Smarter Spaces, Smarter Campus

Sam DeLorenzo
School of Systems and Enterprises
Stevens Institute of Technology
Hoboken, New Jersey
sdelore1@stevens.edu

George Ibuna
School of Systems and Enterprises
Stevens Institute of Technology
Hoboken, New Jersey
gibuna@stevens.edu

Sean Trinh
School of Systems and Enterprises
Stevens Institute of Technology
Hoboken, New Jersey
strinh@stevens.edu

Gregg Vesonder
School of Systems and Enterprises
Stevens Institute of Technology
Hoboken, New Jersey
gvesonde@stevens.edu

***Abstract* - Smart spaces are environments that seamlessly interweave sensors and displays to improve knowledge of surroundings as well as quality of life. For this project, the team constructed sensor suites based off Raspberry Pi's, and mounted them at various locations around a campus building to collect data. Since the creation of a seamless smart space is difficult, simplifying the process to involve citizens of all ages and backgrounds will be vital to the effort.**

Keywords - Citizen science, affordable sensor suite, data collection and analysis, characterizing spaces on campus

I. Introduction

In the late 20th century, the effects of construction and amenities within a space on one's subjective experiences and emotions became a prominent focus. For example, the 1988 film *The Social Life of Small Urban Spaces* discusses concepts such as the canopy-esque feeling of a grove of trees, the importance of sunlight in an area, and the power of water to mask unwanted noises such as conversation or street traffic [5]. As research trends towards the Internet of Things (IoT) and big data, scientists have searched for ways to acquire maximal amounts of data from as many sources as possible. As such, the growth and implementation of **citizen science**, the "volunteer collection of biodiversity and environmental data which contributes to expanding our knowledge of the natural environment" (UK Environmental Observation Framework, UK-EOF, 2011) has been a prominent concern of scientists in recent times. [5]

Smart Spaces seek to gather visible, shareable, and usable data about our environments and surroundings, and subsequently make that data available to improve quality of life in urban areas (UrbanQool). Benchmarks of UrbanQool include environmental, economic, and cultural influences on a given urban area. These "smart areas" interweave sensors with the environment to get realtime feedback, giving objective data about one's surroundings. While IoT focuses more on converting inanimate objects to interactive objects that can "communicate" between one another, citizen science prioritizes the involvement of individuals in both data contribution and, in the future, curation and scientific examination. With the advent of Smart Spaces, citizen involvement will grow more important than ever before. If these Smart Spaces can change the role of citizens from victims to active contributors, they have achieved their goal.

Researchers have pursued the idea of Smart Spaces on multiple scales in the past; from the *EmoMap* [5] -- emotional maps designed to record the subjective experiences of individuals given a certain environment -- to *Greenwatch* [5] -- an app that allows citizens to make important observations on lacking pillars of sustainable communities -- many have tried to involve the general public in scientific pursuits. While these projects provide the general public the tools to report their findings, in comparison, "Smarter Spaces, Smarter Campus" seeks to not only bolster the sensory data of Stevens campus, but also to make an easily replicable sensor-database system that will allow secondary level students (i.e. high schoolers) to both contribute and understand the underlying infrastructure of smart spaces.

Other sensor suites have attempted to tackle the task of smart information gathering and automation within the home. More recently, Gierad Laput, Yang Zhang, and Chris Harrison's developed a "Super Sensor" that utilizes deep learning algorithms to accurately monitor and evaluate its environment. This group pursued a "lightweight, general-purpose sensing approach" [3] to eliminate the issues of cumbersome setup and calibration. The SuperSensor markets itself as a “Synthetic Sensor”, creating smart spaces “without invasive instrumentation” [3]. The SuperSensor is an advanced version of the sensors the team plans to create with “Smarter Spaces, Smarter Campus”, and hides the underlying infrastructure for ease of use.

This paper details the process of creating a similar sensor, but with attention shifted to making an easily replicable and inexpensive sensor suite that can engage and encourage young citizens (i.e. High school level) to feel empowered to collect and contribute data about their environment.

The cost restraints for this project led the team to use inexpensive sensors; their relatively low prices were key to procuring enough sensors to calibrate their readings. Regardless of this calibration, there will be a small degree of inaccuracy within the readings. Additionally, the project assumes that the user attempting to replicate the sensor suite will have a readily available power source in the form of AC power or a battery pack.

