Capstone Project Proposal

Second Generation Low Power Environmental Sensor Suite

Team 13
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February 3, 2022
Version 1.1

Overview

The 2022 Capstone project will continue the work on a Low Power Environmental Sensor Suite, which was begun with the 2021 Capstone team. The Sensor Suite is a network of low power wireless motes capable of integrating a variety of sensors, collecting and transmitting data wirelessly to a remote computer, accessible to the end user. The sensor suite can incorporate sensors such as temperature, humidity, carbon dioxide (CO2), oxygen (O2), nitrous oxide (NO2), wind speed, vibration via an accelerometer, and moisture in the ground. Each mote is designed with low power in mind capable of lasting as much as possible (1 or 2 months) without requiring an external power source, or change of batteries.

Background and Problem Statement

There are many agricultural and industrial applications for a low power, wireless, sensor suite. Managing successful crops requires up to date knowledge of weather patterns, including quickly occurring events such as unexpected drops in temperature that can have a major negative impact on the season's produce. Farmers have a need to monitor temperature, humidity and other environmental factors enabling them to respond to protect their crops, for example, by employing heaters for such an unexpected temperature drop.[1] Building managers may need easy to install sensors in locations where power and data cabling is not possible, and they need the device to function on battery power for an extended period of time.

The Department of Energy has sponsored this project to utilize sensors for nuclear waste monitoring to detect nitrous oxide. This greenhouse gas is a known emission at nuclear waste storage facilities, but it is unknown how much is emitting and requires sensor data to better measure and understand how much is emitted.

Many of these applications require the flexibility provided by a wireless network wherein each mote can act as a data relay node, allowing for a large distance from the ground station to the furthest out mote. These are only a few examples demonstrating the wide range of uses of such a low power, wireless sensor suite.

This Capstone project for 2022 will continue the work of the 2021 Capstone project, to design and build a

[1] K. Brun-Laguna *et al.*, "Using SmartMesh IP in Smart Agriculture and Smart Building applications," *Computer Communications*, vol. 121, pp. 83–90, May 2018, doi: 10.1016/j.comcom.2018.03.010.

low power, wireless, sensor suite. We aim to use the SmartMesh IP as the wireless network mesh for transmitting data. A microcontroller will be used to add the various sensors and will be programmed to enter an ultra low power sleep state when not collecting data. The sensor data will be stored on on-board and all data will be accessible to the end user on a remote computer. We will build a single device, called a mote, consisting of a SmartMesh DC9018B-B evaluation board, connected to the microcontroller and chosen sensors, and batteries to power the mote. This will be enclosed in a weather resistant IP65 enclosure.

Product Design Specification

The Product Design Specification explains what we will design and build on the Sensor Suite during the 2022 Capstone period. The following sections describe the Sensor Suite, the stakeholders, design requirements, specifications, and how the final product will be used.

Concept of Operations

The Sensor Suite to be designed is a single mote with functioning sensors able to collect sensor data, store them on an on-board storage, and wirelessly transmit the collected sensor data to a remote computer. The mote will run on batteries, and may have a solar power option. It has an onboard microcontroller capable of running at very low power, including a ultra-low power sleep state with the intention of maximizing battery life, allowing the mote to cycle through a wake state, collecting, storing and transmitting data, and back to a sleep state, functioning for long periods of time before needing any intervention including battery replacement. Depending on the installed onboard sensors, the mote will be capable of collecting temperature, humidity data, as well as gaseous concentrations, such as NO_2, CO_2, and O_2. The Sensor Suite is intended to have a flexible design allowing various sensors to be installed, removed, or turned off, in order to give the end user the flexibility they need for their application. The mote will be enclosed in a weather resistant IP65 container allowing it to function outside in inclement weather, or other locations near water and moisture.

Stakeholders

The primary stakeholder for the Environmental Sensor Suite is PSU faculty, David Burnett, who requires the sensor suite for his research purposes.

