Modular Home Monitoring System

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OVERVIEW

- The system measures various quantities (smoke, carbon monoxide, humidity) and sends the data to the Internet for monitoring

Motivation

- We want to make smart home technology convenient and accessible for the consumer.
- Commercial products are limited in features, and not easily extensible.
    - Many also require a monthly subscription to a monitoring service.
- There is a demand for a simple, modular, and low-cost home monitoring solution.

Goals and Objectives

- Modular interface that can easily accommodate new sensors
- Web-based remote monitoring interface and alerts
- Sensor data and application hosted in the cloud
- Wireless communication between sensors and base station
- Basic sensor suite
  - Carbon monoxide, smoke, humidity, cameras
  - PIR introduced to show modularity and growth potential

SPECIFICATIONS

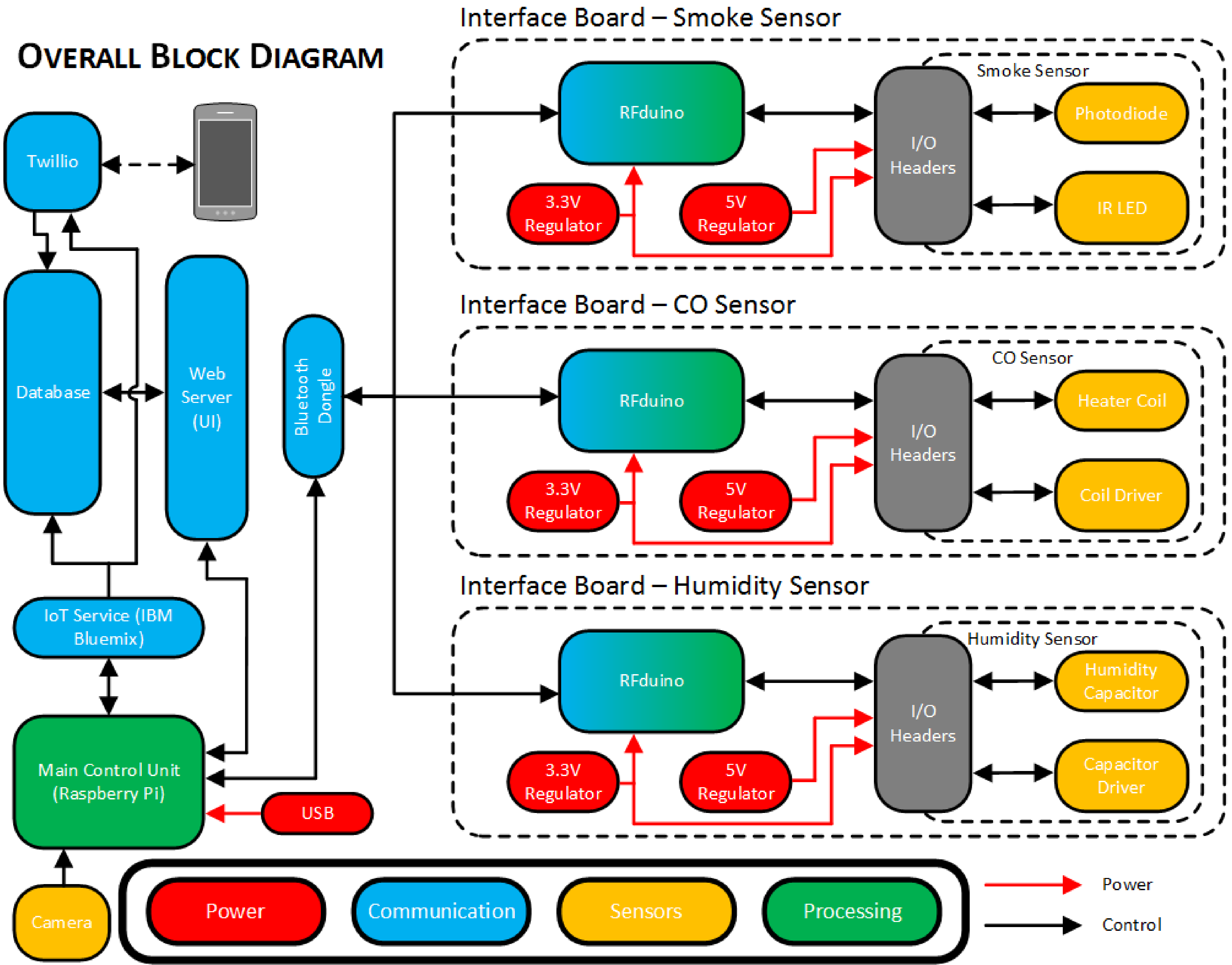
Component	Parameter	Requirement
Whole System	Time from hazard detection to user alert	< 10 Seconds
Cloud Application	Uptime	99.99%
Carbon Monoxide	Accuracy	50 ppm
Humidity Sensor	Accuracy	±5% Relative Humidity
Smoke Sensor	Accuracy	13obs/m

Related Standards

- Electrical Code of Federal Regulations Title 47 – Telecommunications
- Bluetooth 4.0
- IEEE 802.11 Wi-Fi
- ISO 7240-15:2014 Fire Detection and Alarm Systems
- CSI-3 Camera Serial Interface Standard
- BSR/IEEE 2413-201x Standard for an Architectual Framework for the IoT

Hardware Design

Overall Block Diagram



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Main Control Unit

- Raspberry Pi 2 Model B running Raspbian
- Competitors: Beaglebone Black, Arduino Uno
- Reasons chosen:
  - Supported by Bluemix Internet of Things Foundation
  - Runs Operating System – Quick Development
  - Familiarity with Debian Linux distributions
  - Universal linux libraries for low level hardware interaction
- Hub of Bluetooth and WiFi communication

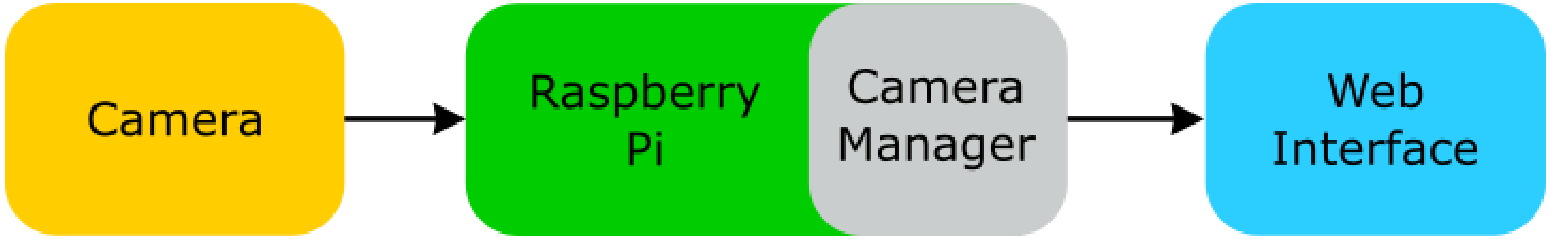
Specs:
900MHz Quad Core CPU
1GB RAM
4 USB ports
CSI Camera Interface
Cost:
$35 most retailers
$10 WiFi Dongle
$13 Bluetooth Dongle

CAMERA

Raspberry Pi Camera	TeckNet Webcam
$26	$28.99
1080p, 30 FPS	1080p, < 30 FPS*
CSI	USB
25 x 24 x 6 mm	152 x 76 x 61 mm
Raspbian	Windows XP/Vista/7

*No published figure, but users reported less than 30 FPS when used at 1080p.