II. Methodology

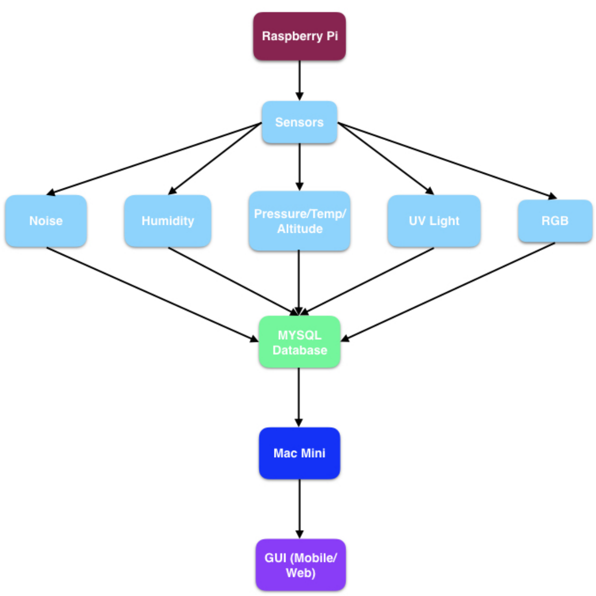

Fig. 1. Sensor data flowchart.

For this project, a microcontroller or mini computer needed to be outfitted with numerous sensors via jumper cables and a breadboard in order to efficiently collect data. The team considered using either a Raspberry Pi 3 Model B [2] or an Arduino Uno as the mainboard [1]. The Arduino Uno was initially considered due to its inherent sensor compatibility, but its lack of built-in wi-fi connectivity led the team to use the Raspberry Pi. An additional consideration was connecting the Arduino to the Raspberry Pi, but this idea was scrapped in favor of cost and power efficiency.

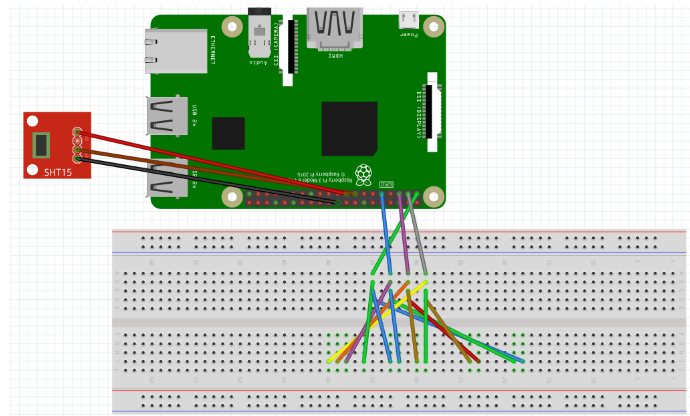

Fig. 2. Fritzing diagram of Raspberry Pi sensor suite. Not pictured above: various Adafruit sensors non-native to Fritzing.

Sensor Suite. The team’s next step was to determine the sensor suite. Multiple temperature, humidity, barometric pressure, sound, and light sensors were tested to determine the most accurate sensor for measuring each type of data. The team also used a RuuviTag Bluetooth Sensor Beacon [6] to check the accuracy of the sensors wired to the Raspberry Pi with a commercially available product. Because the sensor suite created in the lab is intended to be a cost-effective, simple-to-make alternative to commercially available sensors, they must have a reasonably similar level of accuracy. After testing numerous amounts of sensors, the team decided on using the SI1145 UV Index/IR/Visible Sensor, the TCS34725 RGB sensor, the DHT 22 Temperature and Humidity sensor, and the BMP180 Barometric Pressure/Temperature/Altitude Sensor.

Sensor Encasement. After preliminary outdoor testing, it became apparent that the UV and RGB sensors required direct sun exposure to work optimally. The temperature and humidity sensors, however, needed to avoid this exposure to read accurately. From these findings, the team decided that the sensor suite encasement would need to protect the temperature and humidity sensors from the rain, while covering the UV and RGB sensors with either glass or plastic to enable direct sun exposure. (From reading the specification sheet of the SI1145 sensor, the team realized the casing did not need to preserve the UV waves to estimate the UV index.) Using Solidworks and the MakerBot Replicator [8], the team designed and 3D-printed a case that would satisfy these requirements and provide each sensor an optimal environment to collect accurate and meaningful data.

