Pollution Detection Network

Group 41

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1 Introduction

1.1 Narrative Description and Motivation

For this project, we plan to create a sensor network used for measuring quantities of certain pollutants over a certain area in an urban environment. The sensor network will consist of multiple identical nodes. These nodes will be physically mounted in various locations and evenly spread throughout the area to be monitored. Each node will contain various sensors that will be used to measure certain pollutants. Each node will also contain a LoRa transceiver that will be used to send the sensor data to a gateway. This gateway will process then send this data to an external server over the internet, where it can be further processed and analyzed. This network should help determine areas of concern with regards to pollution and, hopefully, allow for measures to be taken to reduce it.

1.2 Project Goals

- The sensor nodes should be low cost.
- The sensor nodes should be lightweight.
- The sensor nodes should be able to read data in from the environment and that data through other nodes to the gateway.
- The sensors nodes should be able to communicate over a large enough distance in order to make it feasible to cover large enough area with nodes.
- The nodes should require little to no maintenance.
- The sensor nodes should be easy to install.
- The gateway should be able to connect to the internet to send the data it receives from the nodes to an external server over the internet.

2 Requirements and Constraints

2.1 Engineering Requirements

Table 1: The gateway requirements

No.	Requirement	Value	Units
1.0	The gateway should cost no more than $200	200	dollars
1.1	The gateway should be no larger than 24" x 24" x 24"	24x24x24	inches
1.2	The gateway weight should be no more than than 10 pounds	10	lbs
1.3	The gateway should utilize LoRaWAN with the base station as the gateway with the capacity to connect with up to 8 devices simultaneously.	8	nodes
1.4	The gateway should be able to communicate with nodes up to 10 km away with ideal conditions	10	km
1.5	The gateway should be able to communicate with nodes up to 3 km away in an urban environment	3	km
1.6	The gateway should be able to manage up to 256 nodes	256	nodes

Table 2: The sensor node requirements.

No.	Requirement	Value	Units
2.0	The sensor node should cost no more than $150	150	dollars
2.1	The sensor node should be no larger than 12" x 12" x 12"	12x12x12	inches
2.2	The sensor node weight should be no more than 10 pounds	10	lbs
2.3	The sensor node should stay operational without intervention for 1 year	1	year
2.4	The sensor node sensors should have a maximum tolerance of +/- 20%	20	%
2.5	The sensor node should transmit for no more than 30 seconds every 24 hours	30	seconds

2.2 Engineering Specifications

Table 3: The gateway and networking engineering specifications

No.	Requirement
3.0	The gateway shall use LoRa and LoRaWAN for the wireless communication protocol
3.1	The gateway should adhere to the LoRa Fair Access policy
3.2	The gateway should have enough internet bandwidth to support all of its connected nodes
3.3	The network shall utilize a star networking topology.
3.4	We define a component of our network to be known as a cell, which shall consist of nodes connected to a gateway.
3.5	The gateway shall be able communicate with an external server over the internet.
3.6	The server shall be hosted on existing web hosting platform.
3.7	The server shall host a website that displays data collected from the sensors.

Table 4: The node engineering specifications

No.	Requirement
4.0	The sensor node shall use a radio and antenna that is part of a daughterboard that can be attached to the main PCB.
4.1	The node should use a battery and solar panel
4.2	The sensor node shall contain a microcontroller.
4.3	The sensor node microcontroller shall support the UART protocol.
4.4	The sensor node microcontroller shall have at least one ADC.
4.5	The sensor node microcontroller shall support JTAG debugging.
4.6	The sensor node shall contain a NO2 sensor.
4.7	The sensor node shall contain a PM sensor.
4.8	The sensor node shall contain a SO2 sensor.
4.9	The sensor node shall contain a O3 sensor.
4.10	The sensor node shall contain a CO sensor.

2.3 Constraints

Table 5: The constraints.

Constraint
The nodes must be light enough so that they can be affixed to a building or other structure and not be of a concern to fall off.
The nodes must low cost to be able to placed in greater number.
The nodes must be able to withstand water from rainfall.
The nodes must be able to withstand high winds.
The nodes must be able to withstand temperature extremes.
The nodes must be able to support a communication range of at least 1 km
The nodes must be able to operate on less power than what one solar panel could generate in a single day to allow for operation when there is no sunlight present.
The gateway must be able to operate off of mains power.