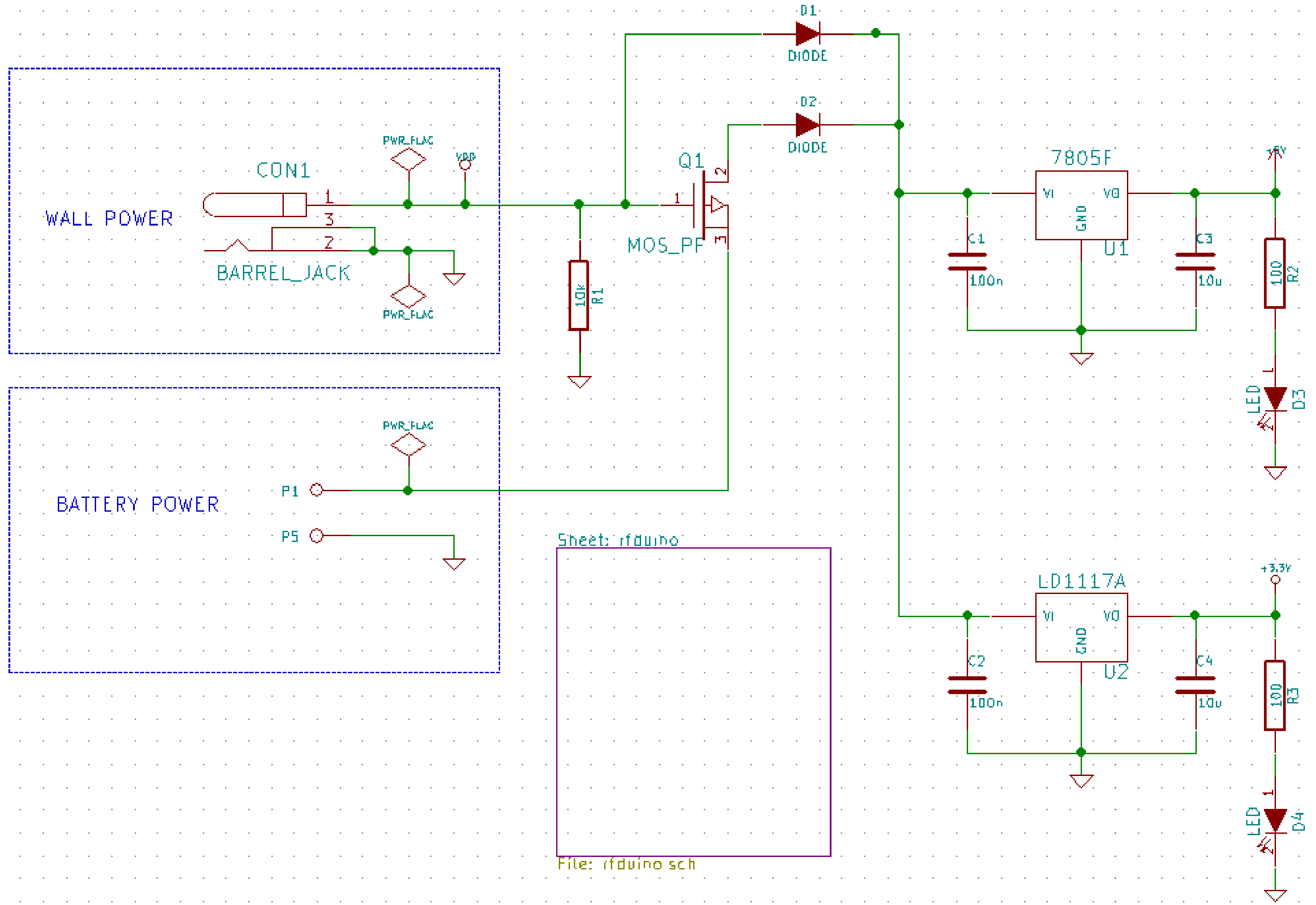
- 5MP (2592x1944) sensor
- Video formats:
  - 1080p30
  - 720p60
  - 640x480p60/90
- Use custom made script to capture and send pictures over the Internet



Interface Board

- The interface board connects to and supports the sensor modules.
- Provides 3.3V and 5V to power Micro Controller and Sensor Board
- Bluetooth 4.0 BLE is used to broadcast data to base station.
- Wall power is used when available, with a rechargeable backup in case of a power outage.

Interface Board Schematic



- Two power sources
  - Wall power (commercial transformer)
  - Backup battery (9V)
    - FET switches to backup only if primary isn’t present
- Linear regulators used instead of switching regulators
  - Cheaper and simpler
  - Not driving high current loads

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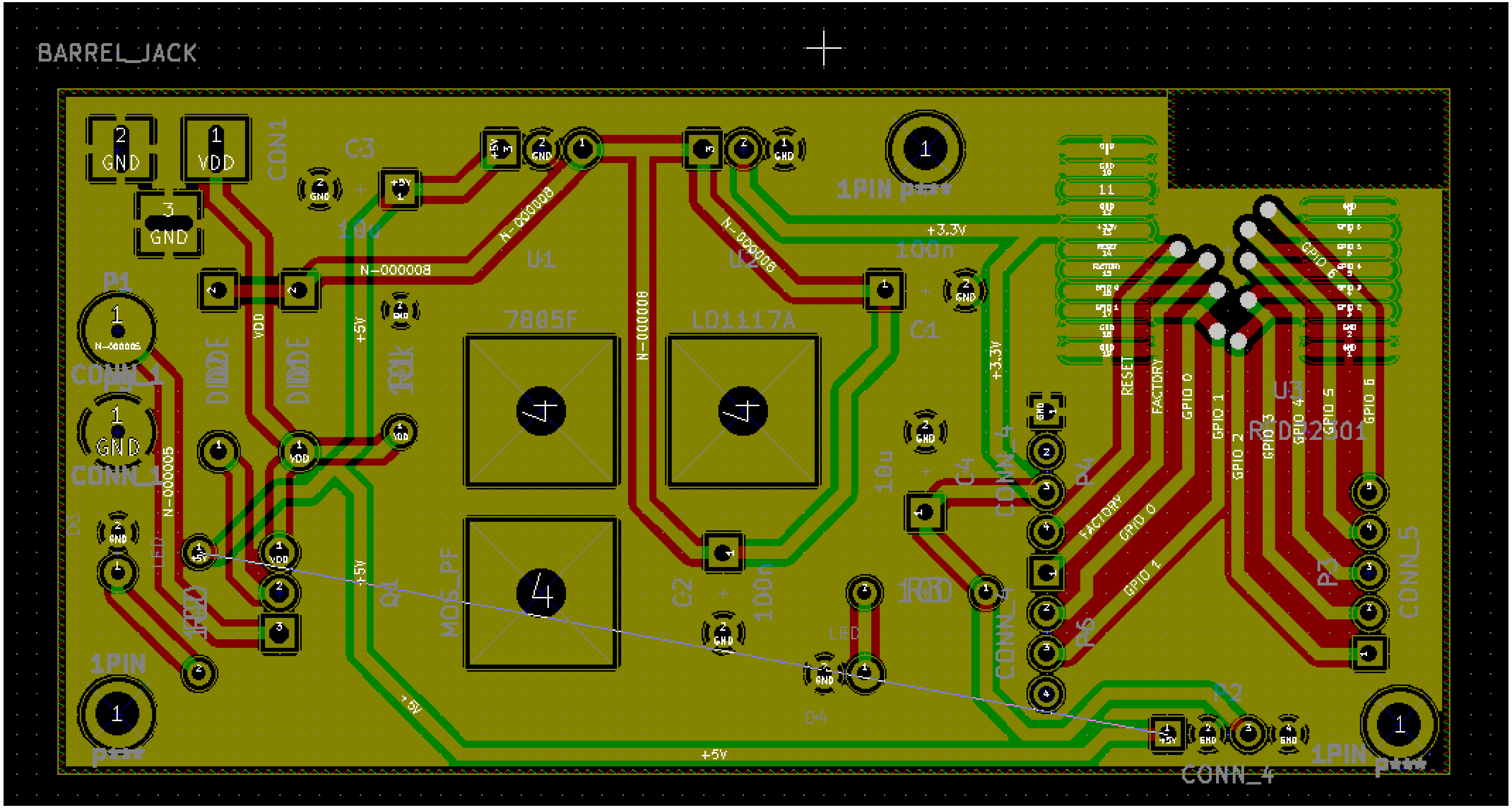
Interface Board PCB Layout



