Commuter Tracking Sensor Net (CTSN)

Seth Hendrick, Alex Sarra, Jared Mistretta

*NOT Human Trafficking Network

Description

A wireless sensor network that will utilize computer vision and mesh networking will be used to track the usage of the Lehigh Valley trail. The network will be comprised of a series of modules that use image sensors to recognize commuters and their modes of transportation. Additionally these modules will communicate with one another to determine what are the entry and exit points commuters are using to access the trail. The network will have a gateway node that allows the data to be backhauled to the internet. These data will then be stored via cloud storage and accessible via a web interface.

Map of Lehigh Valley Trail

Customer Needs

1. Modules will detect commuters and the path they are taking.
2. Modules will determine the mode of transportation used by the commuter.
3. Modules will be deployed for a week of time without need for maintenance.
4. Trail modules will be able to intercommunicate via a network.
5. Data gathered by the network will be stored via a cloud solution.
6. Data will be accessible via a website interface to a limited set of users, including stakeholders and developers.
7. The website will display the status of each trail node, and provide basic control of the nodes.

Specifications

Spec #	Marketing Reqs.	Engineering Specification	Justification
1	1,2	The image sensor must be able to capture the image.	The image is needed so that CV can be performed.
2	1,2	The image sensor must be able to perform in a variety of light intensities and directions including overcast weather, dusk and dawn visibility, and midday brightness levels.	The image sensor will be outside and exposed to various weather conditions and light levels throughout the day.
3	3	The image sensor must draw a small amount of power relative to other image sensors on the market, which is 50 μA in standby and 110 mW in active mode on average.	The image sensor will be running on a battery, and must draw a minimal amount of current to maintain charge for prolonged periods.

4	1,2	The lens responsible for image acquisition must have a field of view that creates a consistent image size across the various positionings that the modules will have relative to the image subjects.	The image subjects will vary in size and must produce the same size image for increased consistency and accuracy in CV algorithm output.
5	1,2	The processor must be able to acquire images from the sensor and perform CV algorithms on the acquired images.	The commuter's mode of transportation must be determined.
6	3	The processor must draw a relatively small amount of power, which is 140mA on average while performing CV algorithms.	The processor will be running on a battery, and must draw a small amount of current to maintain battery charge for prolonged periods.
7	4	The trail nodes must communicate on a band that is allowable by the FCC.	The project must adhere to IEEE ethical standards, and therefore must be legal in all regards.

8	4	The trail nodes must have a range of at least 3 miles.	The greatest distance between any two nodes is approximately 1.75 miles assuming line of sight is unobstructed.
9	5,6	A module must provide gateway services that will link the network to a database service.	The data from the network must be transferred to a database, so it can be accessed through the Internet.
10	5,6	The cloud storage solution must have enough memory to hold all of the data set that is collected.	The data acquired must not be lost due to insufficient space.
11	6	The data from the database must be accessible via a standard web browser for both mobile and desktop devices.	The data must be easily accessible.

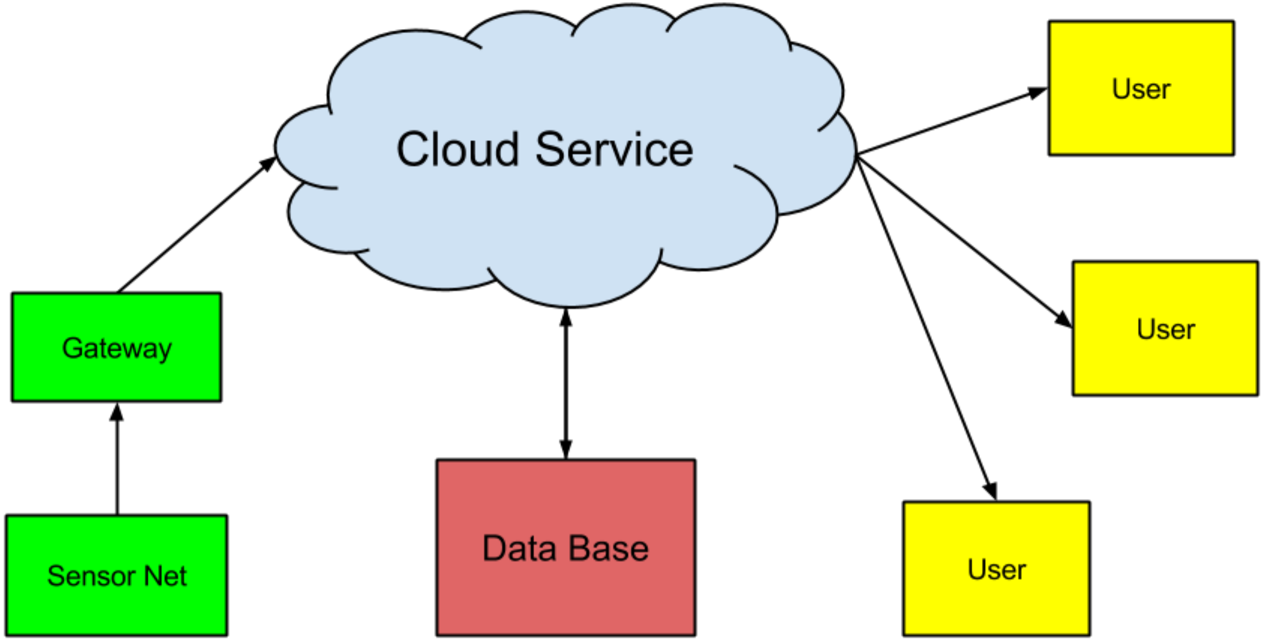
12	6	The data from the database must be viewable in a variety of graphical representations.	The data must be easily readable.
13	6	Web site access must be limited to a select user base.	The data should not be viewed by the public due to privacy concerns.
14	3	The trail nodes should enter a low-power state in the evening.	The image sensors will not be able to capture images in the dark, and all power-saving options must be considered.
15	3	The trail nodes must be able to operate in the weather conditions of Rochester, NY.	Replacement of nodes would be costly, and loss of data would also result.

16	3	The modules should be hidden from view when deployed in the field.	Strategically placing the modules will deter theft.
17	3	The trail modules’ communication method should draw approximately 120mA while active and 30mA while on standby.	The trail modules are battery operated, and must draw a minimal amount of current in order to maintain charge for prolonged periods.
18	3	A sustainable energy source shall be provided to each trail module.	The module’s battery source is recharged, and will last longer.
19	4	Modules will use a wireless mesh protocol.	A mesh protocol will provide the needed flexibility.

20	6	The server that hosts the data must be secure to prevent any unauthorized access.	The server’s data must be private, and can not be tampered with from outside forces
21	4	Mesh protocol must have encryption services.	Needed to maintain security of data.
22	6	Server must have an uptime of 95%. This means that protections from DDOS and similar attacks must be built in.	With no server, the data is not accessible to stakeholders.
23	6	There should be a “Status” page hosted somewhere other than where the main server is to notify the user if the server is down, or if maintenance is going on.	Users (and developers) should be kept in the loop if the service is down, and why.

24	4	The network will also be configured so that nodes have a common operating picture.	Information will be made redundant and synchronization of data will be maintained between all nodes and the server.
25	3	The sensor nodes should not provide an environmental threat of any nature.	It is plausible for the battery unit within the sensor nodes to plate, potentially causing a hazardous situation. The enclosure should prevent an internal hazard from escaping to immediate surroundings.
26	7	The website user interface should allow an admin user to power-cycle a node.	Performing a manual power-cycle on a node is time consuming, as the user must travel to the trail, walk to the node and reset it.
27	7	The admins should be alerted through the web interface or email if a node requires maintenance.	If notifications of the node’s status are automatic, it prevents maintainers from walking out to the trail every day and ensuring all the nodes still work.