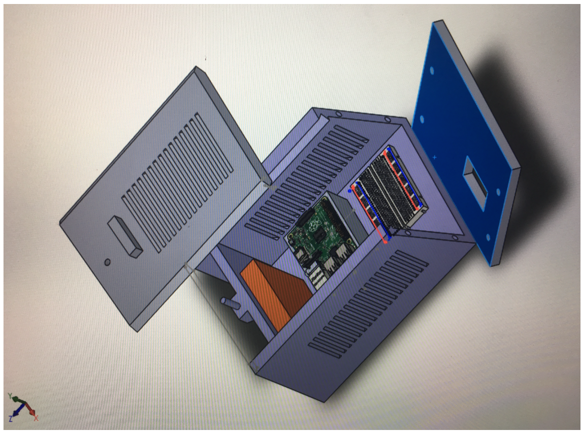

Fig. 3. Solidworks model of the sensor suite case.

Database and Sensor Locations. The sensors took data from three locations around the Altorfer building on the campus of Stevens Institute of Technology: inside of the Altorfer Design Studio (ADS) lab, the second floor hallway of Altorfer, and just outside the windowsill of the lab. The sensor suites were given permissions to select and insert data from specific IP addresses to a MySQL database located on a remote machine in the Altorfer building. Users needing to access and view the data could do so via Secure Shell (SSH) and the appropriate MySQL permissions. Originally, access to the MySQL database was only given to users and sensor suites on a local access network (LAN) within the ADS lab, but for a campus-wide implementation of the project, controlled access from outside the LAN would need to be given to allow members of Stevens Institute of Technology to interact with and contribute to the project. Thus, the appropriate steps were taken to do so.

The power consumption and effects of direct sun exposure on the sensor suite were also measured, and the results are discussed later in this paper.

Temperature sensors. After acquiring the RuuviTag Bluetooth Low Energy (BLE) Sensor, the team compared it the temperature readings from the Bosch BME280 within the RuuviTag to the multiple temperature sensors provided. The sensors themselves were relatively precise when compared to each other (barring one errant sensor), the accuracy of the rating was significantly incorrect. While the RuuviTag would read temperatures near 69 degrees within the lab, the sensors wired to the breadboard would read, on average, about 54.5 degrees. The barometric pressure sensor, for the most part, has shown the most accuracy in recording temperature.

Multiple sensor power draw. Initially, the team planned to experiment with the effects of power draw of multiple sensors on the accuracy of the readings. However, after testing a Raspberry Pi wired with multiple sensors, and observing a relatively high degree of accuracy (compared to the RuuviTag readings and iPhone native Weather app), the team concluded that the power draw's effect on the accuracy of the readings of the sensors was negligible. Using the *Kill A Watt™* [7] wattmeter to measure power draw, preliminary testing of just the Raspberry Pi showed that it consumed 0.01 kilowatt hours (kWH) in three hours and twenty five minutes. A Raspberry Pi with two sensors consumed 0.06 kWH in approximately twenty hours and fifteen minutes, approximately three hours and twenty two minutes per 0.01 kWH, proving that sensors had an effect on power draw. Tests were also done to determine the length of time a Raspberry Pi wired with sensors would last while being powered on a Jackery Rechargeable Battery Pack. Initially, a test was done on a Raspberry Pi with no sensors, which lasted approximately twenty-two hours. Another test was done on a different Raspberry Pi with the four sensors used in the sensor suite. The team expected this Raspberry Pi to last a shorter amount of time than the Raspberry Pi with no sensors. However, tests showed that the Raspberry Pi with four sensors lasted thirty and a half hours, eight and a half hours more than the Raspberry Pi with no sensors. What the team did not recognize was the presence of heat sinks on the Raspberry Pi with four sensors and the absence of heat sinks on the other. Heat sinks clearly had a significant effect on power consumption. Further tests could be done to determine the life of a

Raspberry Pi with heat sinks and no sensors, but because the ideal life, for the project, of the sensor suite on the battery pack was only twelve hours, the readings obtained by both the Raspberry Pi with no heat sinks and no sensors and the Raspberry Pi with heat sinks and four sensors verified that the battery pack was sufficient for the project's purposes.

Direct sun exposure. The team, after running preliminary outdoor testing, realized that the presence of direct sun exposure on given sensors was of significant concern, but for different reasons. After more testing, the team established that the UV sensor required direct line of sight with the sun to be able to return accurate readings of the UV Index. The barometric pressure and temperature sensors were negatively impacted by this exposure, heating up significantly and reading inaccurately (a problem shared by both the DS18b20 temperature sensor and the RuuviTag's BME280). The RGB sensor acted as expected, reaching maximum values when in direct line of sight of the sun. These findings led the team to further consider the structure of the sensor suite encasement.