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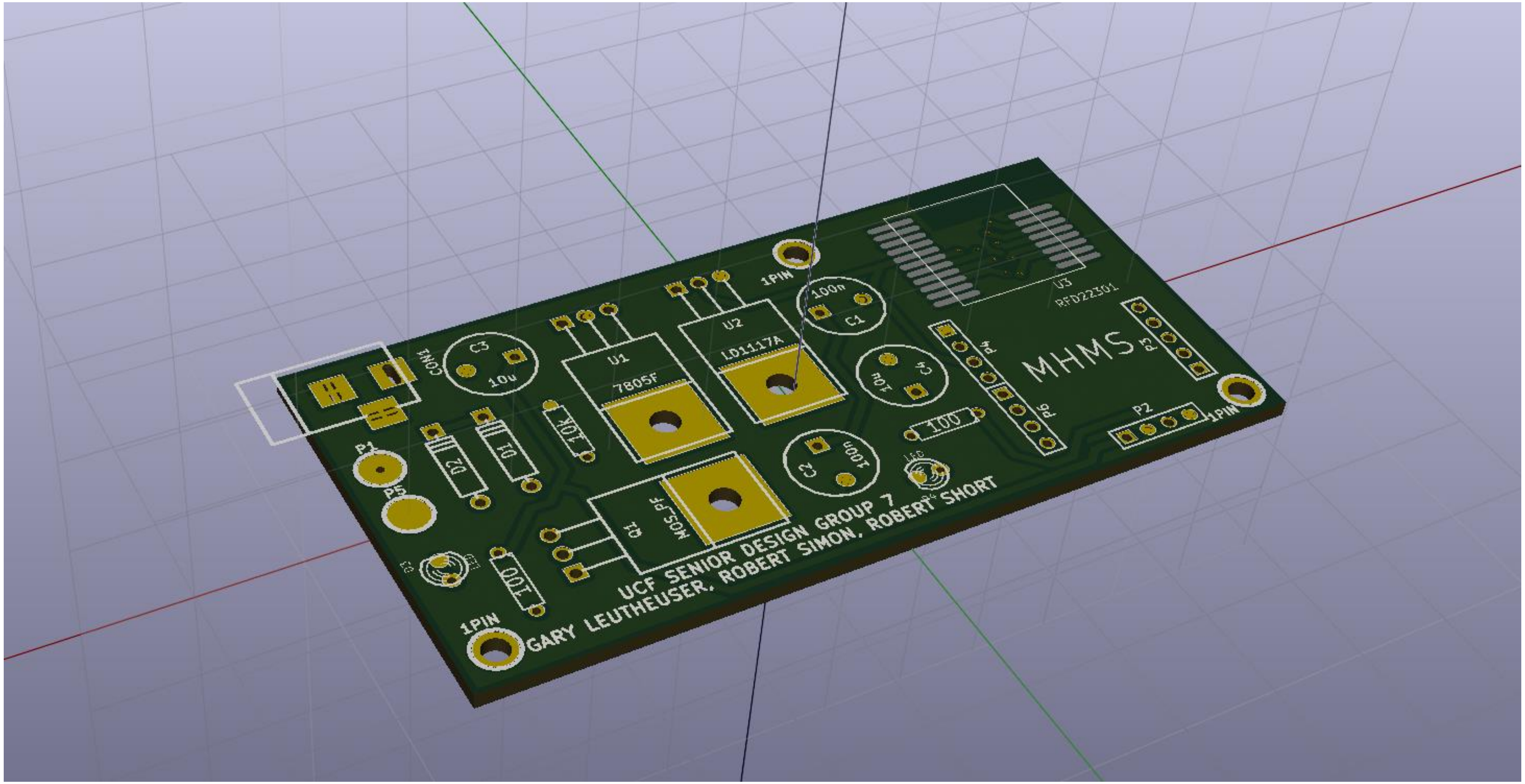
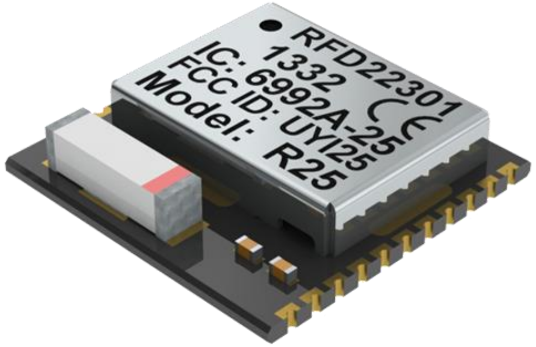
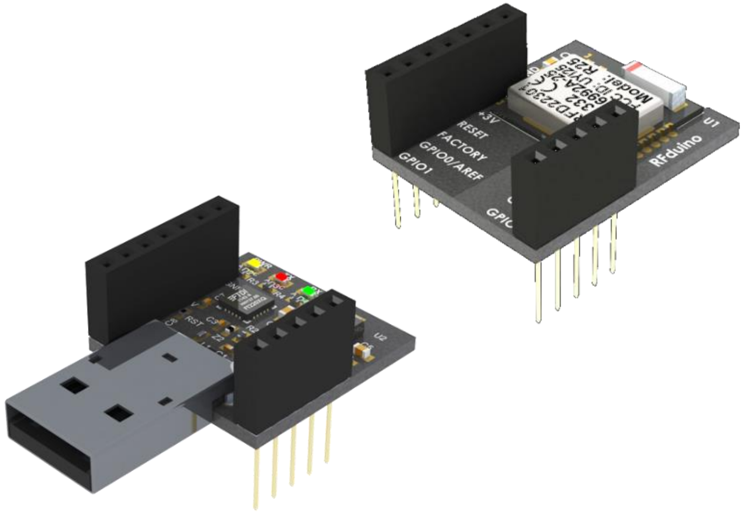
Interface Board PCB Rendering



RFDuino

- Bluetooth 4.0 enabled Arduino microcontroller
- Based on the Nordic Semiconductor nRF51822 SoC
- Chosen Because:
  - Arduino ease of use
  - Bluetooth libraries provided by the company
  - Prototyping made easy

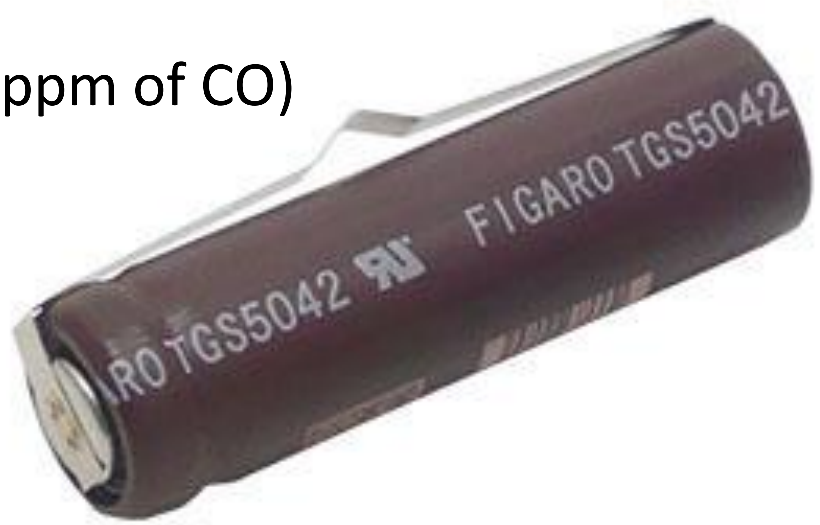




Device	Cost	Flash	Power	CPU	Ease of Dev
RFDuino	$15	128KB	12mA Tx	16MHz Cortex M0	🟩
QN902X	$3	64KB	8.8mA Tx	16MHz Cortex M0	🟥
CC2540	$5	256KB	24mA Tx	16MHz 8051	🟨