System Overview



System Elements

Power Module -

- Sustainable power
- Power routing
- Power storage

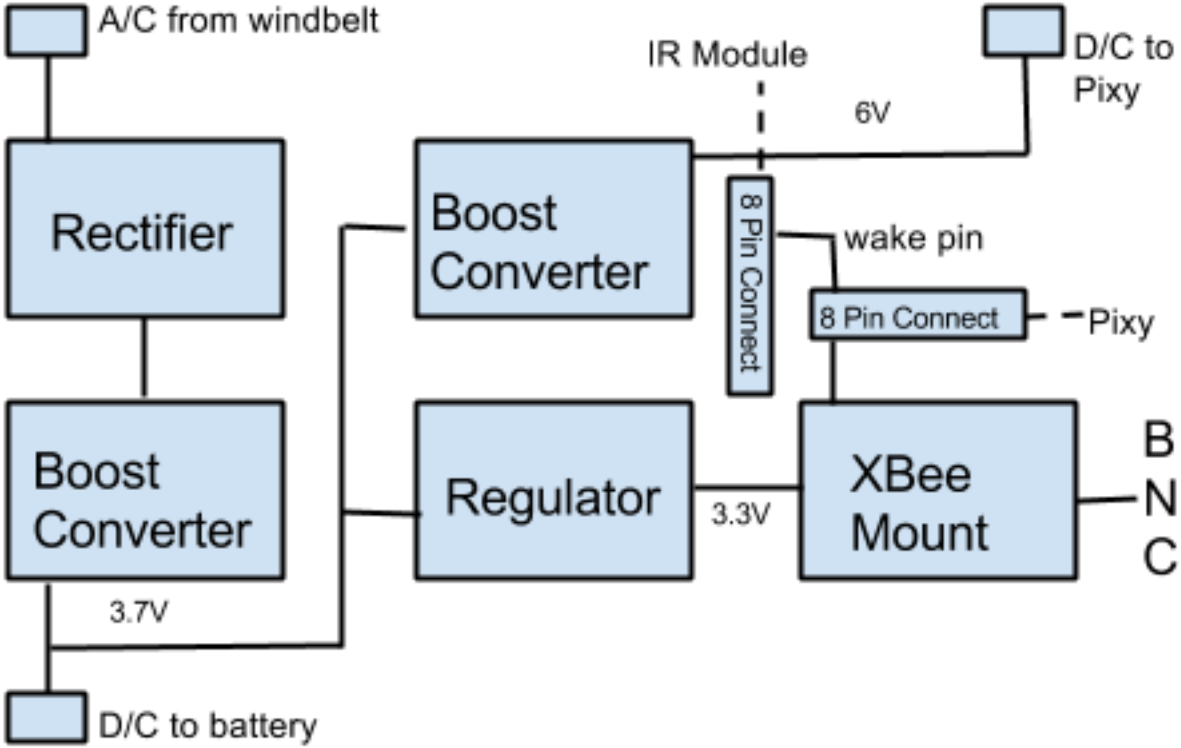
Tracking Sensors -

- Computer Vision
- RF Communication

Gateway -

- Collects data from trail
- Hosts Database
- Hosts website
- Logs any errors
    - Notifies admins if trouble occurs

Power Module - Overview

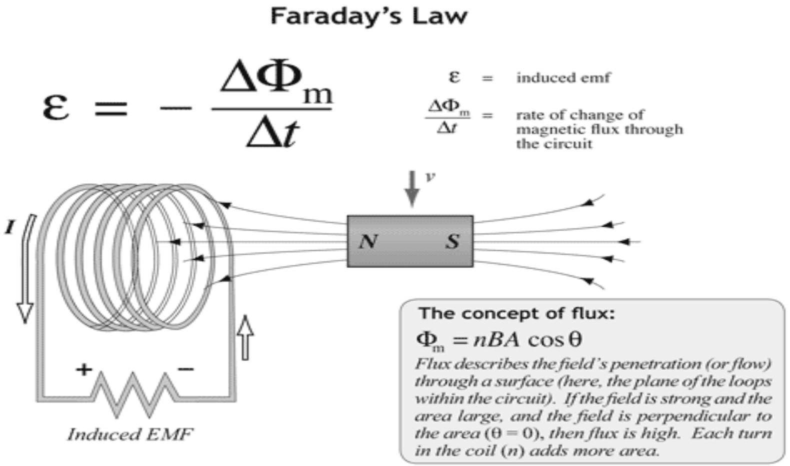


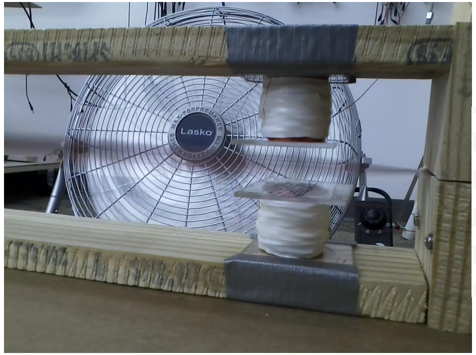
Sustainable Power - Concepts

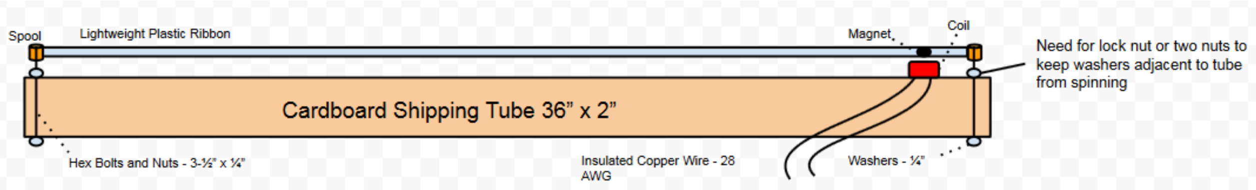
Alternatives	**Design 1 Windbelt**	**Design 2 Solar**	**Design 3 Turbine**	**Design 4 None**
Efficient	5	5	3	1
Unique	5	3	3	1
Adequate	3	5	4	1
Low-Profile	5	3	1	5
Cost	5	3	1	5
Sum	**23**	**19**	**12**	**13**

Sustainable Power - Windbelt

- **Faraday's Law**
- **Windbelt Prototyping**
  - 4th iteration of design
  - ~2 $V_{AC\ p\text{-}p}$ at ~ 1 mA

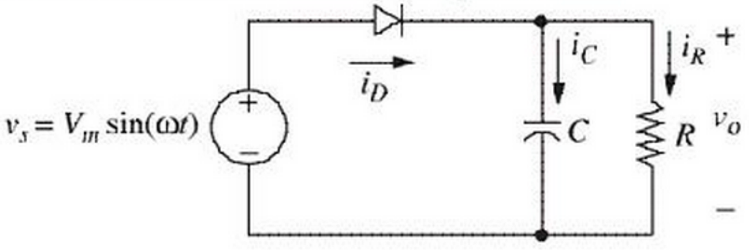


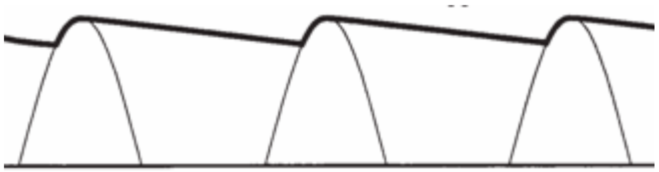




Signal Rectification

- **Testing**
  - ½ wave rectifier with filter
    - ~2 $V_{AC\ p\text{-}p}$ before diode
    - 3 mA after diode
    - 1.25 V_{DC} after diode
    - ~3 mW power
    - meets specification
  - full wave rectifier
    - shouldn't be needed





