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STEM Project Experiences with Wireless Sensor Networks

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Work-in-Progress: STEM Project Experiences with Wireless Sensor Networks

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Abstract
This paper discusses the use of hands-on STEM laboratory and project activities to engage STEM students in middle and high schools through the assembly and testing of wireless sensor networks for radio frequency imaging of space. Radio frequency signals can be used to perform non-invasive and device-free target localization of objects or entities in space. Radio tomographic imaging uses wireless sensor networks to form images from the attenuation of the radio frequency signals. Radio tomographic imaging is useful to locate security breaches, to perform rescue operations, and to design “smart” buildings. The radio tomographic imaging system is comprised of three subsystems the wireless sensor network, the command and data collection platform, and the user interface.

Broadly speaking, the STEM activities for the students comprise

- Assembly of each node of the wireless sensor network using the ESP32 Wi-Fi modules and accessories.
- Execution of software and hardware tests on the functionality of each node.
- configuration of the wireless sensor network grid using an organized collection of nodes.
- Set up of the communication with the command and data collection platform to collect the received signal strength data from each transmitting node in the network.
- Identification and display of objects within the space enclosed by the wireless sensor network.

The distinction between the two groups of students – middle school and high school – is made through the complexity of the processes outlined above. While the hardware assembly and testing procedure is easy to comprehend by both groups, the software aspects of the operation of the network will be the basis for deeper STEM engagement by the high school students. Specifically, the high school students will investigate methods to improve the capture and display of the information at the command and data collection platform.

In addition to creating and piloting STEM laboratory and project experiences with wireless sensor networks, the integrated radio tomographic imaging system will engage undergraduate and graduate students in research on imaging with radio frequency signals, as well as the faculty in course and curriculum development.

Introduction
Tomography is widely used in medicine as a transmission-based imaging process. Computed tomography (CT) is used in radiology as the noninvasive technique to obtain cross-sectional

images of the internal organs, the bones, the blood vessels, and tissue in the body for diagnostic purposes. The body moves through a gantry as the x-ray beams rotate around the body. The images of the cross-section of the body are generated by solving the inverse problem using the attenuation of the intensity or beam strength as it passes through the body. The cross-sectional images can be created in multiple planes and generate three-dimensional images to be viewed on a computer monitor, printed on film, or transferred to electronic media.

Radio tomographic imaging (RTI) is like CT but is based on radio frequency signals. The RTI system, unlike optical and infrared imaging systems, can travel through obstructions such as walls, foliage, and smoke. RTI systems can operate in the dark unlike video cameras. RTI uses the device-free passive localization (DFPL) technique [1]-[9] based on sensor nodes set up as radio transceivers to transmit and receive radio frequency signals within the wireless sensor network (WSN). The images of the objects or entities (also called targets or obstructions) are formed from the attenuation in received signal strength (RSS) of the radio frequency signal along the path or link between each transmitting sensor node and each of the receiver nodes. The presence of stationary or non-stationary entities within the radio frequency network leads to changes in the measured RSS levels at the receiver nodes in the network. Radio frequency signals can travel through physical obstructions, but unlike x-rays, introduce significant non-line-of-sight or multipath propagation. In indoor environments with clutter, radio frequency measurements from wireless links corrupted by multipath effects compromise the accuracy of the localization achievable by the RTI system.

Section 2: System setup and operation
Figure 1 illustrates the typical setup of the RTI system for data collected in the field. The set up comprises the wireless sensor network (WSN), the command and RSS (CRSS) platform for data collection, and with the appropriate user interface for the display of network information. The sensor nodes in the WSN are Wi-Fi modules which transmit and receive radio frequency signals. The Wi-Fi router interfaces the WSN to the CRSS platform. Time-stamped RSS data is captured at the CRSS.