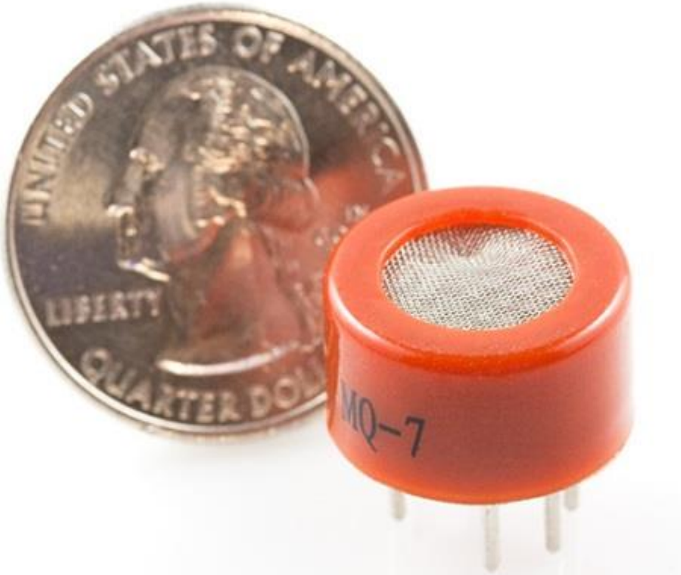
CO Sensor

- The Figaro TGS5042-B00 was one option
  - Not available for retail purchase (quote only)
  - Simple output, but requires amplification (1.8 nA / ppm of CO)
  - No power consumption (electrochemical sensor)
  - Sensitive to other gases (primarily hydrogen)
  - No need for pre-heating



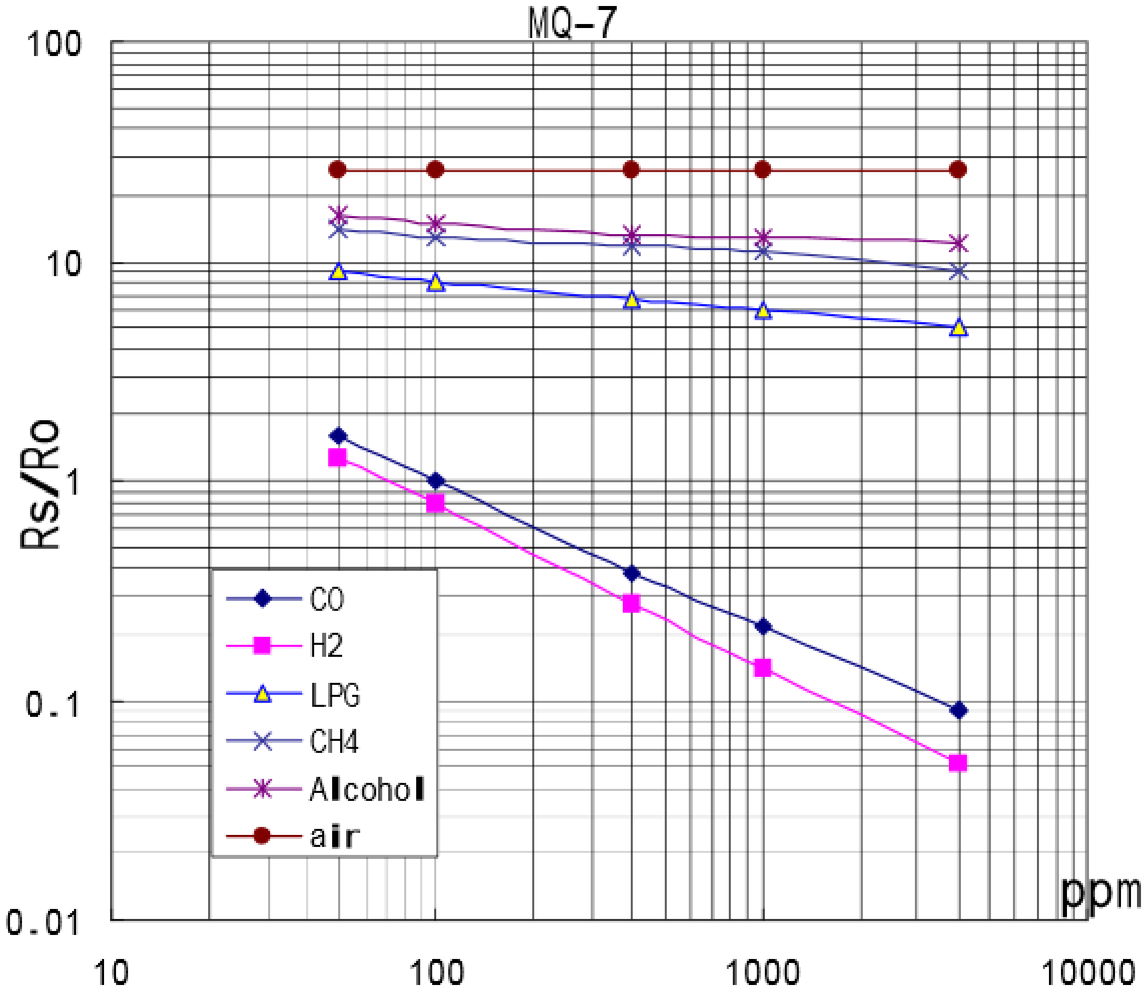
CO Sensor

- The MQ-7 carbon monoxide sensor is the best fit for our project
  - Low cost (less than $10)
  - Simple output (resistance changes with CO concentration)
  - Moderate power consumption (1 W)
  - Sensitive to other gases (Hydrogen, LPG, Methane, etc.)
  - Must be pre-heated for stable readings



CO Sensor

- The sensor decreases in resistance as CO concentration increases.
- Output resistance is referenced to a fixed 10 kOhm resistor.



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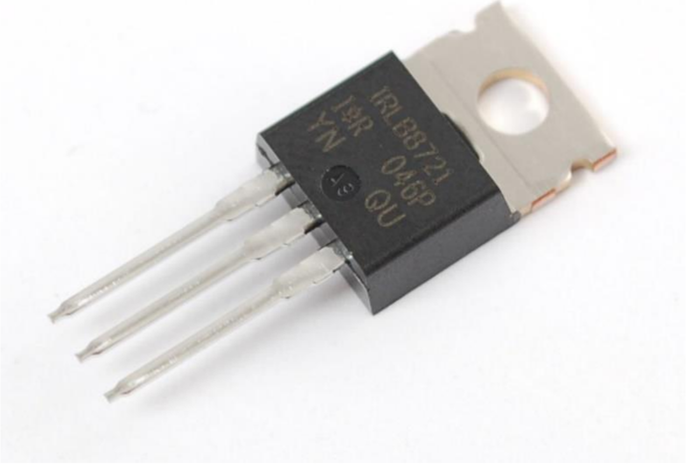
CO Sensor

- The sensor operates by detecting CO adsorbed onto the semiconductor surface.
- A significant peak heater current (200 mA) is needed for this process
- However, a lower current is necessary to periodically refresh the sensor.



