Sophisticated 1:4 Scale Internet of Things Model Home for K-12 STEM Outreach

Luke Kindelin, Joseph Morgan, Jacob Brookins, Avery Tijerina and Abigail Morris

January 10, 2019

Sophisticated 1:4 Scale Internet of Things Model Home for K-12 STEM Outreach

Luke Kindelin, Dr. Joseph Morgan, Jacob Brookins, Avery Tijerina, Abigail Morris

Texas A&M University – Electronic Systems Engineering Technology Fermier Hall Room 111, 3367 TAMU, College Station, TX, 77843-6667, US E-mail: kindelin@tamu.edu

ABSTRACT

LANA Advanced Systems a multidisciplinary Capstone Project team, has designed and built a quarter scale model home and embedded system interface board to connect control modules to enable K-12 students to interact with a high quality educational manipulative to foster interest in Science, Technology, Engineering, and Mathematics (STEM) topics. The interface board has been designed to be able to support future modules. This quarter scale model home, known henceforth as HANS (Home Automated Networking System), is four feet wide, eight feet long, three feet high, and has a roof with a one foot peak. The roof is split evenly between an asphalt shingle analog and a corrugated metal analog that one would find on a real home. HANS is equipped with six different sensors in each room; these sensors are ambient light, ambient temperature, relative humidity, pressure, moisture level, and motion detection. All sensor data is processed through an intelligence board, The Texas Instruments CC3200, to a cloud platform, Cayenne, and is displayed for user interaction. HANS is also equipped with control modules. These control modules include servo motors for automatic window shades, a front door lock, zone control air vents, and motion flags. HANS is also equipped with five cameras located around the model home. One in each room that displays a live view of the control modules, and one outside that shows the heat lamp simulators and the exterior of the house.

The purpose of HANS is to be an educational manipulative for STEM outreach in primarily K-12 education. Teachers from around Texas will come to Texas A&M to learn more about STEM topics, and HANS will help facilitate this learning. When these teachers return to their schools with this new knowledge, they will also be able to access HANS to run experiments remotely with students. This can be accomplished through Cayenne, a cloud based service , and the WyzeCam smartphone application which displays live and recorded video feeds from the

house . Over the course of 10 months, LANA Advanced Systems has designed and built HANS. The design process included electrical design as well as mechanical, structural, and software design.

Introduction/Background

The Home Automated Networking System (HANS) is an educational manipulative for the purpose of Science, Technology, Engineering, and Mathematics (STEM) outreach and applied research into the field of Internet of Things (IoT).

Because STEM outreach enables interested students to experience unique learning potentials, The Texas A&M University Engineering Technology and Industrial Distribution (ETID) department requires a model home for their summer STEM education program. This program brings educators from around the state to Texas A&M to give them tools to excite young minds about learning about STEM. Internet of Things describes the integration of intelligent devices into our everyday life; IoT enables these devices to send and receive data to the internet, usually via a cloud based platform. IoT is used in a variety of applications in everyday life; these applications include but are not limited to: health and welfare, safety and security, energy and cost management, and home automation and convenience. An example of health and welfare is a heart monitor that is connected to an application on a smartphone. Safety and security typically consists of smart cameras located at entry points outside a house that will notify the homeowner if it sees motion activity. An example of energy and cost management is a smart Heating, Ventilation, Air Conditioning (HVAC) unit that can be updated via an application on a smartphone. The category of home automation and convenience would include smart window blinds that react to lighting from inside and outside the home. For HANS specifically, we are focusing on home automation and convenience. This will take the form of smart blinds, lights, door locks, zone controlling HVAC vents, and a motion flag to simulate human activity[1].