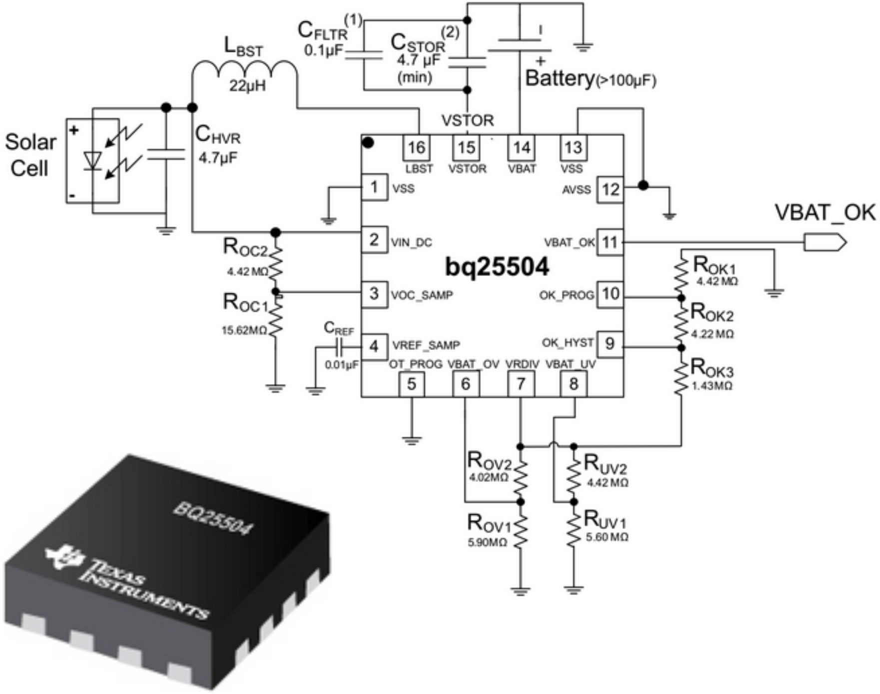
Signal Amplification

Boost Converter

- Data sheet
- Spice transient model
- Design help spreadsheet
- Solar power example

Derive Working Model

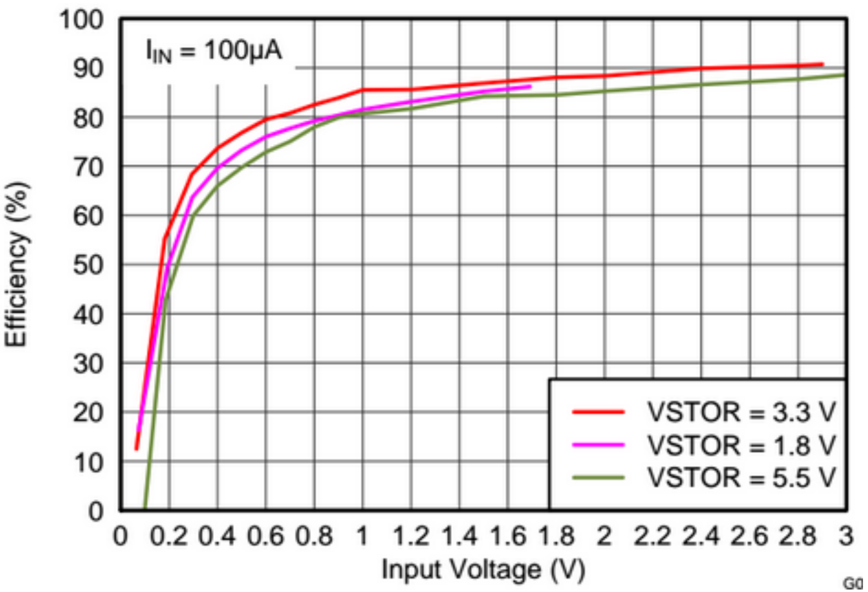
- App-specific schematic
- Breakout module
- Breadboard prototyping

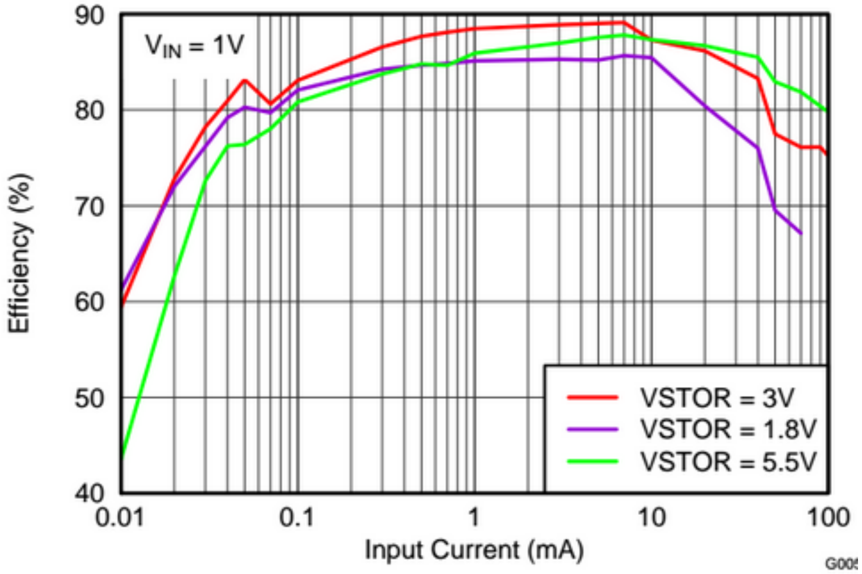


Maximizing Power

TI Efficiency Curves

- I_{IN} = 3 mA, V_{IN} = 1.2 V, VSTOR = 3.7 V





- ~ 87% efficiency
- can be improved slightly
- MPPT

Storage Element

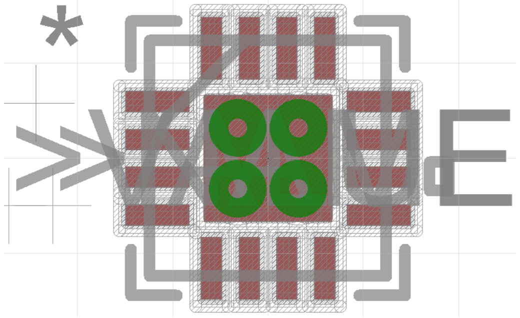
Li-Ion Battery

- 3.7 V
- 15600mAh
- Lightweight
- Overcharge/discharge protection
- Smart charger

Power Module Routing

Custom PCB

- Eagle
- BXL for bq25504
- Fine details
  - Passives
  - Connectors
  - Wires and vias
- Auto-route and CAM



Power Module - Risks

- Current too low
  - Boost converter won’t start
- Overvolt/undervolt battery
  - Affects battery life
  - Affects charge capacity
- Send surges through circuitry
- Explosions and fires

Power Module - Test Plan

Windbelt

- Vary length of belt, fan speed, and fan angle to maximize AC current production.
- Test AC/DC rectification component using half-wave and full-wave versions of the circuit, checking for minimal ripple voltage.

Boost Converter

- Connect the boost converter via a QFN to DIP module and test output levels when not configured for MPPT, or OV/UV with a resistive load.
- Do the same for MPPT, and OV/UV.
- Add the battery and perform the same tests.