The Department of Energy is sponsoring this project for their purposes in detecting NO_2 emissions at nuclear waste storage facilities in Richland, Washington.

Other stakeholders may include farmers, building engineers, and others working with David Burnett.

Requirements

The requirements for the Sensor Suite are tiered for those that we *must* deliver, *should* deliver, and *may* deliver.

Musts

By the end of the Capstone 2022 project, we must have completed the following requirements. The microcontroller must be able to enter a low power state when not in use, and the whole system must use less power than that achieved by the Capstone 2021 team (should use less than 325mW without lower power mode, and use less than 135mW with lower power mode). The system must be able to transmit data wirelessly to a remote computer and be able to store data to an on-board storage. The system must be able detect and collect temperature, humidity and nitrous oxide data. Each mote must be enclosed in an IP65 weather resistant enclosure, and run on battery power for a minimum of 1 month before requiring battery replacement.

- The microcontroller must be in a low power state when not in use.
- The system must be able to transmit data wirelessly to a remote computer.
- The system must be able to store data to on-board storage.
- The system must consume less average power compared to last year's system.
- The system must include at least 3 field monitoring sensors.
    - Temperature
    - Humidity
    - Nitrous Oxide
- The system must be placed in a weather resistant IP65 enclosure.
- Each mote must be able to run on battery power for a minimum of 1 month.

Shoulds

The "shoulds" are the first stretch goals and include the following requirements. The system should last at least 1 year on batteries. The system should be built on a PCB assembly, and include the sensors to collect carbon dioxide and oxygen data.

- Each mote should be able to run on battery power for a minimum of 1 year.
- The system should be converted into a PCB assembly.
- The system should also include the following 2 field monitoring sensors.
    - Carbon Dioxide
    - Oxygen

Mays

The "Mays" are the second stretch goal and include the following requirements. The system may use rechargeable batteries and have power scavenging capabilities from either solar or wind power. Each sensor's sampling rate may be adjusted by the end user. Each mote may be able to perform the wake to sleep cycle autonomously, and may have a battery lifetime of 5 years. The system may include sensors to collect wind speed, accelerometer, light intensity and water detection data.

- The system may use rechargeable batteries.
- The system may have forms of power scavenging such as solar power and/or wind power.
- Every sensor may have a programmable sampling rate by the user.
- Each mote may be able to perform wake / collect data / sleep cycle autonomously.
- Each mote may be able to run on battery power for a minimum of 5 years.
- The system may also include the following 4 field monitoring sensors.
    - Wind Speed
    - Accelerometer
    - Light Intensity

  - Water Detection

Specifications

The sensors used by the Capstone 2021 team will be given first consideration for usage and implementation, but may be replaced should it be necessary to meet requirements. The temperature and humidity sensors are combined on the Honeywell HIH8120 sensor. The Department of Energy sponsor has determined the nitrous oxide to be used is the Dynament DS0002. The CO2 and the O2 sensor are the DFRobot SEN0219 and SEN0322 respectively. The wind speed sensor is the Modern Device Wind Sensor Rev. C. The accelerometer is the Analog Devices ADXL345. The light intensity sensor is the Texas Instruments OPT3001. The water contact sensor is the Texas Instruments LM393.

The microcontroller must be capable of handling all required sensors, entering low power modes, and transmitting sensor data to the SmartMesh IP for wireless data transfer. Such a microcontroller considered for this is the MSP430. This will be a replacement to the CC3200 used by the Capstone 2021, because the 2021 team found limitations with the CC3200 such as having analog inputs with a maximum voltage of 1.46V, which was insufficient for certain sensors.

The output of the mote will be data from all the sensors stored on on-board storage, such as an SD card, and also transmitted to a remote computer via wireless accessible to the end user.

The mote will be powered by COTS batteries, such as lithium button cells, or 1.5V AA batteries.

The physical design will incorporate the smallest form factor possible and be mounted inside an enclosure with an IP65 rating.

The development environment will be Energia IDE and Code Composer Studio.