3 House of Quality

		Cost	Battery Life	Node to Gateway Distance	No. Nodes per Gateway	Node Weight	Node Size	Sensor Accuracy
		-	+	+	+	-	-	+
Light	+		↓		↓↓	↑↑	↑	
Low Cost	-	↑↑	↓	↓				↓↓
Small Size	+	↓					↑↑	
Accurate	+	↓↓			↑			↑↑
Low Maintenance	+	↓	↑↑					↓
Easy to Install	+				↓↓	↑↑	↑↑	
Reliable	+	↓	↑	↓	↑			↑↑
Real Time	+	↓	↓↓	↓	↓↓			
Targets		< $500	> 1 year	> 1 km	> 15	< 10 lbs	< 2	Within 3%

Figure 1: The house of quality diagram.

4 Stretch Goals

Requirement	Value	Units
Operability with the decentralized Helium LoRa Network	Yes/No	Boolean
Increased sensor accuracy	10-15	percent
Twitter alerts for hazardous air pollution	Yes/No	Boolean
Increased battery life of the sensor nodes	2-4	years
Sensor nodes are completely sustainable through the use of solar panels	Yes/No	Boolean
Increased sensor node LoRa range in highly urban environments	4-5	km
Highly responsive and modern graphical user interface (web site)	Yes/No	

5 Block Diagrams

5.1 Sensor Node Hardware Diagram

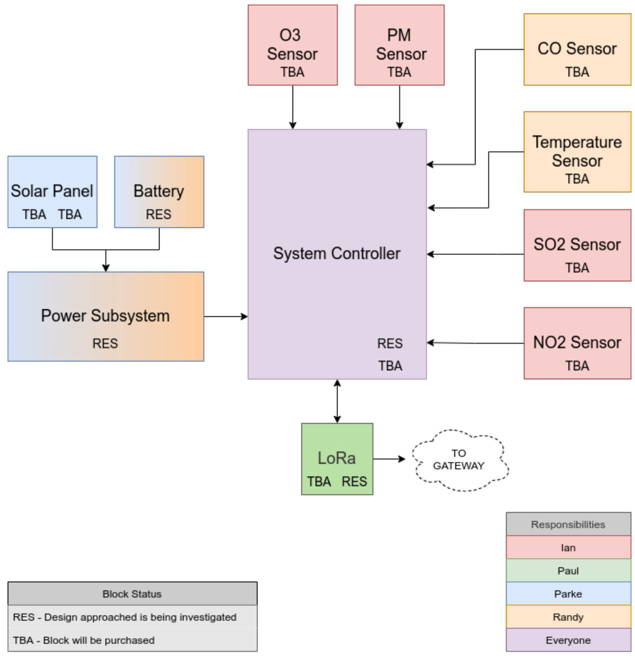

Figure 2: The block diagram for the sensor node hardware.

5.2 Gateway Hardware Diagram

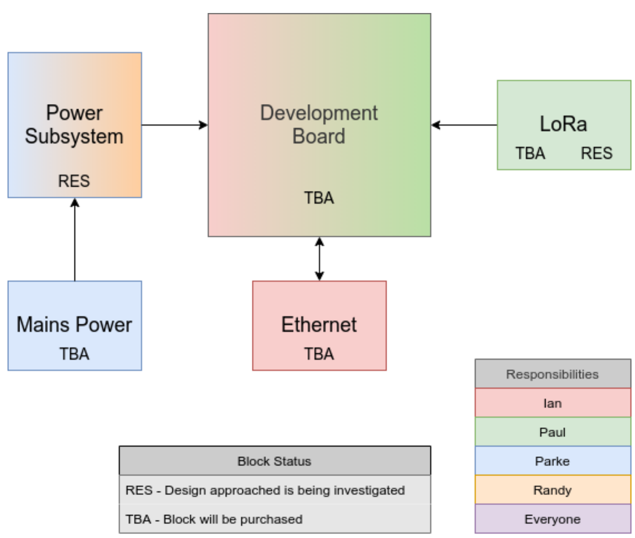

Figure 3: The block diagram for the gateway hardware.