Custom PCB

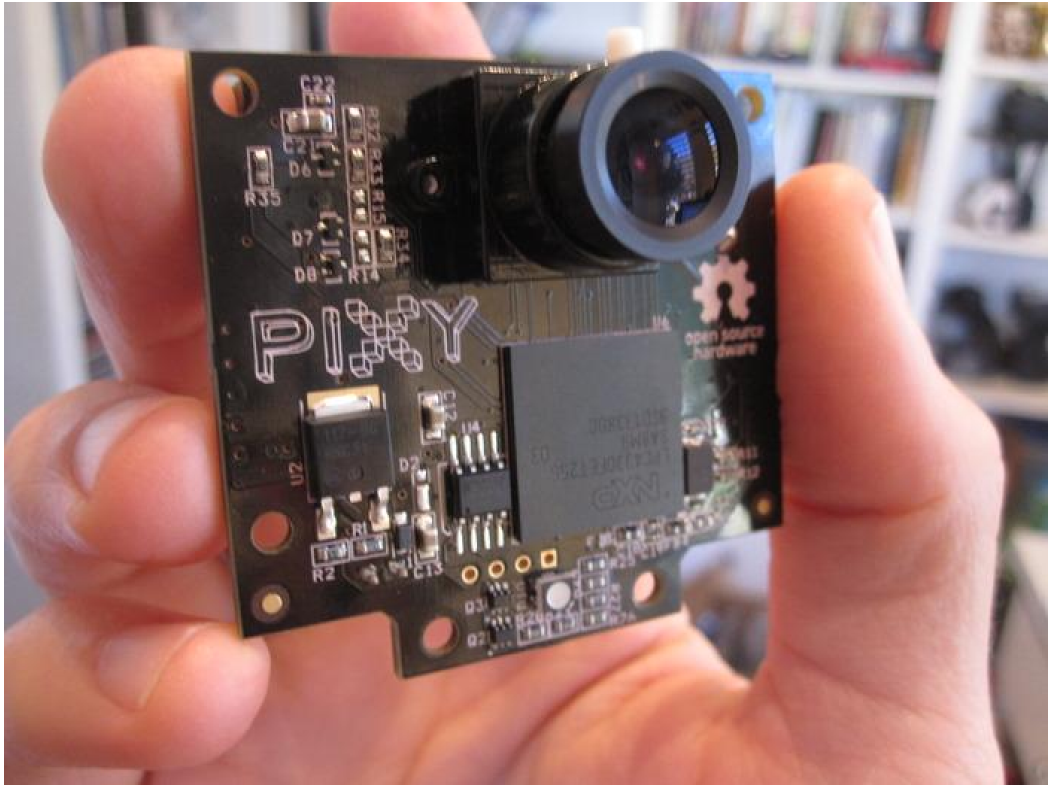
- Test for continuity.
- Test voltage levels to make sure they match the specifications for each component.
    - After boost converters
    - After regulator

Li-Ion Battery

- Connect battery and test rate of discharge and cut-off functionality.
- Measure charge duration over extended periods of use.

Computer Vision

- System consists of modules with an image sensor and onboard Computer Vision processing capabilities.
- Relevant data is processed locally and minimal data is sent over the network.
- Several different computer vision problems to be addressed.



PIXYCam (Hardware Solution)

PIXYCam Technical Specs

- Processor: NXP LPC4330, 204 MHz, dual core
- Image sensor: Omnivision OV9715, 1/4", 1280x800
- Lens field-of-view: 75 degrees horizontal, 47 degrees vertical
- Lens type: standard M12 (several different types available)
- Power consumption: 140 mA typical
- Power input: USB input (5V) or unregulated input (6V to 10V)
- RAM: 264K bytes
- Flash: 1M bytes
- Available data outputs: UART serial, SPI, I2C, USB, digital, analog
- Dimensions: 2.1" x 2.0" x 1.4
- Weight: 27 grams

Computer Vision

Three Specific Problems:

1. Feature Detection, Description, Matching
   a. Is that a horse, pedestrian, werewolf, ETC?
2. Object Tracking
   a. Determine where the object is traveling in the frame.
3. Multi-Camera Tracking
   a. Where in the network is the object.

Computer Vision

General Solution:

1. Find existing implementations of algorithms that address each of the problem areas.
2. Create software interface for PixyCam to plug in and test the selected algorithms.

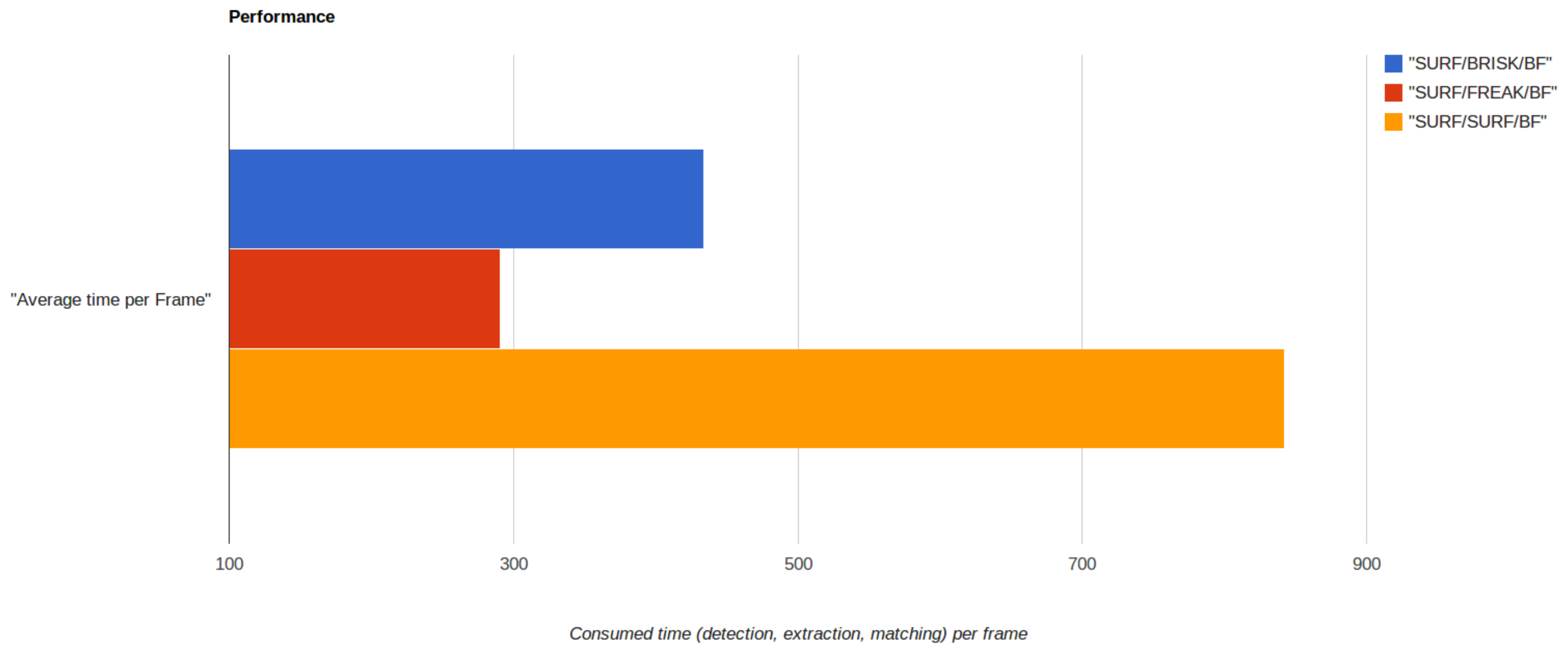
Computer Vision

Three Specific Solutions:

1. Feature Detection, Description, Matching
    a. Speeded up Robust Features (SURF)
    b. Binary Robust Invariant Scaleable Keypoints (BRISK)
    c. Fast Retina Keypoint (FREAK)

Computer Vision

1. Object Tracking
   a. Predator (TLD)
   b. Kanada-Lucas-Tomasi (KLT)
2. Multi-Camera Tracking
   a. Probabilistic Occupancy Map (POM)