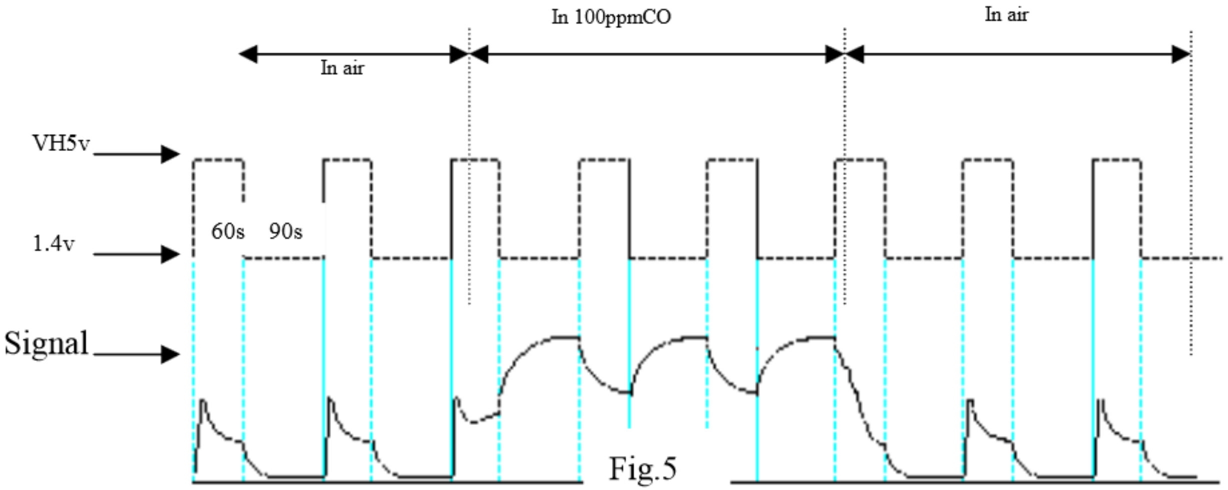
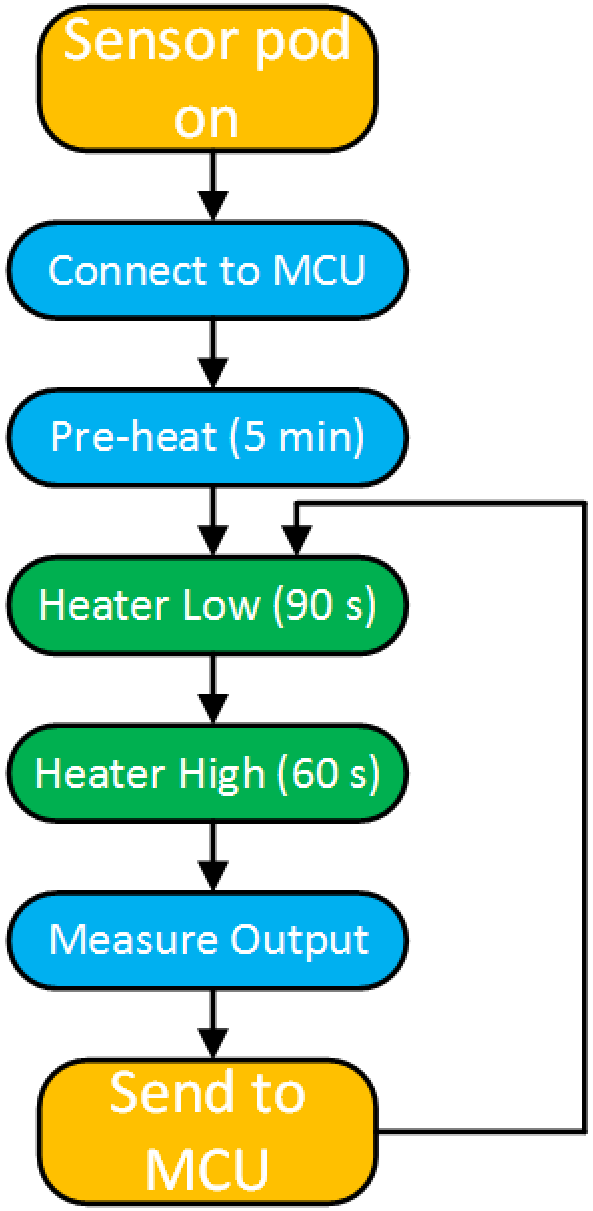


Fig.5

CO Sensor

- The sensor will report at intervals of 2.5 minutes.
- For more stable readings, a rolling average may be desirable, but this would increase an already large (150 sec.) measurement delay.
- A power saving mode is not practical, due to the large warm-up time required.



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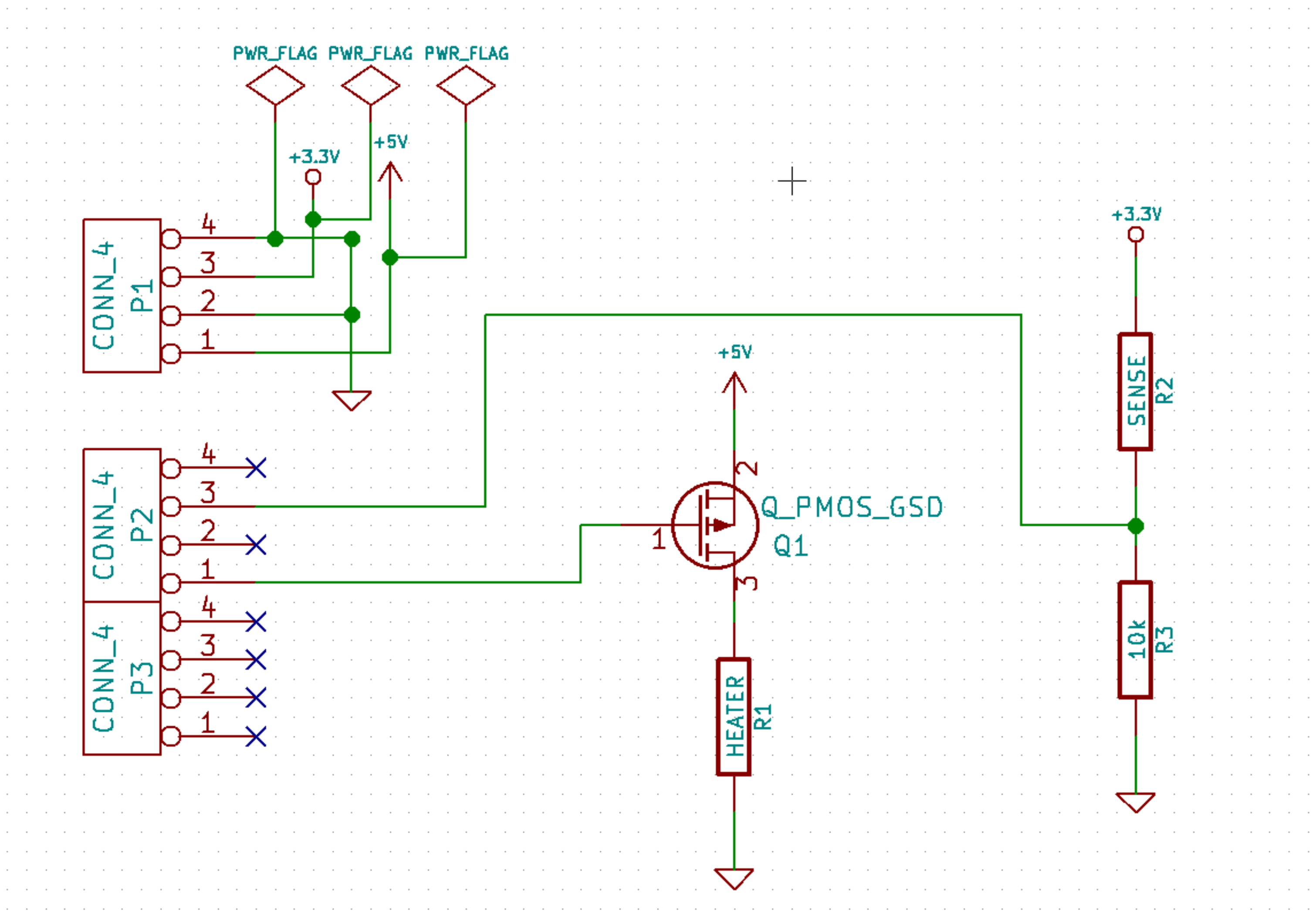
CO Sensor

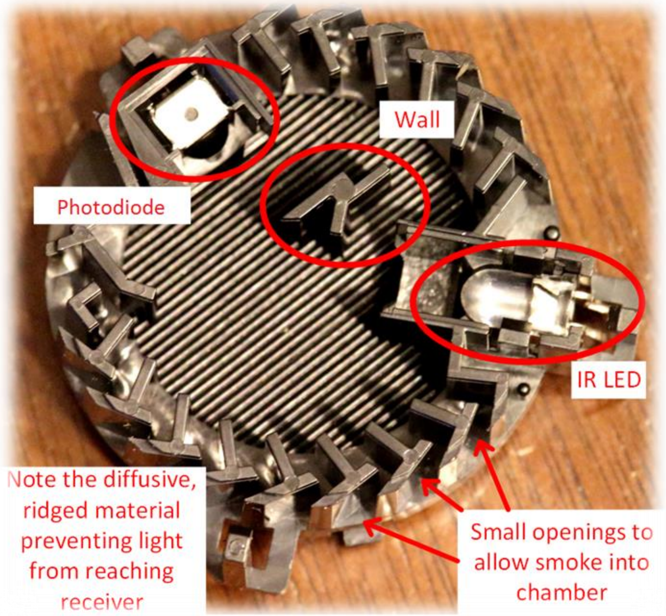
CO Concentration (ppm)	COHb percentage	Symptoms
35	<10%	Headache and dizziness within 6 to 8 hours
100	>10%	Headache in 2 to 3 hours
200	20%	Headache in 2 to 3 hours; loss of judgement
400	25%	Frontal headache in 1 to 2 hours
800	30%	Dizziness, nausea, and convulsions within 45 minutes; insensible within 2 hours
1600	40%	Headache, tachycardia (rapid heart rate), dizziness, and nausea within 20 minutes; death in less than 2 hours
3200	50%	Headache, dizziness, and nausea in 5 to 10 minutes; death within 30 minutes
6400	60%	Headache and dizziness in 1 to 2 minutes; convulsions, respiratory arrest, and death in less than 20 minutes
12800	>70%	Death in less than 3 min