5.3 Sensor Node Software Diagram

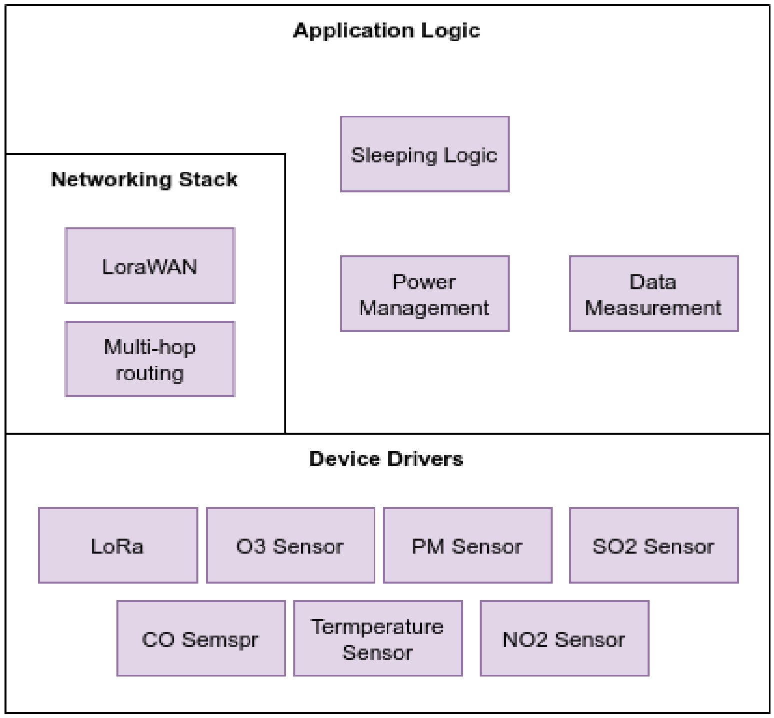

Figure 4: The block diagram for the node software.

Table 6: A description of each block in the sensor node hardware block diagram.

Block Name	Description
Battery	The battery will take in power from the power subsystem and will store whatever is left over from the consumption by the system controller.
Power Subsystem	The power subsystem will take in and regulate power from the solar panel charging the battery as well as taking power from the battery for whatever needs the system controller requires. The power subsystem will also invert the DC power from the solar panel and battery to AC if required.
Solar Panel	The solar panel will feed power to the power subsystem where a solar power controller will be placed to take in the generated power.
System Controller	The system controller take in and process data from the sensors and output data to the LoRa transceiver.
Temperature Sensor	The temperature sensor will take a measurement of the current temperature and send it to the system controller.
O_3 Sensor	The temperature sensor will take a measurement of the current amount of detected ozone (O_3) and send it to the system controller.
CO Sensor	The temperature sensor will take a measurement of the current amount of detected carbon monoxide (CO) and send it to the system controller.
SO_2 Sensor	The temperature sensor will take a measurement of the current amount of detected sulfur dioxide (SO_2) and send it to the system controller.
NO_2 Sensor	The temperature sensor will take a measurement of the current amount of detected nitrogen dioxide (NO_2) and send it to the system controller.
PM Sensor	The temperature sensor will take a measurement of the current amount of detected particulate matter (PM) and send it to the system controller.
LoRa	The LoRa transceiver will receive data from the system controller and send that data to the gateway.

Table 7: A description of each block in the gateway hardware block diagram.

Block Name	Description
Power Subsystem	The power subsystem will take in power from the battery for whatever needs the development board requires. The power subsystem will also invert the DC power from the solar panel and battery to AC if required.
Mains Power	This is the AC power coming from a wall outlet.
Ethernet	The Ethernet module will allow the development board to connect to the internet.
LoRa	The LoRa transceiver will receive data from the sensor nodes and send that data to the development board.
Development Board	The development board will process the sensor data received from the sensor nodes. This data will then be sent to an external server over the internet where it can be analyzed.

Table 8: A description of each block in the sensor node software block diagram.