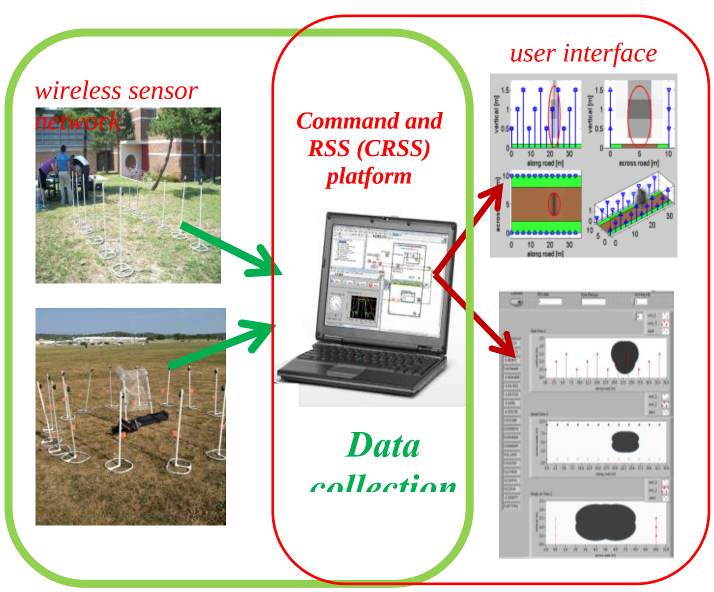


Figure 1: RTI system

The user interface communicates with the CRSS platform to control, display, and evaluate the performance of the network. The user can retrieve RSS data collected by the CRSS across the specified range of timestamps. This facilitates: 1) the off-line analysis of the recorded data and 2) the study and evaluation of the performance of the image reconstruction models. Due to the UDP protocol, the user interface will not receive real-time data from the CRSS. However, the direct interface between the user interface and the WSN can be set up to determine the status of the WSN in real-time.

The current hardware setup in the laboratory involves two parallel arrays of ESP32 development boards as shown in Figure 2. The ESP32 is a readily available development board with both Bluetooth and Wi-Fi capabilities. For this setup each board is attached to a mount and equipped with a power delivery method as shown in Figure 3. The mounts used, while designed to be clipped into ceiling rails, can be used standing upright as well. The power delivery method used can either be a direct power line that runs directly to the power and ground pins of the boards or a micro-USB connection. To collect the data transmitted by the WSN a router was used to create an isolated network that the data can be communicated to a base station over. The base station runs a python script that queries the receivers for the RSS data they have collected and outputs so it can be read. To program the WSN the Arduino IDE was used. To program an ESP32 with the Arduino IDE specific libraries are needed. These can be found on the web [10]. The transmitters are programmed to create a Wi-Fi access point and the receivers are programmed to connect to each access point and record the strength of the connection to that transmitter. The recorded RSS value is then sent to a base station that collects all the data.

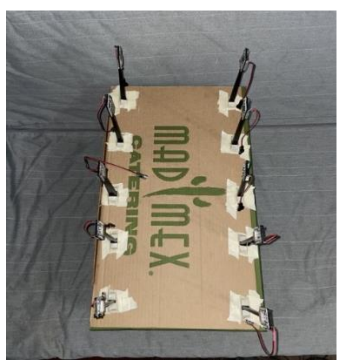
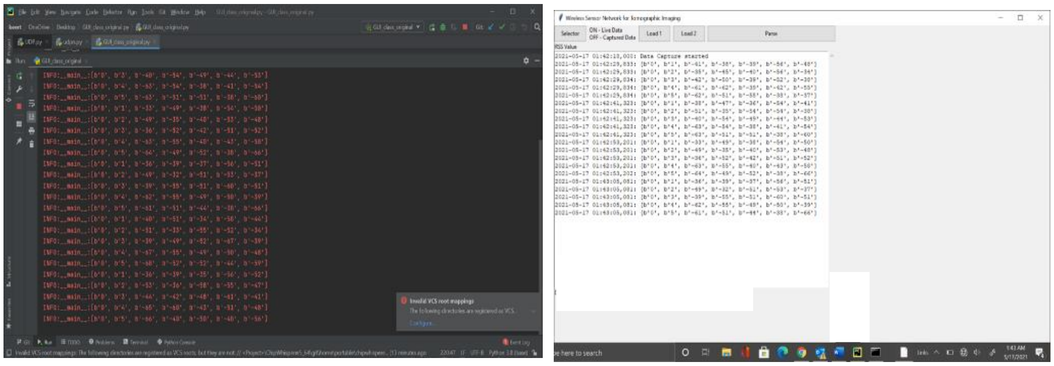