Algo Performance

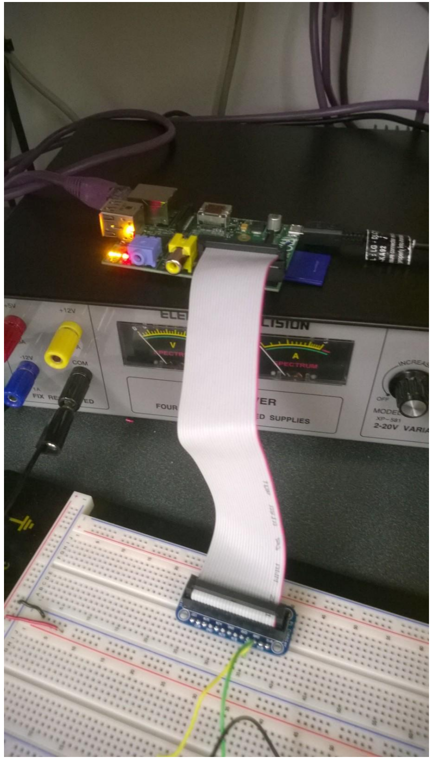
Computer Vision Risks

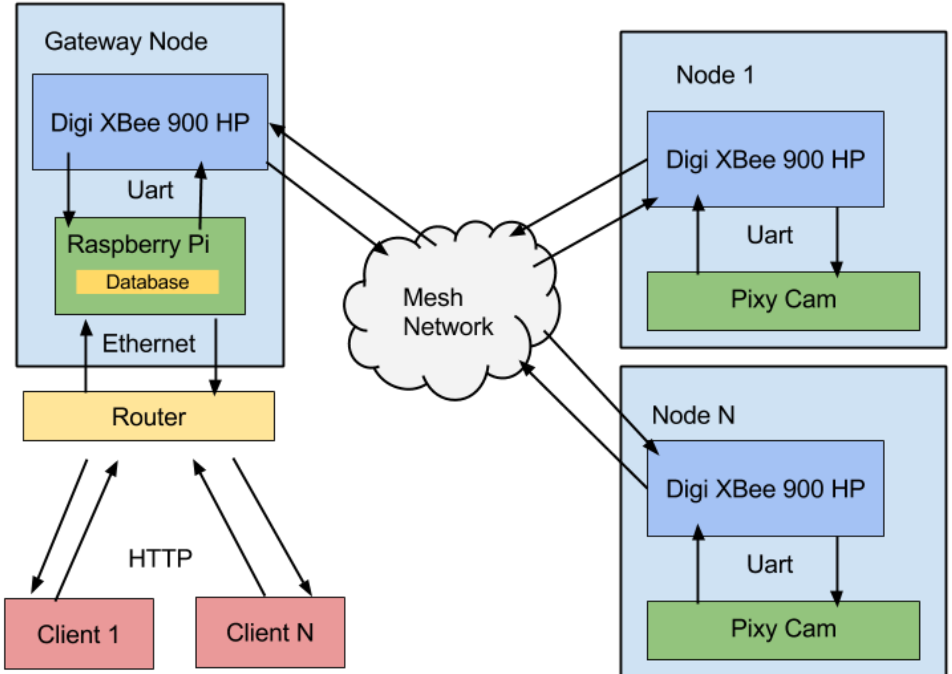
- Risk of not being able to track subjects across the entire network considering the relatively small amount of the trail that is actually being observed.
- Risk of not achieving satisfactory results with the image sensor on the PixyCam; due to the great variety of conditions outdoors.

Computer Vision Testing Strategy

1. Gather reference video, with the PixyCam, from the trail of various subjects and under various conditions.
2. Utilize this reference video to test various algorithms for both accuracy and computational performance.

Gateway Node & Communication

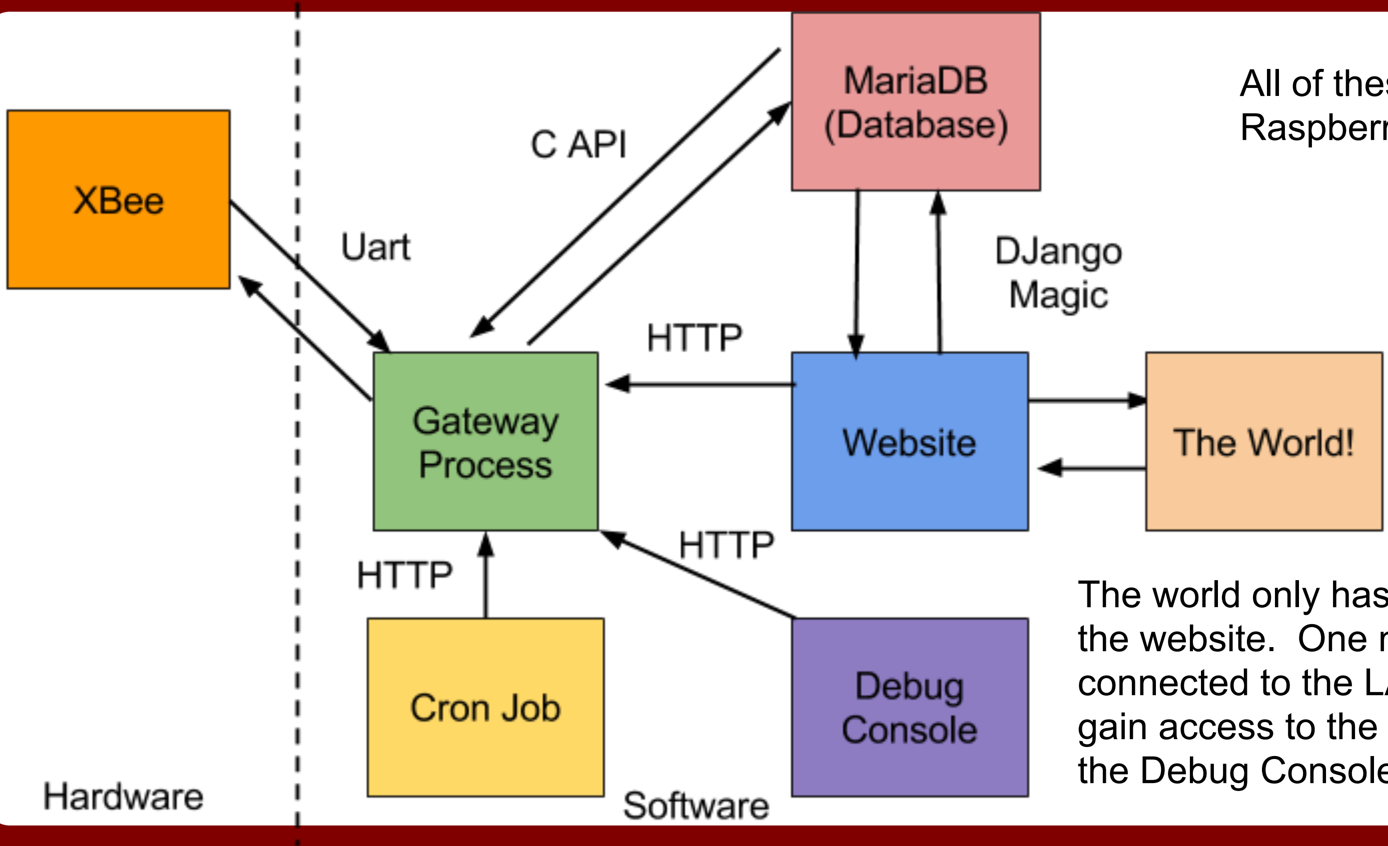




Other Ideas

- Host the database and website from a third party
  - Costs money, we don't have complete control
  - Still need a Gateway node to send data to it anyways
- Host the database and website ourselves via a Linux box
  - Costs nothing
  - complete control
  - Can interface with the trail nodes directly via an RF module
  - (We picked this one)

Gateway Node Processes



All of these run on a Raspberry Pi!

The world only has direct access to the website. One must be directly connected to the LAN in order to gain access to the database or use the Debug Console.