III. Results

Temperature sensors. The team found that temperature sensors were significantly more difficult to work with than first expected. While the initial expectation was that the temperature sensors would be accurate immediately following wiring, what we found were there sensors that would change seemingly at random, there were also imperfections within the sensors that had relatively stable temperature readings. As mentioned earlier, the Ruuvitag's BME280 gave an almost entirely different reading than that of the DS18b20. For a significant period of time, the temperature sensors all averaged about a fifteen degree difference from their readings and the readings given from the RuuviTag. Initially, the team had considered whether or not the RuuviTag was reading the temperature or simply taking location data and reading a corresponding (i.e. outside) temperature. However, after finding a discrepancy between the temperature displayed and the outside temperature, the team determined that the sensor was operational.

Ultimately, the team found that two sensors (the BMP180 Barometric Pressure/Temperature/Altitude sensor and the DHT22 Temperature and Humidity Sensor both showed consistent accuracy in recording temperature. Knowing this, the team decided to test the precision of readings between the two, the results of which are discussed later. But because both sensors measured other things, in addition to temperature, the team ultimately decided that both sensors were suitable for the sensor suite.

Humidity sensors. Two humidity sensors were tested, the DHT11 Temperature and Humidity sensor and the DHT22 Temperature and Humidity sensor. The DHT11 was significantly more cost efficient than the DHT22, but its accuracy lacked. When compared to local weather readings, the DHT22 was much more accurate and was suitable for the sensor suite.

UV/RGB sensors. After a short recording session, it was obvious that the UV sensor requires direct line of sight with the sun. Meanwhile, the RGB sensor gave values of red green and blue light as values from 0-1024. Values reached maximums when put in direct contact with sunlight, and lowered accordingly once brought back indoors and exposed to artificial light. The team hypothesized that the amount of sunlight in a room, as opposed to artificial light, was a contributing factor to its "comfort level," but no tests were conducted to prove this. But because of this, the SI1145 UV Index/IR/Visible Sensor and the TCS34725 RGB sensor were found suitable for the sensor suite.

Noise sensors. The DIYMall noise sensor was the team's first sensor. After a complicated wiring process, the team noticed that the noise sensor was unresponsive to noise, outputting a singular value. This showed the inefficacy of the sensor and that it was not suitable for the sensor suite. No other noise sensors were available at the time for testing, therefore, no noise sensor could be placed in the sensor suite. Noise is still a significant issue and will be a part of future work on the project.

Data readings. Data was collected in the ADS Lab for a full week. Measurements made include, red, green, blue, and clear light, color temperature, luminosity, visible and infrared light, the UV index, pressure, sea level pressure, relative humidity, and temperature (which was measured on two different sensors). Graphs for the temperature, pressure, and humidity readings are provided.

The team gathered only a few conclusions from the red, green, blue, and clear light (See Fig. 4), color temperature, luminosity, visible and infrared light, and UV index readings, the most significant being that all readings reached a maximum value when the lights in the lab were on and a minimum value when the lights in the lab were off.

The temperature readings (See Fig. 5) gathered from the two different sensors displayed a negligible difference, showing that both can be relied upon to gather temperature readings. Temperature readings peaked during the day and reached a minimum during the night. Particularly interesting was the fact that temperature readings were relatively high during the week compared to the weekend, which the team attributed to the presence of multiple people in the lab. It must also be noted that a lab occupant raised the temperature on the thermostat on multiple occasions throughout the duration of the project. It is not known whether an instance of this occurred during this particular week of data collection, but it may very well have contributed to the relatively higher peaks in temperature during the week. Understanding this is on the list of future work.

Pressure and sea level pressure readings also displayed a negligible difference. One interesting observation made was that pressure started to drop significantly as overall temperatures started to decrease as well. Temperature and pressure are directly proportional, which complies with the Ideal Gas Law.

Humidity (See Fig. 6) significantly increased during the weekend. Similar to the conclusion the team made with regard to the temperature readings, the team also attributed this hike to the presence, or absence in this case, of people in the lab. During weekdays, people come in and out of the lab, and the opening of the door of the lab provides a brief moment of ventilation, somewhat moderating the humidity levels. During the weekend, no one is here to trigger this sort of ventilation, which caused the humidity to peak.