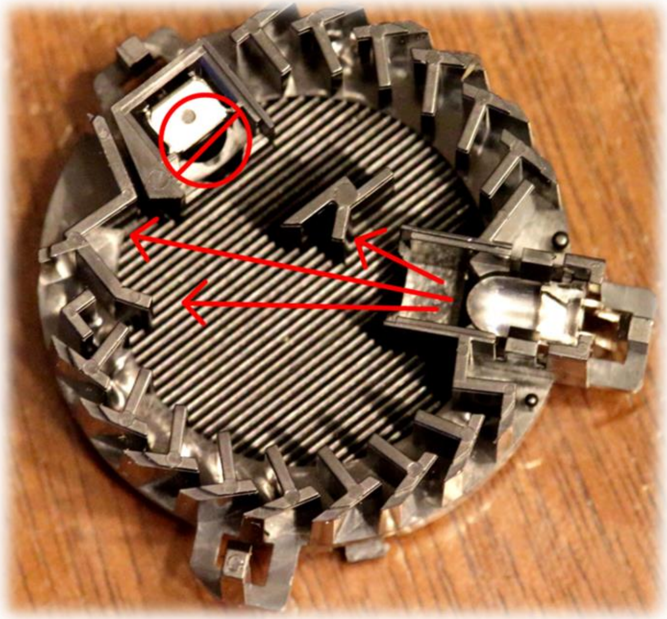
CO Sensor Schematic

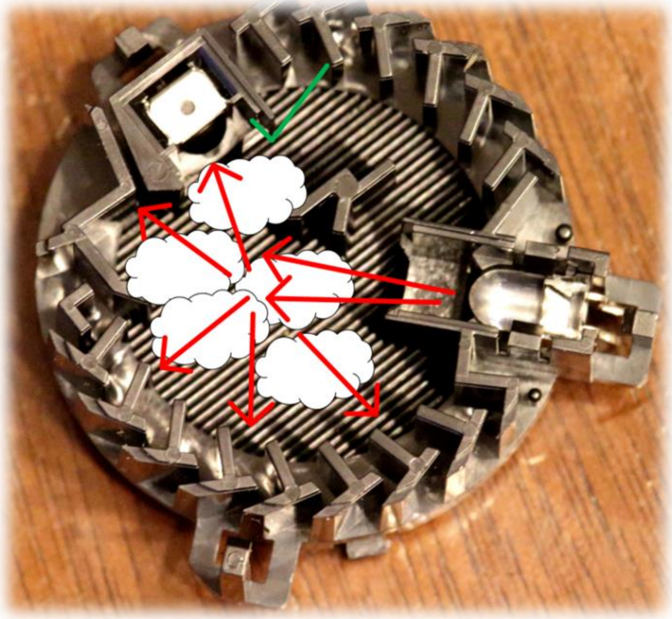


Smoke Sensor

- Photoelectric smoke sensor
  - Cannot detect fires that do not produce smoke
- Consists of an IR LED and a photodiode in a special chamber

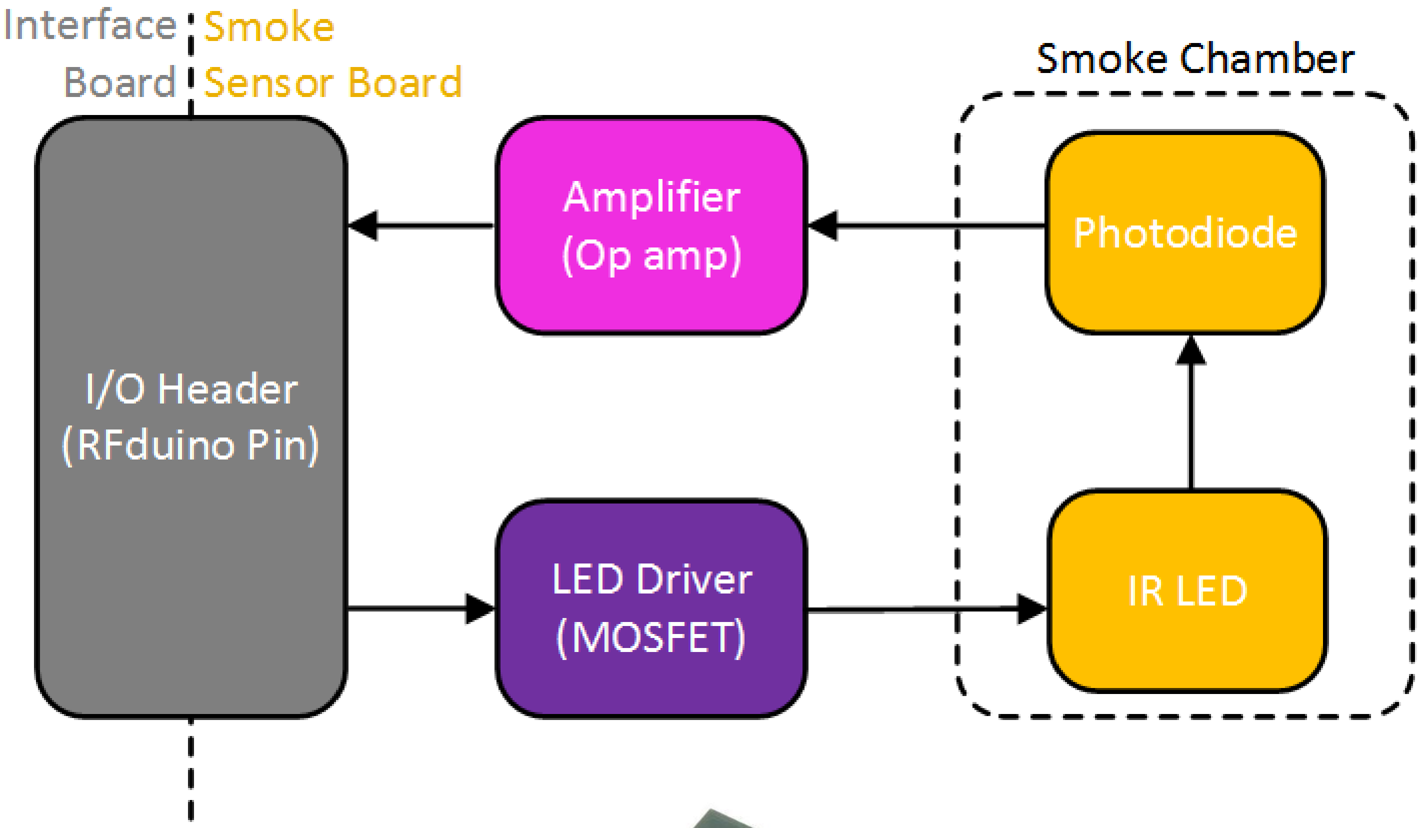

Wall
Photodiode
IR LED
Note the diffusive, ridged material preventing light from reaching receiver
Small openings to allow smoke into chamber





Smoke Sensor

- Small photocurrent results in small voltage, need amplification
- RFduino pins cannot drive LED directly, need driver
- Op amp: ON Semiconductor TLC082CP | Free Sample| Texas Instruments
  - Output current: 100 mA
  - Min supply voltage: 3 V
  - Slew rate: 0.6 V/µs
- N-channel MOSFET: ON Semiconductor 5LN01SP | $0.41 | Mouser
  - On resistance: 10 Ω
  - Threshold voltage: 1.3 V
  - Continuous drain current: 100 mA