Description of Project

The Electronic Systems Engineering Technology (ESET) Department at Texas A&M University has continuously enhanced its curriculum into a learning experience that culminates with the completion of a two-semester Capstone project. This ever evolving program now includes more laboratory experience than ever and over half of the courses involve major projects that utilize real industry sponsors along with real industry projects. These hands-on learning environments lead to a type of experiential learning that is unrivaled by other more theory centric programs. By the time that an ESET student graduates, he or she will have pursued, managed, and delivered a real life industry project. The sponsors for these projects vary from smaller local companies to the Department of Defense and the United States Air Force to NASA[2]. This rigorous culmination experience provides a crucible through which aspiring engineers grow and develop into industry-ready professionals. Capstone projects expose developing engineers to experiences in other aspects of industry such as project management, project planning, budgeting, and marketing. These useful life skills give TAMU ESET students a beneficial competitive edge in industry with marketable skills and experience defining and solving unique engineering challenges.

With this context in mind, LANA is creating a scaled model home for the purposes of STEM outreach and applied research in the field of smart home technology. The model home will function as a tool for educators to use in order to ignite a passion in the hearts of their students for engineering and technology. This will be focussed on the fields of additive manufacturing, smart network connectivity, and energy management technology. The Home Automated Networking System (HANS) provides a solution for this need for a model smart home with functionality using Internet of Things. Internet of Things refers to a collection of devices connected through a network. These devices can be a multitude of different things to include computing devices, sensors, and physical objects such as actuators or relays. There are four main areas that make up IoT: home automation and convenience, energy cost and management, health and wellness, and safety and security. This understanding of IoT is one topic that four researchers from Texas A&M University are trying to teach. Those four researchers from the Engineering Technology and Industrial Distribution (ETID) Department at Texas A&M University were award a National Science Foundation grant to promote interest in STEM careers in classrooms across Texas. The ETID department will be utilizing HANS primarily as a teaching tool to promote interest in STEM careers with a long-term objective towards remote outreach. HANS will be used in STEM education by showing teachers different lab experiments and teaching them how they work. These experiments will all be relevant to the fields of smart technology and IoT connectivity as they can be applied in a home[3].

For the scope of this project, this technology is applied to a number of control and sensor parameters within the functionality of the house. HANS has fifteen functional requirements and performance specifications. These range from the physical measurements of the model to the sensor requirements to the internet connectivity protocols. HANS has the ability to control internal temperature, light levels, and a number of other physical systems such as door locks and window blinds. Along with these functionalities, the system has the ability to sense ambient temperature, internal temperature, internal lighting levels, ambient light, humidity, water levels, and motion. All of these sensors are connected to a local network through a custom designed intelligence board. This multi-functional intelligence board, paired with a TI CC3200 Launchpad will provide the monitoring and control of the system. These aspects will be covered in more detail in this paper.

Conceptual Design

Once the ESET seniors have formed a team and solidified a sponsor and faculty advisor for their project, a System Design Process document is produced during team meetings with their stakeholders. The document is a working process that allows the team and stakeholders to monitor the progress of the project design. The initial step in the design process is to work with the customer to identify the problem statement and the concept of operation. Then, functional requirements are developed to solve the problem statement and begin the design of the prototype. These functional requirements are non-quantitative descriptions that the final electronic system must deliver.

From the functional requirements, a conceptual block diagram (CBD) of the electronic system is drawn to depict the high-level requirements of the functional design. The CBD is constantly referred to and updated by the sponsor and team based on the team's research. Finally, the CBD is used to generate performance specifications, which is explained in detail in the *Functional Design* section.

The CBD created by LANA advanced systems for the Home Automated Network System is shown in Figure 1. It shows the electronic system implemented inside a single HANS room. A DC power converter connects to a wall outlet providing 12V DC to the LANA power board. The power board contains four RJ12 ports with low-side switching and four ports with dual-H-bridge capabilities. The TI CC3200 Launchpad, shown in red, is the intelligence board that is powered by the LANA board and used to control the servos. The CC3200 gathers sensor data from the TI Boostxl Sensor Pack which contains all of the sensors to satisfy the functional requirements. The CC3200 communicates via WiFi to a local router that will publish sensor data and subscribe to control signals from an open source Graphical User Interface (GUI) called Cayenne. In addition, the power board will provide 3.3V to activate a motion and moisture sensor that the CC3200 will read from its digital and analog pins respectfully. The CC3200 will also power a Wyze Camera that will be available for students and teachers to view the interior of the each room in HANS.