Block Name	Description
Power Management	This software will responsible for controlling and monitoring the power subsystem.
Data Management	This software will be responsible for processing data received from the sensors.
Sleeping Logic	This software will handle the logic for switching between taking sensor measurements and residing in a low-power ”sleep” mode between sensor measurements.
LoRa	This is a device driver for the LoRa transceiver.
Temperature Sensor	This is a device driver for the temperature sensor.
O_3 Sensor	This is a device driver for the O_3 sensor.
CO Sensor	This is a device driver for the CO sensor.
SO_2 Sensor	This is a device driver for the SO_2 sensor.
NO_2 Sensor	This is a device driver for the NO_2 sensor.
PM Sensor Sensor	This is a device driver for the PM sensor.
LoRaWAN	This handles the networking for the LoRa networking.
Multi-hop Routing	This software will control how traffic is routed around the sensor node network.

6 Estimated Budget

Component	Unit Cost	Quantity	Total Cost
Solar Panel	$30.00	1	$30.00
Solar Charge Regulator	$5.00	1	$5.00
Battery	$10.00	1	$10.00
Electronic Components	$10.00	1	$10.00
LoRa Transceiver	$30.00	1	$30.00
Microcontroller	$3.00	1	$3.00
PCB	$10.00	1	$10.00
Electronic Components	$10.00	1	$10.00
O_3 Sensor	$49.00	1	$49.00
Temperature Sensor	$4.00	1	$8.00
CO Sensor	$20.00	1	$20.00
SO_2 Sensor	$90.00	1	$90.00
NO_2 Sensor	$50.00	1	$50.00
PM Sensor	$50.00	1	$50.00
		Total	$371.00

Table 9: The budget for each node.

Component	Approx. Unit Cost	Quantity	Total Cost
Power Subsystem Components	$10.00	1	$10.00
LoRa Transceiver	$40.00	1	$40.00
Antenna	$40.00	1	$40.00
Raspberry Pi 4	$35.00	1	$35.00
Electronic Components	$10.00	1	$10.00
		Total	$135

Table 10: The budget for the gateway.

7 Milestones

7.1 Fall Semester

Date	Milestone	Deliverables
Sep. 2nd, 2021	Sensing mechanism finalized	Sensor requirements document
Oct. 1st, 2021	MCU and LoRa module finalized	Order confirmation and, if available, shipment information.
Oct. 8th, 2021	Sensors finalized	Order confirmation and, if available, shipment information.
Nov. 5th, 2021	Software alpha 1.0	Software alpha 1.0 node and base-station release binaries.
Nov. 19th, 2021	Prototype v1.0 PCB	PCB masks, fab order confirmation and, if available, shipment information
Dec 3rd, 2021	Prototype v1.5 PCB	PCB masks, fab order confirmation and, if available, shipment information
Dec 10th, 2021	Software alpha 1.5	Software alpha 1.5 node and base-station release binaries.

Table 11: Fall milestones

Project Milestone	Description
Sensing mechanism finalized	Finish research and create design requirements for accurately detecting wildfires in a cost effective way.
MCU and LoRa module finalized	The MCU, LoRa module/daughter-boards, and Raspberry Pi's are chosen, and multiple developer boards have been ordered to design and test mesh networking.
Sensors finalized	The required sensors are chosen, and multiple parts/developer-boards have been ordered.
Software alpha 1.0	The nodes can communicate and route packets to the gateway, and the gateway can communicate with all or specific nodes on the network. There also exists some sort of command line interface on the gateway to talk to the nodes, but there are no required internet capabilities of the base, yet. The nodes can go to sleep, but a sleep routine isn't configured optimally.
Prototype v1.0 PCB	A PCB first version prototype PCB has been designed and ordered from a fast-turnaround PCB fab containing all required functionalities: power subsystem, MCU, LoRa module connectivity, battery and solar I/O, and sensor I/O with adequate noise isolation and filtering.
Prototype v1.5 PCB	PCB prototype with, if any, major issues fixed. Should also include sensor daughter boards.
Software alpha 1.5	The software works on the prototype PCB

