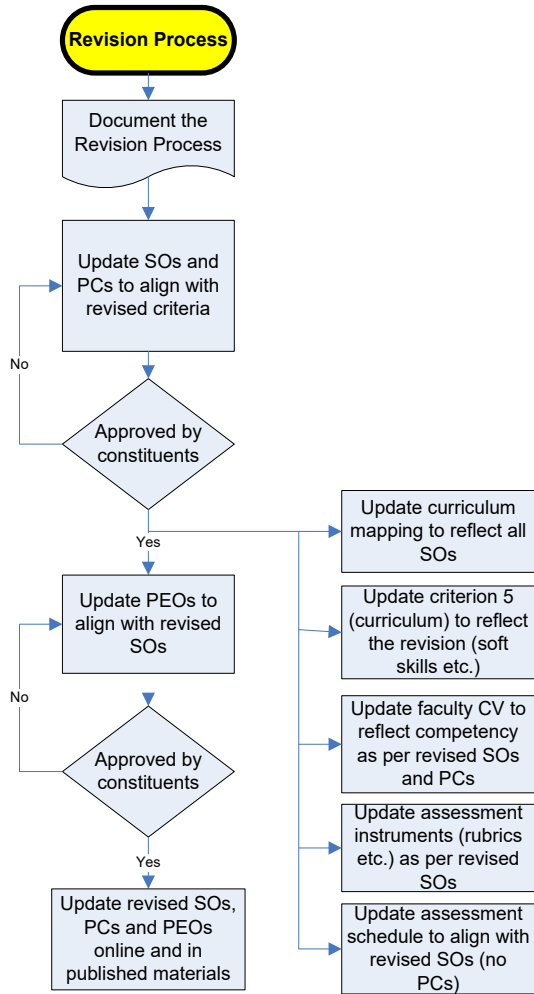


Figure 3. Overflow of tasks for revision.

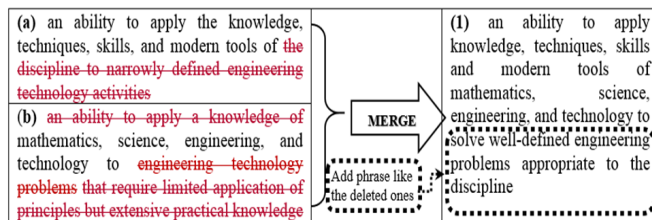


Figure 4. Merging two of the current SOs (a and b) in order to design SO1.

## Conclusions

In this paper, the authors detail a roadmap for a seamless transition to the revised ETAC criteria for the 2019-2020 cycle within the context of EET programs. While it is not exhaustive, it does provide an overview of the substantial tasks that are to be undertaken in light of the revised criteria. It is apparent that adapting to the revision is not an overly complex task, when carried out according to the proposed roadmap. This roadmap can not only be extended to ETAC's bachelor's degree programs, but also to the programs facing similar revisions under the purview of other ABET commissions.

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Table 5. Assessment rubric for SO2.

SO 2: An ability to design solutions for well-defined technical problems and assist with the engineering design of systems, components, or processes appropriate to the discipline.				
Performance Indicators	Exceeds Criterion = 4	Meets Criterion = 3	Progressing toward Criterion = 2	Below Criterion = 1
<b>Demonstrate ability to understand the technical problem</b>	Very clearly identify the technical problem that leads to the objectives and constraints of the solution design	Satisfactorily identify the technical problem that leads to the objectives and constraints of the solution design	Identify the technical problem that barely leads to the objectives but no constraints of the solution design	Cannot identify the technical problem that can lead to the objectives and constraints of the solution design
<b>Demonstrate a solution design strategy, a work flowchart and a timetable</b>	Define efficient design strategy and methodology. Develop a complete plan for managing the tasks and a timetable with milestones to assess the work continuously	Define good design strategy and methodology. Develop a good plan for managing the tasks and a timetable to assess the work continuously	Define adequate design strategy and methodology. Develop a simple plan for managing the tasks but no timetable.	Define unclear design strategy and methodology. No plan developed or timetable
<b>Produce a sound design solution</b>	Exceed design specifications with efficient design	Meet all specifications with good design	Meet nearly all specifications	Missing significant specifications
<b>Accompanies design with appropriate documentation and references</b>	Identify all types of information needed to complete the design tasks. Properly document all significant sources in the references.	Identify most of the types of information needed to complete the design tasks. Properly document most of the significant sources in the references.	Identify some types of information needed to complete the design tasks. Do not document all significant sources in the references.	Important information needed to complete the design tasks is missing. No documentation of significant sources in the references.

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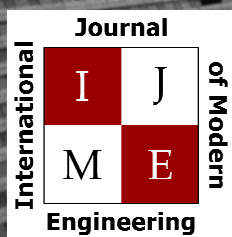


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