Bill of Materials

This is a tentative bill of materials, and may not fully include all components used in the end product.

- SmartMesh IP - LTP5902-IPM / DC9018B-B
- MSP430FR5994 Microcontroller
- Sensors
  - Temperature, HIH8120
  - Humidity, HIH8120
  - Nitrous Oxide sensor, DS0002
- Buck Boost Converter
- Applicable passive components
  - Resistors, capacitors, etc.
- Printed Circuit Board
- Weather resistant IP65 enclosure

Deliverables

By the end of the Capstone 2022 period, June 1st, the following deliverables will be completed and submitted. The prototype mote will include sensors, wireless transmission and onboard storage such as an SD card. Also present will be a weather resistant IP65 housing.

The software will include the frontend software and GUI.

The documentation will include the project proposal (this document), a final report, compiled weekly progress reports, design files, a bill of materials, an operations guide, a Capstone poster and a stakeholder presentation.

Initial Product Designs

Hardware architecture

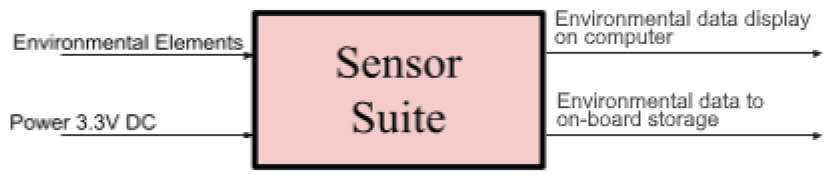


Figure 1: Level 0 Block Diagram

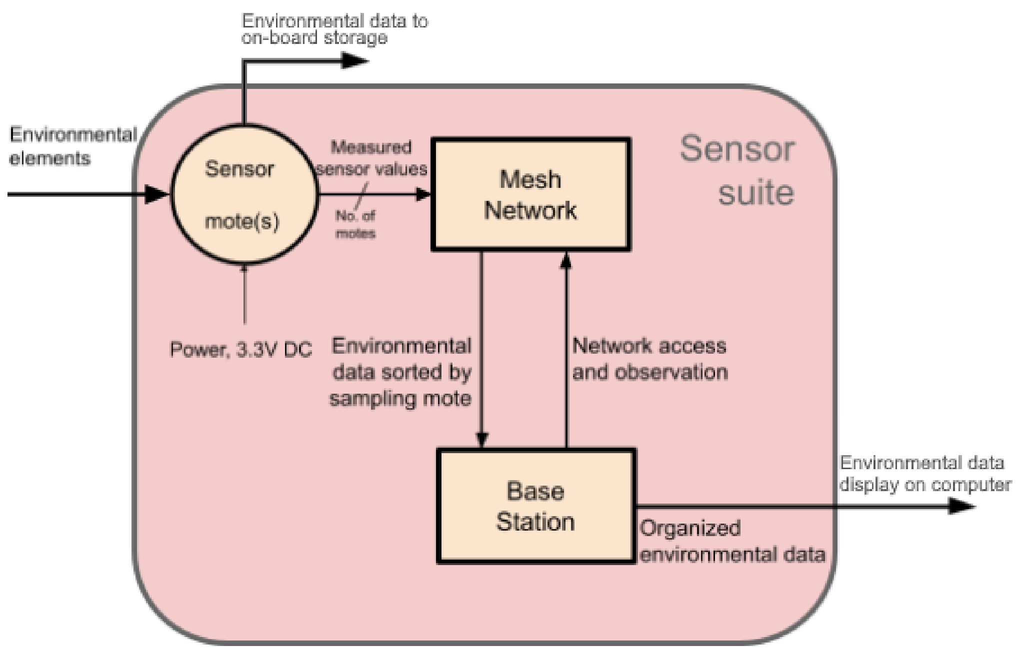


Figure 2: Level 1 Block Diagram

Software Architecture

Languages and development environments that will be used include Energia IDE, Python, C/C++, and Code Composer Studio.