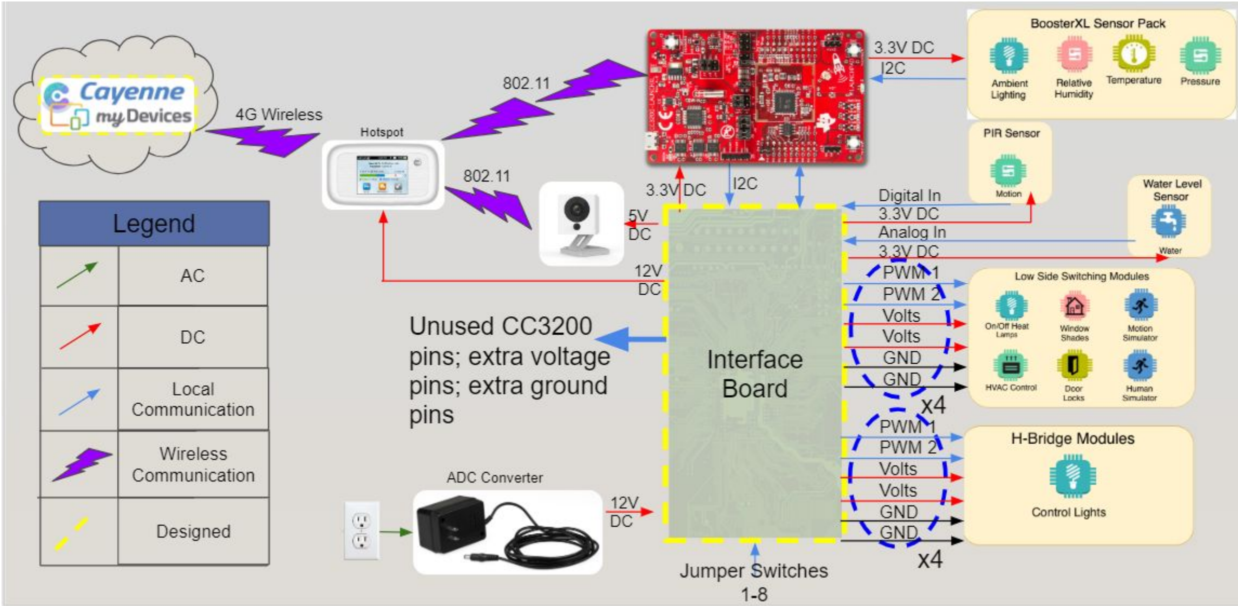

Figure 1: Conceptual Block Diagram for single Interface board system inside HANS scaled model home

A CBD for the overview of the full model home is shown in Figure 2. This CBD diagram depicts the top view of inside the home with all five electronic systems showing the scope of the delivered product. The system outside the home will be used to control the HVAC system that will be placed underneath the model home. The HVAC system's settings will be controlled using the IR circuit already installed. The CC3200 will program GPIO pins to control an Arduino UNO which will supply adequate current to transmit the proper IR signals.

Figure 2: Conceptual block diagram for HANS showing system of systems integration across independently controlled room and environmental sensing and control modules

Finally, an example of the GUI that teachers and students will be able to access is shown in Figure 3. As shown, the users will be able to modify the desired temperature inside each room, change individual window blinds, simulate a small motion using a flag, change the room brightness, activate a energy save mode, and read from all five sensors inside the room.