Gateway Process

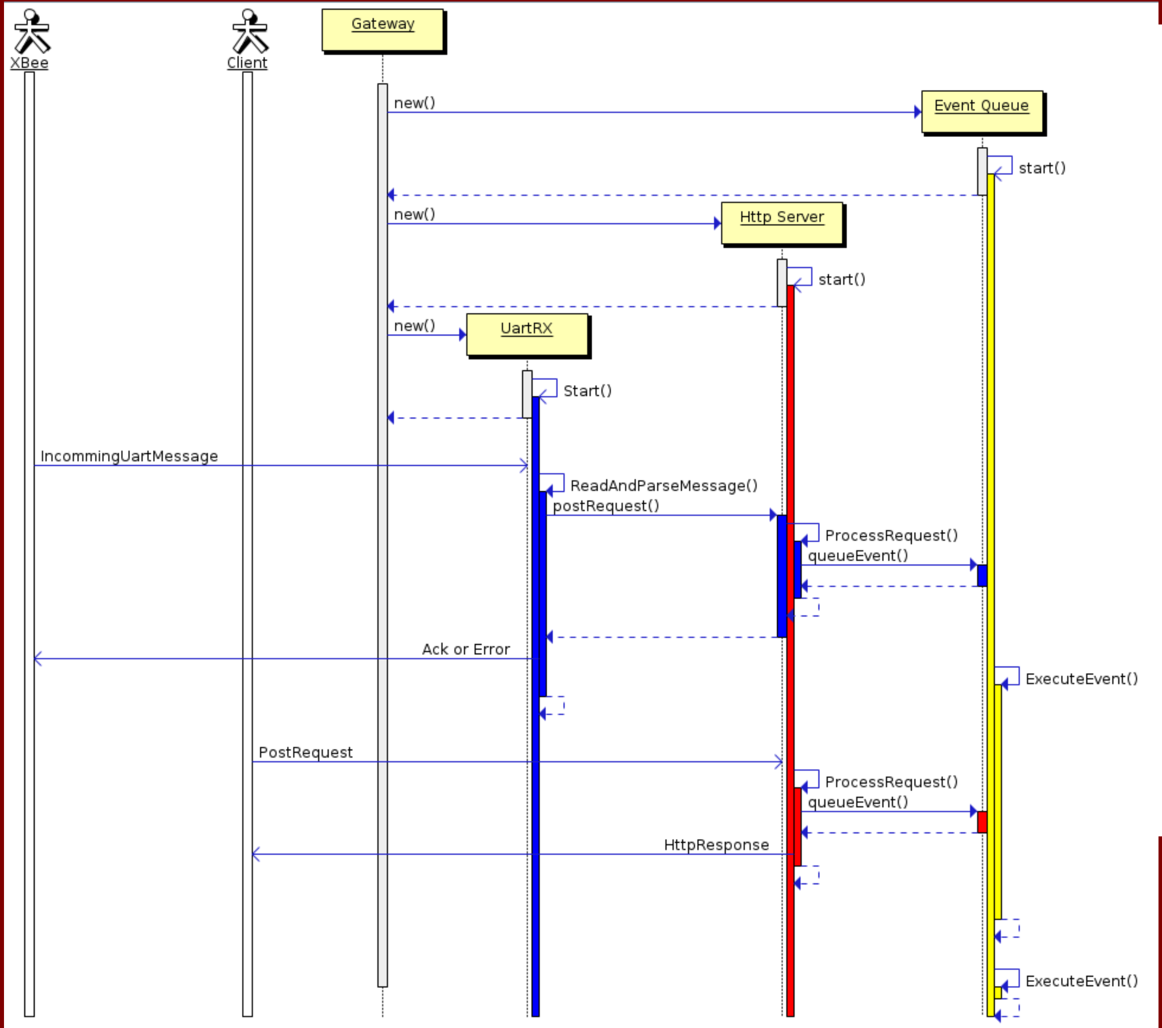
- Customized Program
- C++
- Takes in commands via HTTP from other processes, and executes them.
- Bridge between trail nodes and database.
- Notifies admins (email and/or text) if something bad occurs.
- Tells trail nodes to go to sleep / wakeup

Why HTTP?

- Need a lot of interprocess communication
    - Some ways to do it are:
        - Writing to/reading from a file
        - Interrupts/Signals
        - Sockets
    - Sockets are straightforward
    - Seth is lazy, and didn't feel like writing his own protocol or dealing with sockets directly.
        - There are also several http libraries out there

Node → Gateway Communication

- Use HTTP as much as possible
  - HTTP Posts requests needs a URL to post to and data
    - e.g. http://localhost:9009/log_error
  - From the node, send a string to the gateway over RF with the URL and data separated by something (e.g. a tab)
    - /log_error \t node=2&message=3
  - Have the gateway process split out the URL and data and perform a post request to itself
  - Can be done by calling a subprocess to curl
    - curl -X POST -A CTSN_Gateway --data node=2&message=3 http://localhost:9009/log_error



Gateway Program Sequence Diagram

- Uart waits for HTTP string to come over, and parses it and posts to the HTTP server
- HTTP Server Parses the post requests, add events to event queue (if valid), and returns to listening.
- No wasted CPU time unless something is happening.

Gateway → Node communication

- TBD
  - Unless we can magically get a web server working on the Pixy Cams, its probably not going to be HTTP
  - Probably a custom protocol
    - Need to play with Pixy cam some more first

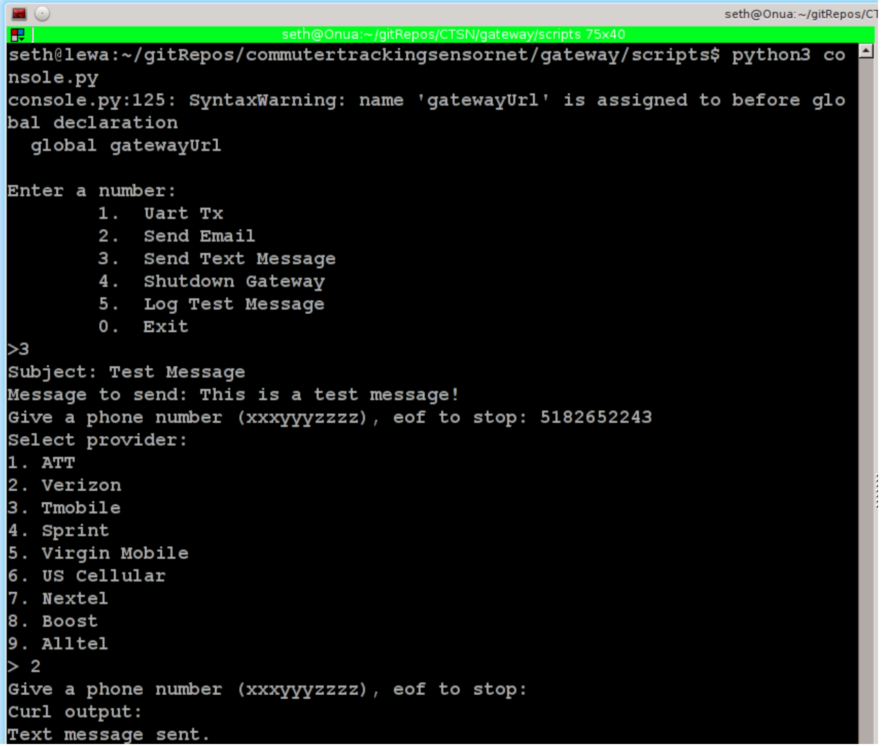
Cron Jobs

- Runs a script at a specific time.
- Useful for when we need to put the trail nodes to sleep at night
  - If hours change, edit the crontab, not recompile the program.
- Cron jobs will run curl, and HTTP Post to the Gateway Process at specific times.

```
00 * * * * bash /home/seth/scripts/dynamic_ip_update.sh
29 * * * * cd /home/seth/gitRepos/sethcommon && git pull
37 * * * * cd /home/seth/skyvo/hail-engine && git pull &
42 * * * * cd /home/seth/gitRepos/fathom && git pull &>
30 * * * * cd /home/seth/gitRepos/dotfiles && git pull &
```