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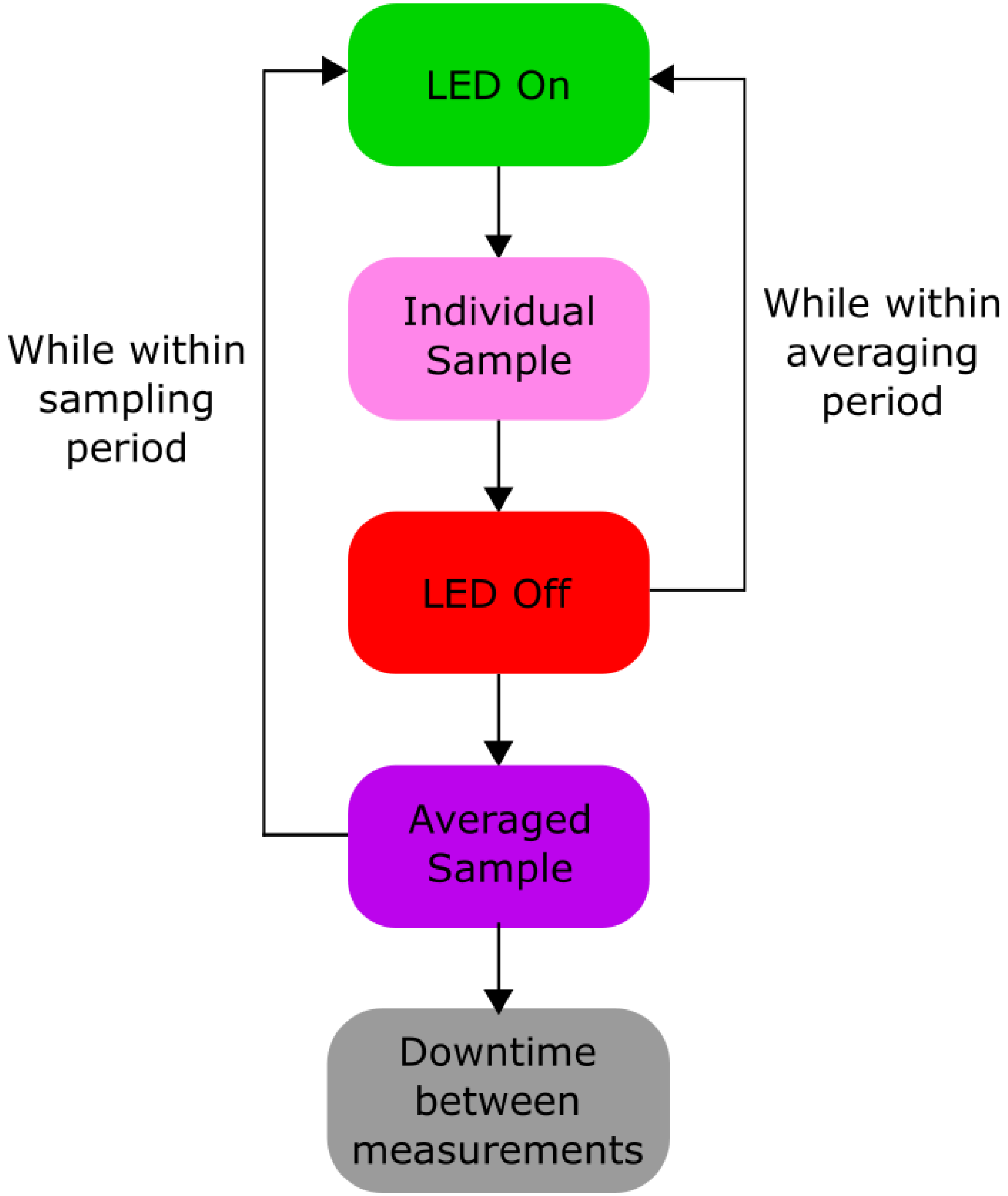
Smoke Sensor

- Smoke Chamber: Kidde FireX Smoke Alarm | $21.37 | Home Depot
  - Had to purchase entire system to salvage chamber (high cost)
- IR LED: Vishay 78-TSHF6210 | $0.67 | Mouser
  - Wavelength: 890 nm
  - Max current: 100 mA
  - Voltage drop: 1.4 V to 1.6 V
- Photodiode: Lite-On 859-LTR-546AD | $0.64 | Mouser
  - Photocurrent: 100 µA
  - Peak Wavelength: 900 nm
  - Rise/fall time: 50 ns

SMOKE SENSOR

- LED can be pulsed quickly by RFduino, and the photodiode has quick response time
- Several individual samples are averaged
  - Several of these “averaged samples” are taken – i.e. many individual measurements
- System then sleeps until taking more measurements to conserve power


LED On
Individual Sample
LED Off
Averaged Sample
Downtime between measurements
While within sampling period
While within averaging period

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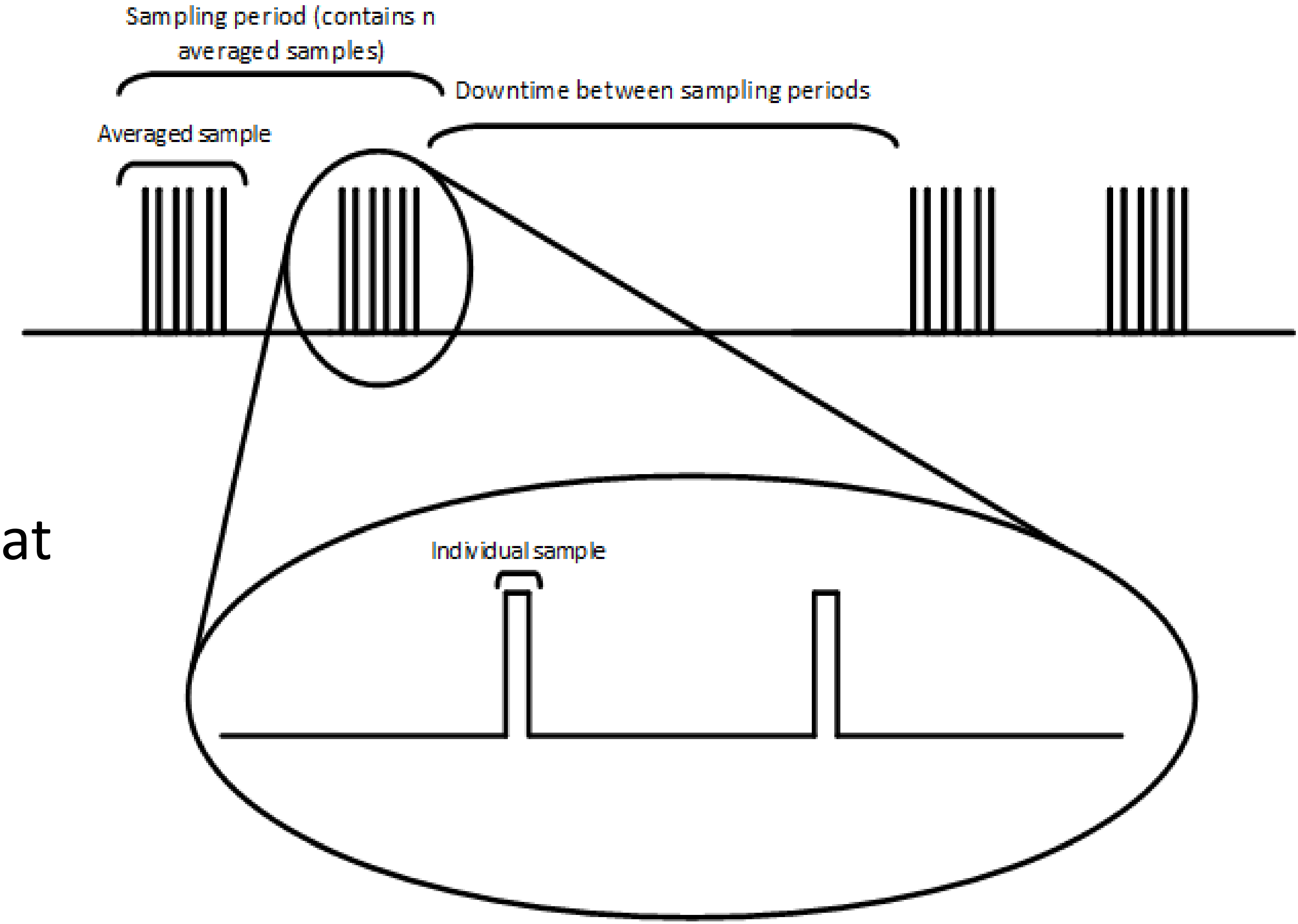
SMOKE SENSOR