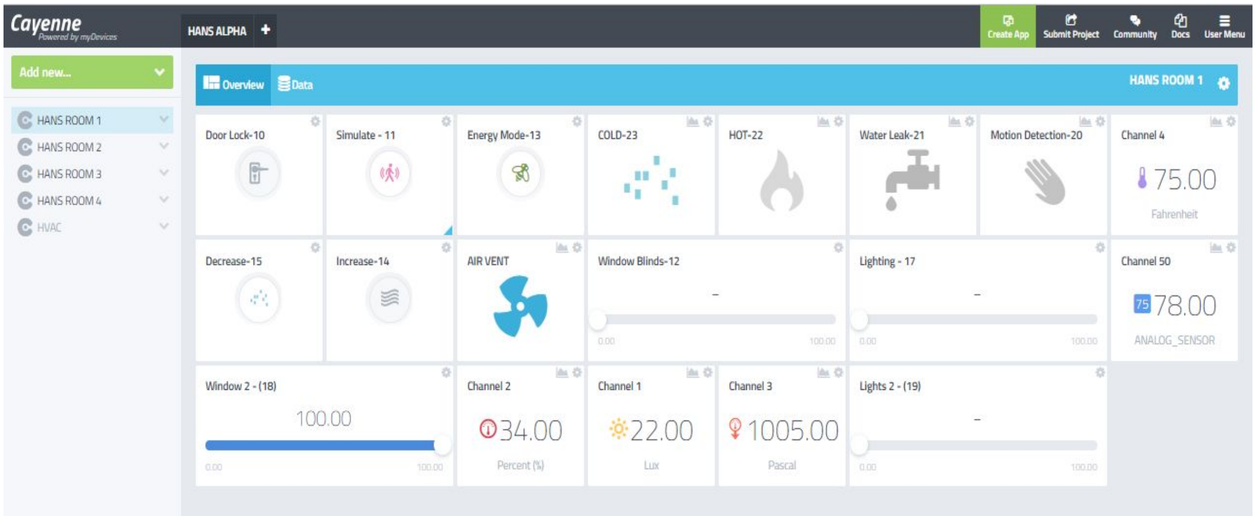

Figure 3: Cayenne Dashboard for HANS living room module showing remote door lock, dual variable window shade controls, dimmable LED lighting, motion triggering and sensing, water detection and live sensor data values

Additionally, the HVAC dashboard, shown in Figure 4, will allow the user to turn on or off the HVAC, modify fan speed, and activate dehumidification.

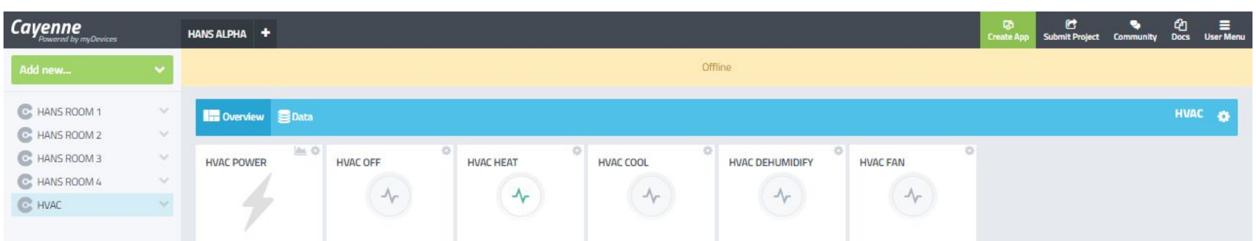

Figure 4: Cayenne Dashboard for HVAC module which can remotely control heating, air conditioning, dehumidification, and ventilation of the HANS environmental control system

All the functionality explained will allow teachers to use these tools to promote and teach students the possibilities of applying the Internet of Things to a home. Moreover, added labs can be created to improve and learn more about the field of IOT by adding new modules that are readily interfaced to the LANA power board.

Functional Design

An important element to any engineering project that integrates hardware and software into the real world is how the design meets what is called an engineering specification. These engineering specifications are measurable and quantifiable attributes that the product is designed to satisfy. The HANS educational manipulative is no different. To measure and quantify the environment inside each room, it utilizes a Texas Instruments BoostXL-Sensors which includes a OPT3001 Ambient light sensor, as well as a Bosch BME280 Temperature, Humidity and Barometric Pressure sensor suite. In addition to these, the HANS interface board has internal routing for attaching to the SeeedStudio Grove Passive Infrared Motion sensor as well as a SeeedStudio Grove Immersion Moisture sensor. Each of these is connected to the Texas Instruments CC3200 Launchpad Microcontroller that in turn uses WiFi 802.11g to connect to a 4G modem that allows communication across the internet to Cayenne, which is used as a data broker to host our user interface. The user interface can then be used by students to directly manipulate variables inside our house, and adjust things like the position of window shades to let in more or less ambient light, Heating and Air Conditioning requests to adjust the temperature and humidity, and motion simulator flags that can be used to activate the motion detectors as described earlier in Figure 3.