Debug Console

- Used to manually send commands to the Gateway Process
  - Used mainly for testing purposes.
- Written in Python
  - Calls Curl to send HTTP post requests to the Gateway Process

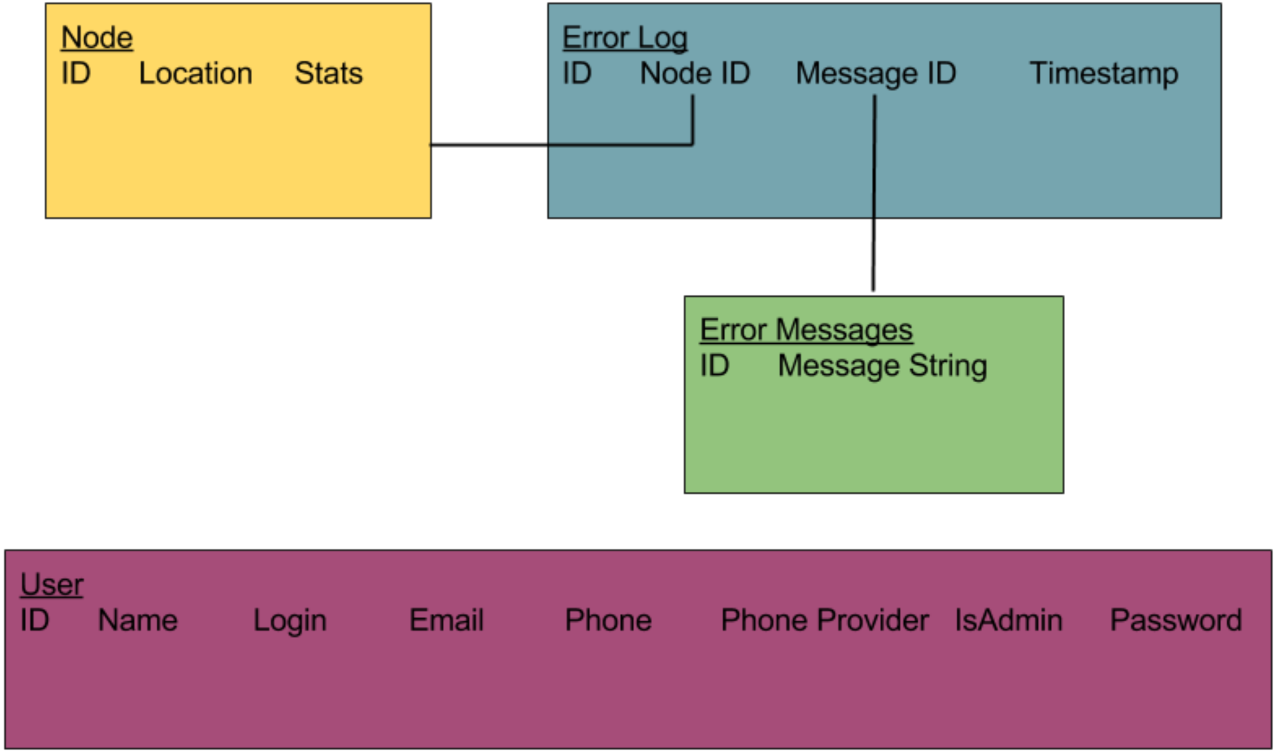


Database

- MariaDB
    - Drop and replacement for MySQL, without the Oracaleness.
- Gateway Process communicates with it via a C API

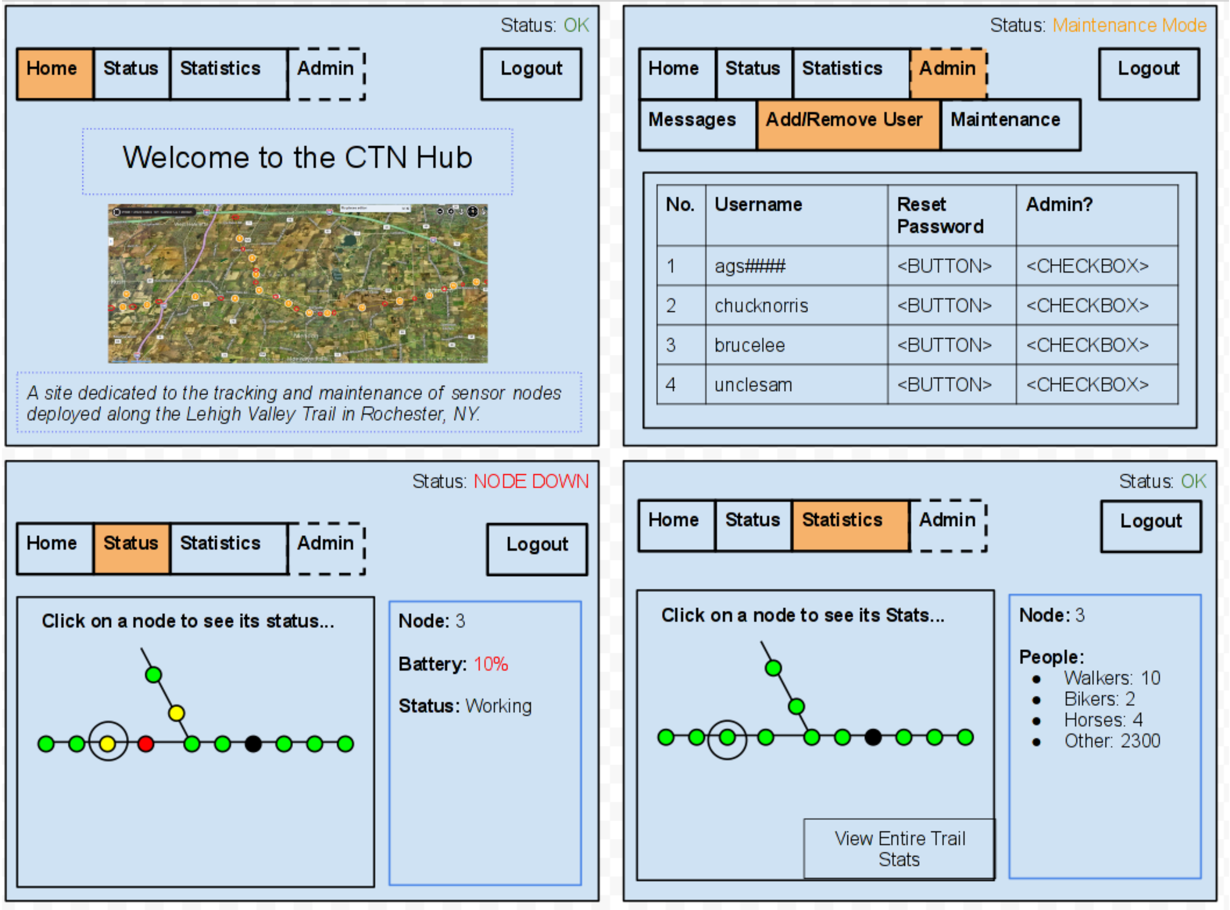
- Website communicates with it via DJango helper classes