Figure 2: Laboratory test setup

Figure 3: Node of the network

Figure 4(a) shows the RSS data recorded at the base station computer of the CRSS. Figure 4(b) shows the RSS data captured on the user interface.



(a) (b)

Figure 4: Typical RSS data (a) at the base station computer (c) on the user interface

RSS data in Figure 4 is converted to RSS attenuations in decibel units (dB) as shown in Table 1.

Table 1: Table of RSS values recorded

Timestamp	Rx_ID	Tx_1	Tx_2	Tx_3	Tx_4	Tx_5
	1	-42	-52	-56	-58	-59
	2	-56	-52	-50	-58	-36
4:39:26	3	-62	-57	-35	-54	-53
	4	-51	-53	-39	-40	-53
	5	-60	-53	-50	-54	-39
	1	-43	-44	-56	-59	-63
	2	-56	-53	-51	-59	-50
4:39:34	3	-59	-57	-38	-55	-54
	4	-51	-54	-38	-39	-52
	5	-57	-50	-49	-51	-35
	1	-61	-46	-53	-60	-66
	2	-56	-43	-52	-58	-49
4:39:43	3	-63	-57	-38	-52	-54
	4	-50	-52	-41	-46	-53
	5	-60	-54	-52	-54	-39

Section 3: STEM Target Groups & Outreach Activities

The project activities and the anticipated learning outcomes are specifically tailored for two distinct groups of students – middle school and high school. The nature of the engagement recognizes the differences in the STEM preparation and experiences of these two groups.

Middle school students

This group of students will be given a simplistic and practical overview of the system shown in Figure 1 with real-world examples. They will be introduced to the individual components required to assemble each node of the network. This will be followed with a step-wise assembly of each node. Teams of two students will work on each node. The steps to install the software will be explained and the action of uploading the software to each node completed by each team. They will be guided through the creation of the grid of nodes to form the WSN. The procedure to test the network will be detailed so that each student can understand and recognize the successful operation of the network. The learning outcomes for middle school students are as follows:

- Understand and distinguish the different engineering hardware components required to assemble each sensor node.
- Recognize the need for software to control the action of each sensor node.
- Comprehend the nature of wireless communication between sensor nodes.
- Test the operation of the system to note the success and failure modes of performance.

High school students

This group of students is expected to have the necessary STEM preparation and understanding to comprehend the assembly and testing of the system at a different, and presumably, higher level of complexity. Specifically, they can, at first, be challenged to assemble each node without providing the detailed formal procedure to do so. In addition, they can be asked to edit the software steps for specific responses from the network to be evidenced during the testing of the operation of the network. They can be tasked with setting up and testing different network configurations. The learning outcomes for high school students are as follows:

- Comprehend the action of the engineering hardware components required to assemble each sensor node.
- Incorporate revisions to the software control of each sensor node for intended network operation.
- Demonstrate the ability to set up and test the operation of networks with different physical configurations and requirements.
- Gain some insight and understanding of the procedure to map signals to images

Section 4: Conclusions and Next Steps

The STEM project activities discussed in this paper facilitate the creation of a mobile laboratory comprising the integrated RTI system. In addition to the STEM outreach program for middle and high school students the laboratory will engage undergraduate and graduate students in research on RTI. The STEM project experiences described in this paper will be delivered to local area middle and high school students in spring this year. The details of the STEM outreach activities and learning outcomes assessment will form the subject matter of a future ASEE paper.

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