LANA has designed, documented and delivered a working prototype that includes the capability to perform all of these functions and more. They have internally developed a fully functional 96 cubic foot scaled home with impeccable detail down to the scaled 2x4 studs, internal insulation, both internal and external lighting, as well as internal and external camera systems that are viewable from the internet. This is important to the educational goals of the project, as it allows any classroom with an internet connection to directly connect to the HANS system, then both control and measure observable and unobservable inputs and outputs of the house in near real time. Figure 5.

Figure 5: Highly detailed HANS system utilizing 1:4 scaled single pane glass windows, realistic stucco finish, scaled 3 tab shingles, and scaled galvanized roofing sections

The house has been built as a platform for further integration, and so the electrical hardware has been designed and built as openly as possible. The HANS Custom PCB is built with both a high and lower current output capabilities so it can simultaneously drive up to 8 servos and 4 full h-bridge devices like motors or LED lighting strips per room using the onboard I2C PCA9685 PWM generator. The HANS board has a single 12V 10A wall wart input per room providing power to the board, which then utilizes 3 different voltage regulators onboard to provide power to each external port, as well as the CC3200 and all of the sensors mentioned earlier. Figure 6.

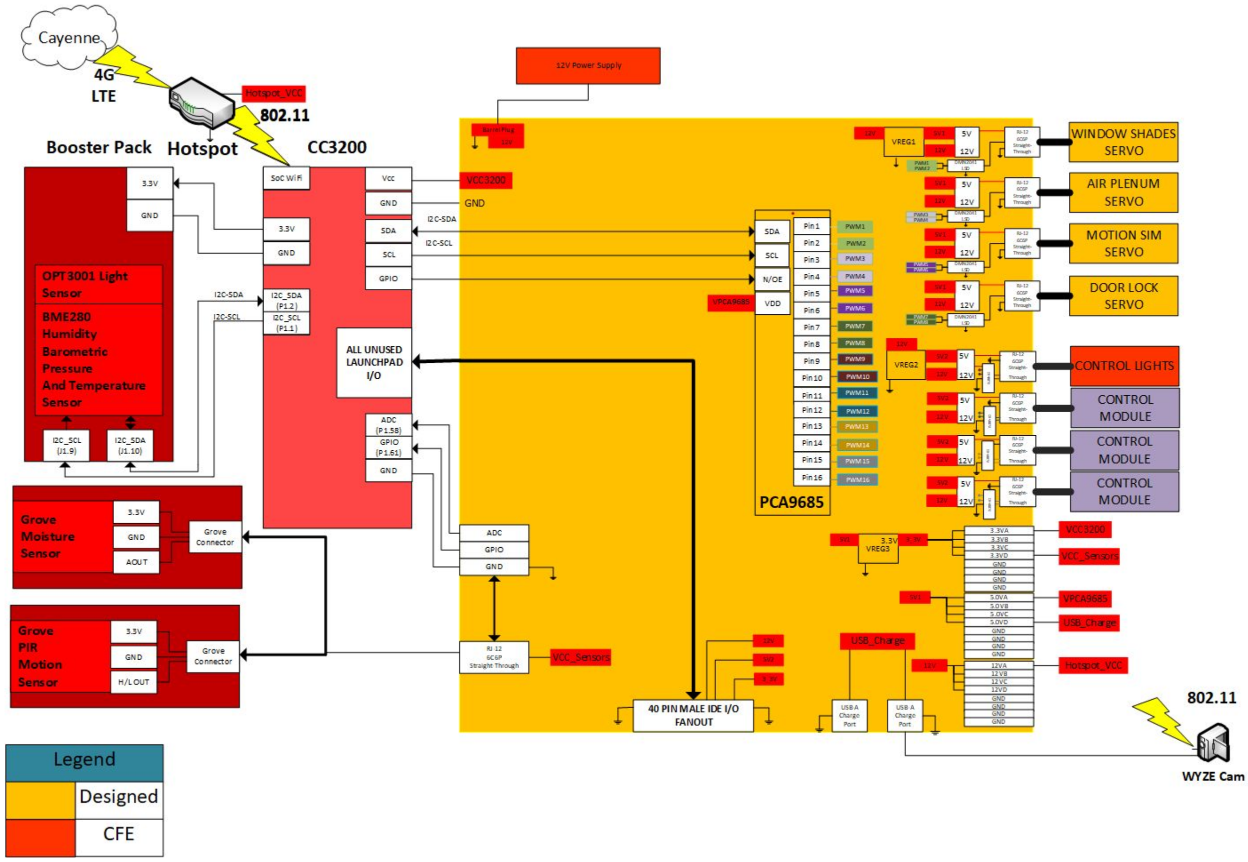

Figure 6: Functional block diagram for the HANS electrical interface board detailing electrical connections, major hardware groups, and general layout and expected usage

These ports are designed to be both durable and scalable, so RJ-12 6 Pin 6 Conductor jacks were used for all expansion modules. Figure 7. This way if a module needs to be moved to another room, it only takes a few seconds to disconnect and reconnect the entire board. For the same reason, the HANS interface board has been designed to utilize a stackable architecture following the Texas Instruments Launchpad architecture, and additionally all unused I/O from the CC3200 is routed across the HANS board to a 40-pin IDE connector for even further expandability.

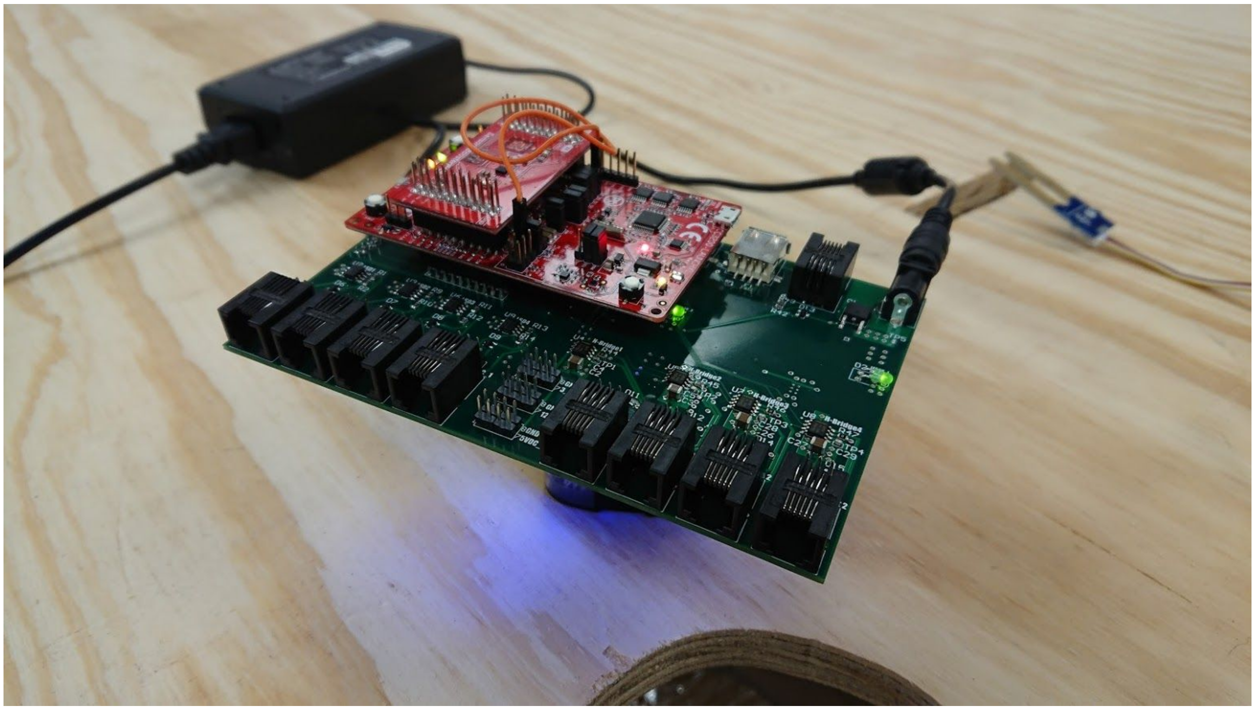

Figure 7: Fully functional HANS custom interface board with Texas instruments CC3200 and BoostXL sensorpack intelligence stack providing power and all necessary sensors and control module outputs to satisfy and exceed all project requirements as well as support future expandable modularity