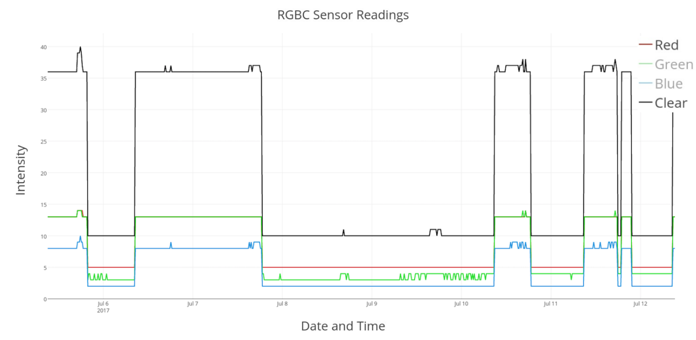

Fig. 4. Red/Green/Blue (RGB) light graph over time.

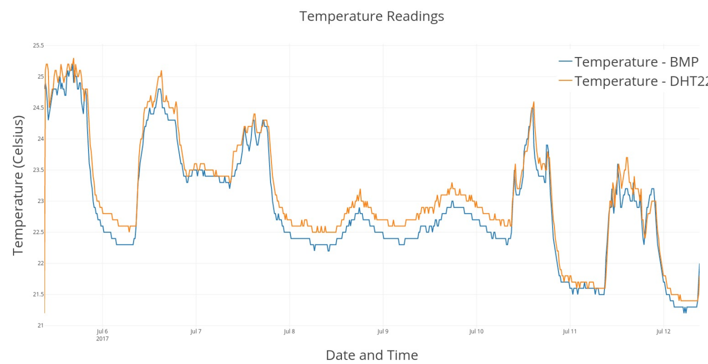

Fig. 5. Temperature graph over time.

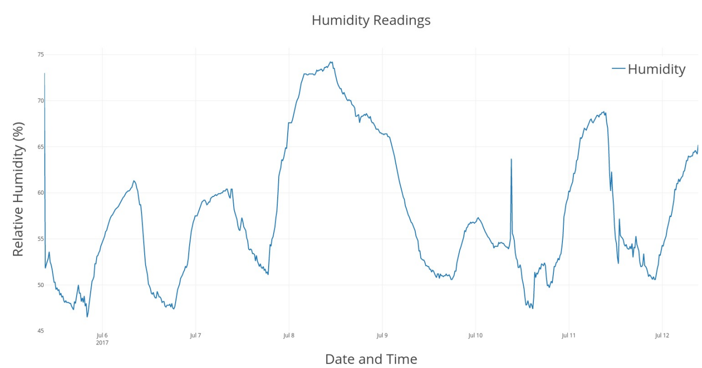

Fig. 6. Humidity graph over time.

IV. Discussion

Creating an interface for citizens to both read and write (i.e. download/upload) environmental data involves complex infrastructure. Simplifying the process is crucial not only in expanding smart space technology, but also involving young, STEM-minded individuals in actively learning and understanding their environment.

Future work will be done to create an accessible and easy-to-use mobile application available for students, faculty, and administrators at Stevens Institute of Technology to view information about the different spaces on campus. Plans are also being developed to introduce this technology to local high school students in order to enhance their STEM education and provide them with the tools they need to learn more about their own homes and environment.

Acknowledgement

This research was supported by the Pinnacle Scholars Program at Stevens Institute of Technology.

References

1. Arduino.cc, ‘Arduino Uno Rev 3’, 2017. [Online].
2. Raspberrypi.org, ‘Raspberry Pi 3 Model B’, 2017. [Online].
3. G. Laput, Y. Zhang, C. Harrison, “Synthetic Sensors: Towards General-Purpose Sensing,” May 6th, 2017
4. The Social Life of Small Urban Spaces. (1980). [film] Directed by W. Whyte. USA: Municipal Art Society of New York
5. M. Craglia and C. Granell, “Citizen Science and Smart Cities,” European Commission Joint Research Centre Institute for Environment and Sustainability, Luxembourg. 2014.
6. Tag.ruuvi.com, ‘What is RuuviTag?’, 2017. [Online].
7. P3international.com, ‘Kill A Watt’, 2017. [Online].
8. Makerbot.com, ‘The All New Makerbot Replicator+’, 2017. [Online]. https://www.makerbot.com/replicator/