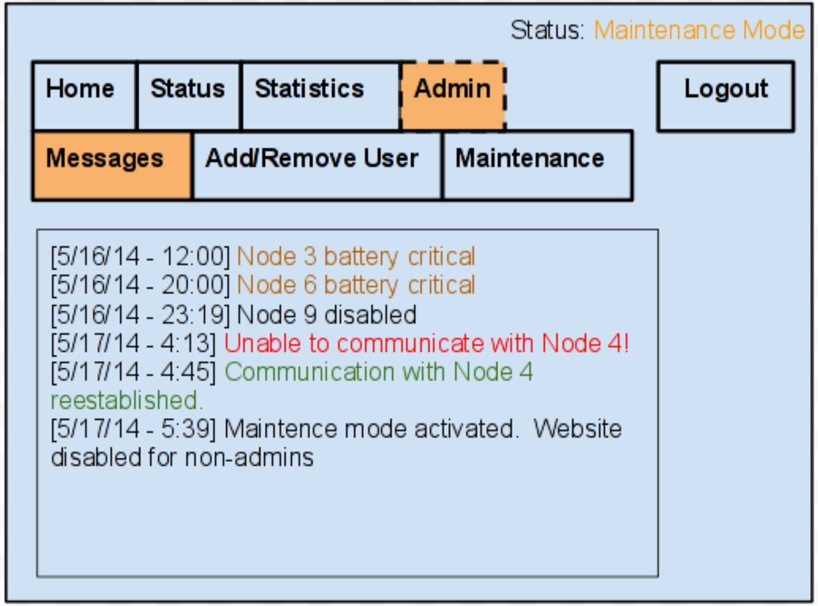
Database Tables (For Now)

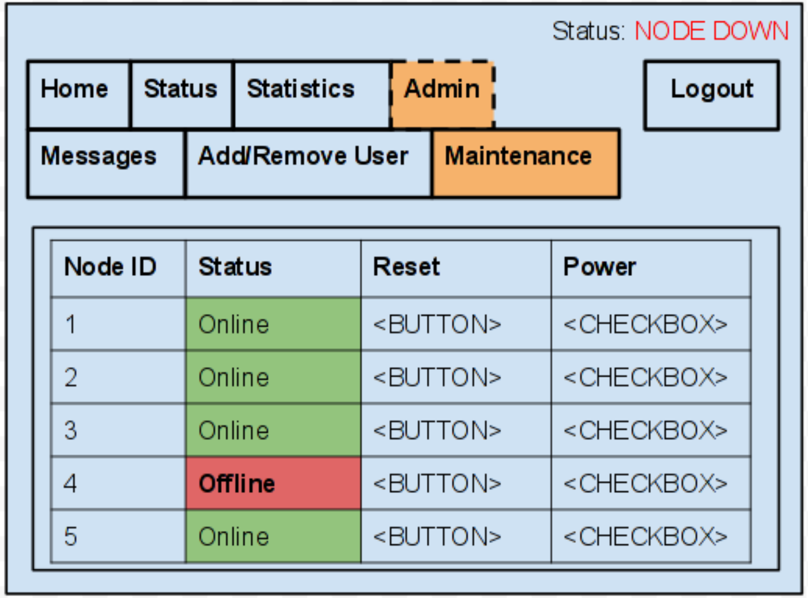


Website

- Our “UI”
- Written using the DJango framework (Python)
- Displays data from the trails
- Displays status of the nodes
  - Battery Readings
- Allows admins to control the nodes.
  - Power Cycling
  - Putting to sleep


Status: OK
Home
Status
Statistics
Admin
Logout
Welcome to the CTN Hub
A site dedicated to the tracking and maintenance of sensor nodes deployed along the Lehigh Valley Trail in Rochester, NY.
Status: Maintenance Mode
Home
Status
Statistics
Admin
Logout
Messages
Add/Remove User
Maintenance
No.
Username
Reset Password
Admin?
1
ags####
<BUTTON>
<CHECKBOX>
2
chucknorris
<BUTTON>
<CHECKBOX>
3
brucelee
<BUTTON>
<CHECKBOX>
4
unclesam
<BUTTON>
<CHECKBOX>
Status: NODE DOWN
Home
Status
Statistics
Admin
Logout
Click on a node to see its status...
Node: 3
Battery: 10%
Status: Working
Status: OK
Home
Status
Statistics
Admin
Logout
Click on a node to see its Stats...
View Entire Trail Stats
Node: 3
People:
Walkers: 10
Bikers: 2
Horses: 4
Other: 2300


Status: Maintenance Mode
Home
Status
Statistics
Admin
Logout
Messages
Add/Remove User
Maintenance
[5/16/14 - 12:00] Node 3 battery critical
[5/16/14 - 20:00] Node 6 battery critical
[5/16/14 - 23:19] Node 9 disabled
[5/17/14 - 4:13] Unable to communicate with Node 4!
[5/17/14 - 4:45] Communication with Node 4 reestablished.
[5/17/14 - 5:39] Maintence mode activated. Website disabled for non-admins


Status: NODE DOWN
Home
Status
Statistics
Admin
Logout
Messages
Add/Remove User
Maintenance
Node ID
Status
Reset
Power
1 Online <BUTTON> <CHECKBOX>
2 Online <BUTTON> <CHECKBOX>
3 Online <BUTTON> <CHECKBOX>
4 Offline <BUTTON> <CHECKBOX>
5 Online <BUTTON> <CHECKBOX>

Gateway Node Risks

- Security
  - SSH Keys REQUIRED to login via SSH
  - SSH and HTTP port are not default
  - IP addresses are banned after multiple failed attempts
  - Unneeded ports are CLOSED, or hidden behind the router’s firewall.

- Hard Drive Space
  - 11GB left on pi (Should be plenty for us)
  - Can upgrade SD card
  - Can use external Hard drive as primary hard drive
    - (SD card will only be for booting)

Gateway Node Risks

- Lack of processing power
    - Not a problem yet
    - Database, Website, and Gateway Program can each go on their own pi if needed.
    - Code is cross-platform (for Linux anyways), “easy” to upgrade to a more powerful system.
    - Probably a low-traffic site anyways
    - Gateway Program uses no CPU unless something is happening
    - Pi is stripped down
        - No GUI, several things uninstalled.

Testing Strategy (Gateway Program)

- Unit tests
  - Find small bugs early

```
..................................................
.........................
Version: 0.1.0+seth
.
Date built: Sep 13 2014 01:17:07
.....
OK (81 tests, 81 ran, 245 checks, 0 ignored, 0 filtered out, 8 ms)
```

- Debug Console
  - Manual Integration tests
  - Tests exist so far for:
    - Sending Email
    - Send Texts
    - Logging error messages
    - Sending UART messages
    - Shutdown gateway Process

Testing Strategy (Security)

- Get a security major (or someone else qualified) to try and hack or take down the server.
  - Test both the website, and other means to take it down.

- (If anyone in this room is interested, the server is located at ctsn.student.rit.edu).

Cost Estimate

- Cost of 5 Nodes
- We got a $1000 Grant for our needs

Part	Price	Quantity	Total Price	Our Cost	Availability
Battery	$40.49	5	$202.45	$202.45	On Hand
XBee	$39.00	6	$234.00	$234.00	On Hand
Schottky Diodes	$0.16	5	$0.80	$0.08	On Hand
Pixy Cam	$75.00	5	$375.00	$375.00	On Hand
Raspberry Pi	$35.00	1	$35.00	$0.00	On Hand
Router	$30.00	1	$30.00	$0.00	On Hand
Ethernet Cables	$6.00	2	$12.00	$0.00	On Hand
Infared Sensor	$10.80	5	$54.00	$54.00	1 Week
XBee Breakout	$27.92	1	$27.92	$27.92	On Hand
Antenna	$10.00	6	$60.00	$60.00	1 Week
PCB	$5.00	30	$150.00	$150.00	12 Days
Windbelt Supplies	$40.00	1	$40.00	$40.00	On Hand
Boost Converter	$6.17	5	$30.85	$30.85	On Hand
		Total Price:	$1,252.02	$1,174.30	
		Grant:	$1,000.00	$1,000.00	
		Total Cost:	$252.02	$174.30	

Any Questions?
Comments?
Inquires?
Threats?

(Hopefully Seth didn’t screw up this time…)