This is a fully integrated system, the conceptualization and development of which has been iterated weekly at meetings with both Engineering Technical Assistance Advisors, as well as Engineering Technology Faculty at Texas A&M University. The two semester long development process has been managed by four undergraduate seniors in addition to their other coursework, and represents over 2,500 documented man hours of team effort from initial conceptualization to final delivery of the functional HANS prototype.

Next steps and Conclusion

The Electronics and Mechatronics programs at Texas A&M University see significant value in including Internet of Things technology in undergraduate education, applied research and STEM outreach activities. Working with secondary-level teachers as part of an NSF-funded project over the past two summers, the programs realized the value in having a scale model of an IoT home that could be used to conduct remote experimentation (system monitoring and control), data collection, reduction, and analysis. To bring these concepts and processes to life, both programs agreed to invest in the design and development of a fully instrumented house that had the ability to be monitored and controlled over the internet from multiple remote locations. Through the capstone design sequence, a group of four ESET and MXET students were able to deliver a working prototype of the educational manipulative envisioned by the faculty sponsors and advisors.

A number of lessons learned have come from the project as the team designed and implemented their solution. These include:

1. Using off-the-shelf technology whenever possible will allow for the replication and improvement of the IoT capability.

2. To augment the off-the-shelf technology, a general-purpose data acquisition and control board has added to the capabilities of embedded intelligence systems while reducing the complexity and numbers of components/modules that need to be interfaced together. Use of common "connectoring" makes the support and maintenance functions more straightforward and time efficient.

3. Using a internet-based Dashboard approach to IoT Broker implementation and the publishing and subscribing processes will allow other users to quickly set up and conduct a wide range of experiments.

4. Having the ability to acquire and log data to common file formats will allow the subsequent data reduction, analysis and conclusions to be easily extracted for each experiment that is conducted.

5. Adding a number of "interesting" features (cameras, window blinds, door locks, etc.) should increase the interest and motivation of secondary education students to engage in the technology and conduct experiential learning activities.

This model home be used in a number of different ways, but will focus on doing STEM outreach to remote classrooms at high schools and junior high schools to support Math, Science and Engineering projects. An example of this process would be as part of a secondary education classroom activity, students would formulate an experiment and submit it to the ESET/MXET Programs for review, acceptance and scheduling. Once the experiment is set up, that group of students would be granted overall control of the resources while other groups will have the ability to monitor the experiment using the video cameras and the data collected. Once completed, the next student group would gain access to the IoT home to conduct their approved experiment. In addition to these types of individual experiments the ESET/MXET programs see opportunities to conduct contests where multiple student teams would create monitoring and control algorithms that would satisfy a set of goals such as power consumption, etc. Each team would execute their algorithm from a known set of environmental conditions, collect data and generate a graphical-based report indicating the results obtained.

The next steps in this project will be to develop educational materials to support teachers in the use of the IoT House in their classes. To accomplish this goal, the ESET/MXET programs have partnered with the College of Education. A Ph.D. candidate with very relevant experience has agreed to work with the programs in the development of course modules that can be used at the secondary educational level. This individual has been working with team for a period of four weeks to learn about the technology. The move forward plan would be use the materials he creates as part of the third year NSF-funded workshop for STEM teachers. Based on their success and feedback, these modules would be made available to other STEM teachers at the end of the summer 2019 for use in the Fall 2019 and Spring 2020 semesters[4].