User interface / experience

A GUI will be displayed on the user's computer screen showcasing numeric sensor data with timestamps, graphical representation of data, and the status of operation of the motes.

Other considerations

Physical security of the mote will be provided in the form of an outdoor fieldable enclosure that may be waterproof.

To comply with regulations, LTP5902IPM wireless mote module is compliant to 6LoWPAN Internet Protocol (IP) and IEEE 802.15.4e standards.

Back up plans

A major step in this project is switching to the MSP430 from the CC3200 because of the need to reduce power consumption. If it is found that the MSP430 does not provide the adequate functionality in order to implement all of the necessary features for the project then switching to a different microcontroller could be an option.

Verification Plans

Upon completing the code and the first PCB prototype, test plans will be written and performed on the system. Testing will verify that sensor data can be collected and stored to a local storage device, that the end user can retrieve sensor data wirelessly, the battery life will be tested and extrapolated, and the power characteristics of each sensor.

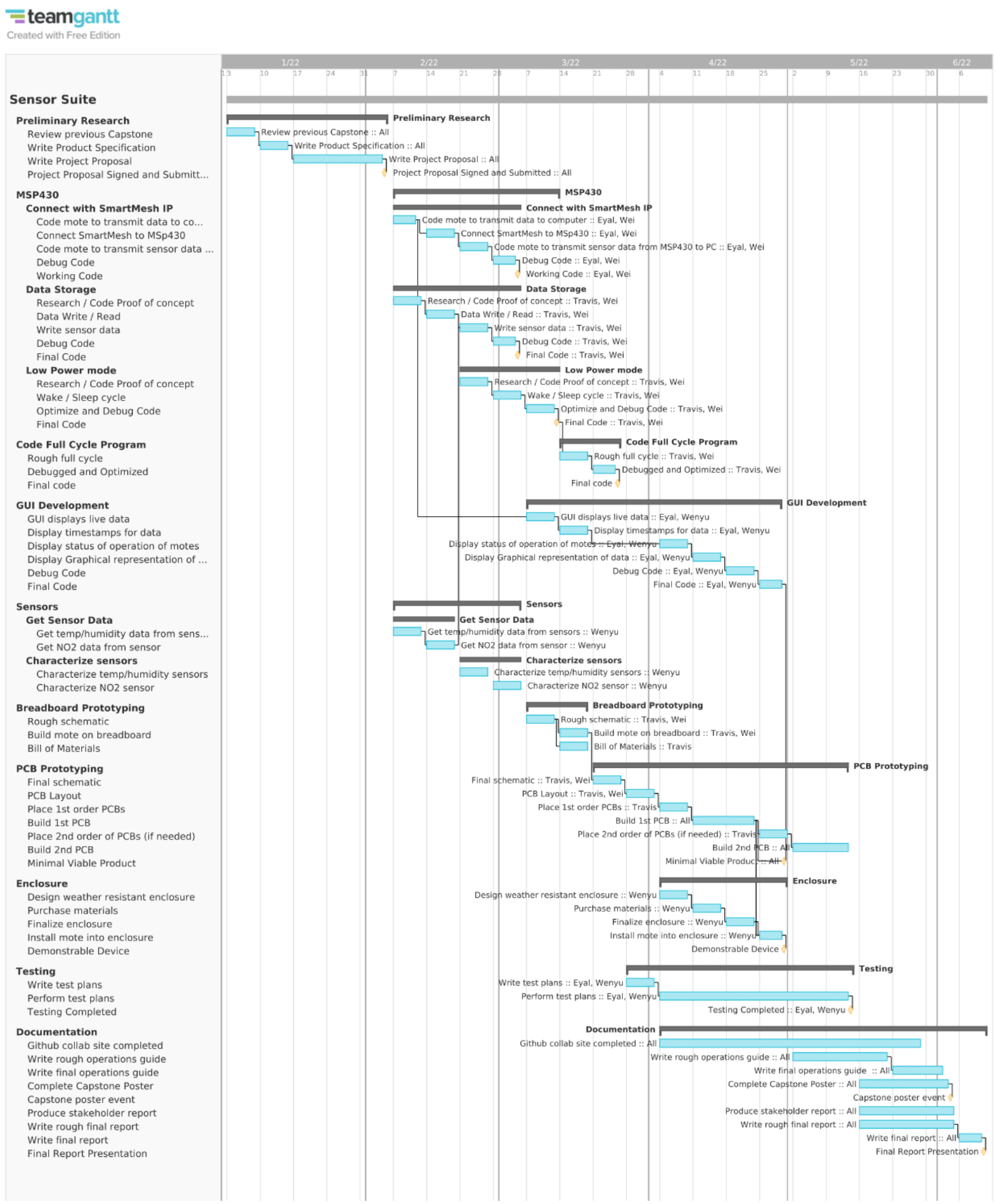
Testing will verify the following

- Sensor data can be collected and stored to a local storage device.
- End user can retrieve sensor data wirelessly.
- Sensor mote expected life will be tested and extrapolated.
- Power characteristics of each sensor.

Project Management Plan

The project management plan describes how the project will progress and includes timeline and milestones, budget and resources, IP discussion, and team and development process. This timeline does not include stretch goals, which will be considered later in the project.

Timeline and Milestones



Budget and Resources

Budget

Funding for the low power environmental sensor suite is provided by the Department of Energy. However, no budget limitation has been announced. Last year's capstone project had a total parts cost of $319.14. Since the SmartMesh IP purchases have already been made, that will be included in this year's budget. This year's budget is estimated at $520, with an upper limit of $1,000.

Items to buy

- MSP430 Microcontroller Develop boards