Table 12: Fall milestone descriptions

7.2 Spring Semester

Date	Milestone	Deliverables
Jan. 19th, 2022	Prototype v2.0 PCB	PCB masks, fab order confirmation and, if available, shipment information
Jan. 19th, 2022	Enclosure prototype	Model and 3D printed enclosure
Jan. 29th, 2022	Software alpha 2.0	Software alpha 2.0 node and base-station release binaries
Feb. 18th, 2022	REST API created	REST API documentation and testing/validation scripts
Feb. 18th, 2022	Enclosure finalized	Model and 3D printed enclosure
Feb. 25th, 2022	Final v1.0 PCB	PCB masks, fab order confirmation and, if available, shipment information
Mar. 1st, 2022	Software release v1.0	Software v1.0 node and base-station release binaries.
Mar. 18st, 2022	Software release v1.1	Software v1.1 node and base-station release binaries.
Mar. 18st, 2022	Final v1.1 PCB	PCB masks, fab order confirmation and, if available, shipment information
Mar. 25th, 2022	Simple website to visualize results	Website front-end and back-end files, and website URL or IP

Table 13: Spring milestones

Project Milestone	Description
Prototype v2.0 PCB	This version should fix most or all remaining hardware bugs, and ensure accurate sensor readings. It should also be mountable in an enclosure.
Enclosure prototype	An enclosure O-rings, or some other kind of sealant, to keep out dust and water splashes. It should be able to mount the sensors to get environmental readings, and provide space for top-mounted solar-panel.
Software alpha 2.0	The gateway should be able to set the node's sleep routine settings, and schedule any specific times to wake up at. The command-line utility should be robust enough with minimal bugs.
REST API created	The gateway should run a server and/or relay to bigger server to provide a REST API for clients to query data about environmental readings pertaining to wildfires.
Enclosure finalized	The enclosure that can house a PCB and mostly not get wet should be good enough.
Final v1.0 PCB	A PCB should be bug-free, and sent to a proper fab to have high-quality board material and a water resistant coating.
Software release v1.0	The software should be able to handle errors gracefully, reliably establish connections on the mesh network, and reliably wake-up and transmit data.
Software release v1.1	Bug fixes and minor improvements.
Final v1.1 PCB	Only if needed. Bug fixes and minor improvements.
Simple website to visualize results	The website doesn't need to look pretty, but it should provide a nice visualization of the nodes deployed plus data readings over time displayed in a graph.

Table 14: Spring milestone descriptions

8 Decision Matrix

Project Idea Name	Cost	Practicality	Familiarity
Forest Fire Sensor Network	Large number of nodes may lead to higher cost. Required sensors (humidity, camera) are more expensive.	Difficult to verify functionality of design i.e. need way to replicate forest fire, may require setting up nodes in an actual forest	Team members not familiar with working with LoRa and complex networking
Smart Aeroponics System	Requires building only one system. Less expensive sensors.	Straightforward verification of functionality. Very centralized system.	Standard networking requirements (client/server model).
Smart Home Management System	Requires lots of WiFi transceivers, along with bright RBG LEDs for light fixtures. Relatively inexpensive (I hope).	Straightforward verification, and provides utility after senior design	Standard networking requirements (client/server model).
Power Line Protection	Requires a 300 and 2 400 series microprocessor relays as well as a varying amount of fiber optic cable which would be very expensive	This would combine the speed of a 400 line differential protection scheme with the utility of a step distance relay	Team members would have to learn about power line protection schemes to complete project

Table 15: A decision matrix of potential project ideas.

Project Idea Name	Description
Forest Fire Sensor Network	A network of sensor nodes designed to detect a forest fire early and alert the appropriate people before it can spread.
Smart Aeroponics System	This would be a smart aeroponics system that utilizes various sensors and data processing to grow plants. Would contain sensors such as moisture and light. Could be remotely monitored and controlled via a website/app. Could utilize machine learning to detect various potential plant issues.
Smart Home Management System	Create a personalized smart-home experience where preferences are stored for each person in the house, and profiles are chosen based on the connect WiFi devices and/or facial detection when entering the door. Positions in the house can be tracked to automatically turn on lights where you walk, and to play music and set an ambiance when you get home.
Power Line Protection	Creating a new protection relay that combines the functionality of 2 other protection schemes. It combines line differential which requires fiber optic between 2 substations that allows the relays to detect and solve problems almost instantly. It also uses step distance which uses a mathematical formula to calculate the position of a power line fault giving field crews the ability to know exactly where a problem is on a power line as they come up.

Table 16: A description of each project idea.