Acknowledgement

This work was performed as the Home Automated Networking System (HANS) prototype, funded and supported by the Electronic Systems Engineering Technology program at Texas A&M University in College Station, Texas. All portions of the design work was performed by LANA Advanced Systems, an undergraduate team consisting of 3 undergraduate seniors in ESET(Electronic Systems Engineering Technology), and 1 undergraduate senior in MXET(Multidisciplinary-Mechatronics Engineering Technology).

References

1. Morgan, J. A., & Porter, J. R., & Johnson, M. (2018, June), *IoT-based Building Automation and Energy Management* Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah. https://peer.asee.org/30732

2. Ryan,C., & Crandall,A., & Martinez, M., & Kennedy, D., & Ecolango, K., & Porter, J. R., & Morgan, J. A. (2018, April), *Space-Based Capstone: Public-Private-Academic Partnership in the Making* Paper presented at 2018 ASEE Gulf-Southwest Conference & Exposition, Austin, Texas.

3. Abraham, S. (2016, June), *Using Internet of Things (IoT) as a Platform to Enhance Interest in Electrical and Computer Engineering* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.27149

4. Porter, J. R., & Morgan, J. A., & Johnson, M. (2017, June), *Building Automation and IoT as a Platform for Introducing STEM Education in K-12* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/27987

LUKE KINDELIN

Luke Kindelin is a senior undergraduate student in the Electronics Systems Engineering Technology major within the College of Engineering at Texas A&M University. He was a founding member of the Austin Community College Batlab Makerspace, and volunteers regularly with the Austin Texas Independent School District as a youth robotics mentor. Based on his applied IT Networking contributions supporting 4G and 5G Research at Texas A&M, he has served as a judge and moderator in the wireless communication and antenna characterization portions of the Annual Texas Science and Engineering Fair (TXSEF) where Texas middle and high schools come from across the state to compete in STEM topics. Luke has accepted a job in the private sector as a RF Test Engineer in the Austin Area upon graduation.

DR. JOSEPH MORGAN D.E. P.E.

Joseph A. Morgan has over 20 years of military and industry experience in electronics and communications systems engineering. He joined the Engineering Technology and Industrial Distribution Department in 1989 and has served as the Program Director of the Electronics and Telecommunications Programs and as the Associate Department Head for Operations. He has served as Director of Engineering and Chief Technology Officer in the private sector and currently a partner in a small start-up venture. He received his BS degree in electrical engineering (1975) from California State University, Sacramento, and his MS (1980) and DE (1983) degrees in industrial engineering from Texas A&M University. His education and research interests include project management, innovation and entrepreneurship, and embedded product/system development.

JACOB BROOKINS

Jacob Brookins is a senior undergraduate student in the Electronics Systems Engineering Technology major within the College of Engineering at Texas A&M University. Jacob has distinguished himself during his time at Texas A&M with his enrollment in the Corps of Cadets, where he served as a member of Company D-2, a Ross Volunteer, as well as with the Major Unit Commander for the 3rd Brigade his senior year. Jacob has also distinguished himself at the national level by winning the prestigious Commandant's trophy for being the highest-ranked graduate of his 363-member class at the Marine Corps Officer Candidate School at Quantico, Va. Jacob has accepted a commission in Helicopter Flight Special Training with the United States Marine Corps upon graduation.

AVERY TIJERINA

Avery Tijerina is a senior undergraduate student in the Electronics Systems Engineering Technology major within the College of Engineering at Texas A&M University. A true polymath, Avery has achieved academic distinction in Physics, Astronomy, Philosophy and Mathematics. He has developed fellow undergraduate students by acting as a teaching assistant in Mixed Signal Semiconductor Testing classes and dominates as a first resource for many of his colleagues because of his openness and ability to explain difficult concepts to any audience. Avery has accepted a job in the private sector as a Silicon Test Design Engineer in the San Jose Area upon graduation.

ABIGAIL MORRIS

Abigail Morris is a senior undergraduate student in the Multidisciplinary Engineering Technology major within the College of Engineering at Texas A&M University. She will be a member of the first graduating class for her major when she graduates in April 2019. Abigail is pursuing a job in the private sector as a Robotics Design Engineer in the Houston Area upon graduation.