- Various passive components and devices
- Manufacture PCBs (Beginning of April)
- Materials for outdoor fieldable enclosure (Beginning of April)

Resources we are bringing

Currently, hardware is stored in the lockers found in the Fourth Avenue building. Both the Tektronix lab (060-01) and the Capstone lab (060-04) will be used to assemble and test the system as it is developed.

IP Discussion

The Department of Energy is funding the low environmental sensor suite and therefore the assumption is that the DOE now owns the IP. However, the GitHub repository for the project has a GNU General Public License v3.0.

Team and Development Process

Team members and skillset

- **Wenyu Bi** -LTspice, Arduino IDE, Word, Excel, PowerPoint, Soldering, AutoCAD
- **Eyal Eynis** - LTspice, MATLAB, SolidWorks, KiCad, C++, Java, Word, Excel, PowerPoint, Multimeter, Oscilloscope, Function Generator, Soldering.
- **Travis Johnson** - KiCAD, C, Arduino, MATLAB, DMM, Soldering
- **Wei Yan** - LTspice, MATLAB, Oscilloscope, Function Generator, C, Power World, Excel, Word, Multimeter

Rough task assignment

- **Wenyu Bi** - Add to project proposal, code MSP430 to collect temperature, humidity, and NO2 data.
- **Eyal Eynis** - Add to project proposal, connect SmartMesh to MSP430, SmartMesh IP GUI development, transmit data wirelessly to computer, adjust sampling rate, allow graphical illustration of data.
- **Travis Johnson** - Add to project proposal, code MSP430 low power sleep mode, write data to SD card, operations guide for end user, operation guide for engineers/development team, bill of materials.

- **Wei Yan** - Add to project proposal, code MSP430 low power sleep mode, write data to SD card, code MSP430 to collect temperature, humidity, and NO2 data, connect SmartMesh to MSP430.

Point person that communicates with faculty advisor and industry sponsor

All individuals on the team will communicate with the FA and IS every Friday from 1pm-2pm.

Team leader

The Capstone leader during ECE412 will be Travis Johnson. The Capstone leader during ECE413 will be determined in April.

Collaboration tools

Slack used for team discussions. GitHub will be used as a repository for code, design files, and documentation.

Methodology

No specific methodology is being followed.