- Graphical representation of averaging system
- Continuous driving of the LED and conversion of photodiode output is an inefficient solution
- Instead, the LED will be pulsed at high frequency and low duty cycle while checking for smoke


Sampling period (contains n averaged samples)
Downtime between sampling periods
Averaged sample
Individual sample

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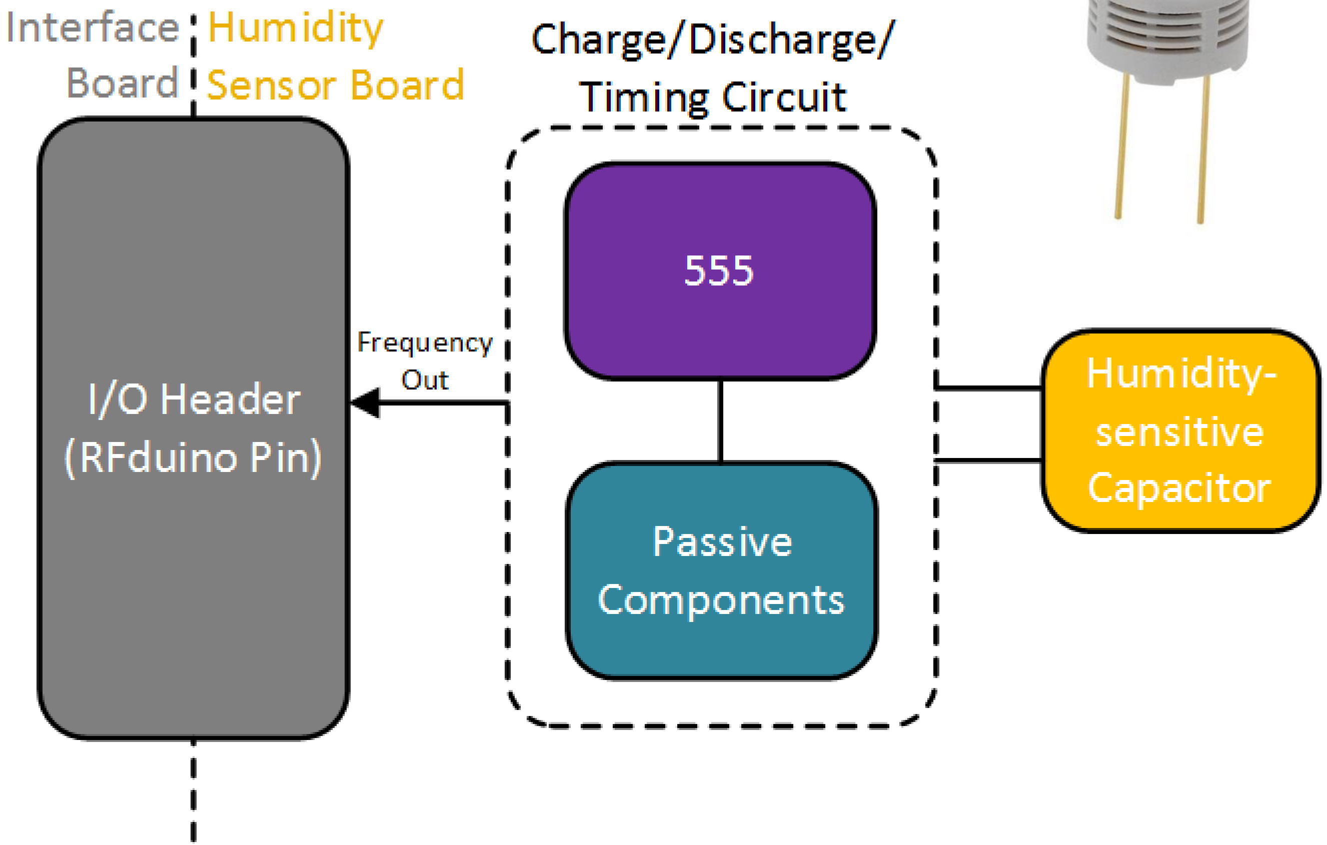
Humidity Sensor

- Humidity-sensitive capacitor continuously charged/discharged to determine relative humidity (RH) level
- Capacitor: Parallax 27920 (HS1101) | $8.99 | Mouser
  - Transfer function: approx. linear
  - Response time: 5 s
  - Low cost in terms of humidity sensors



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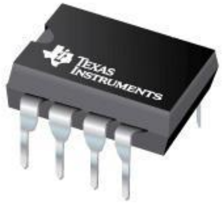
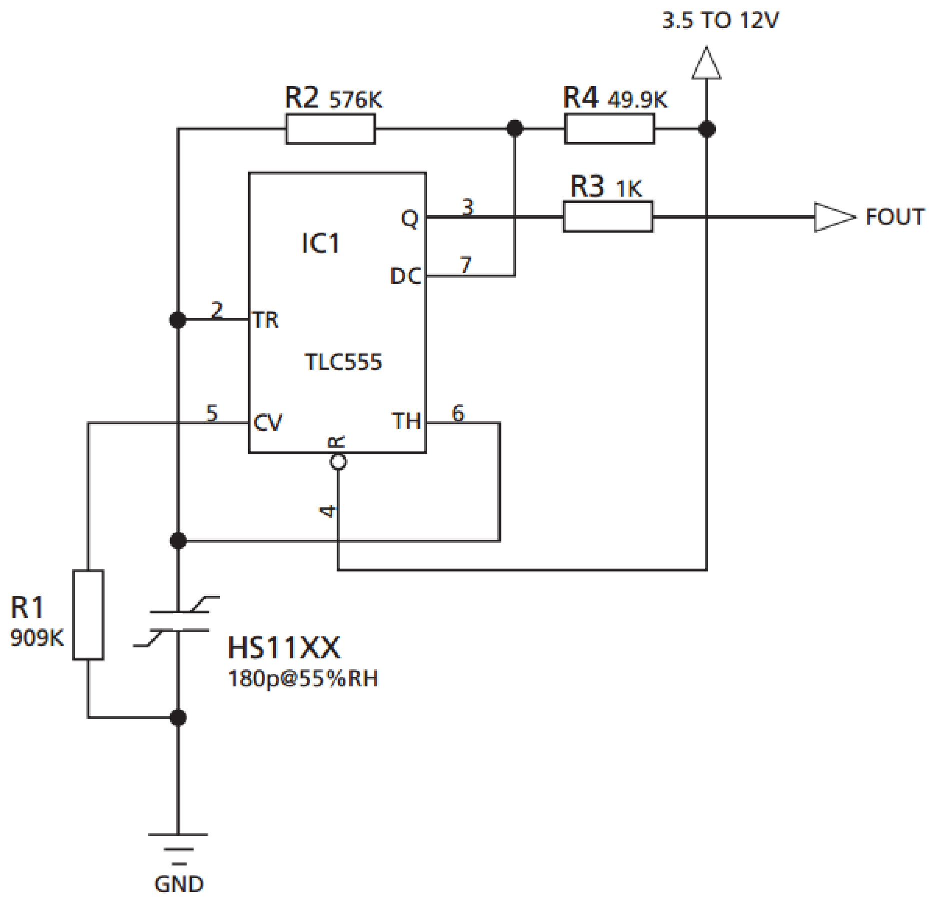
Humidity Sensor – Charge/Discharge Circuit

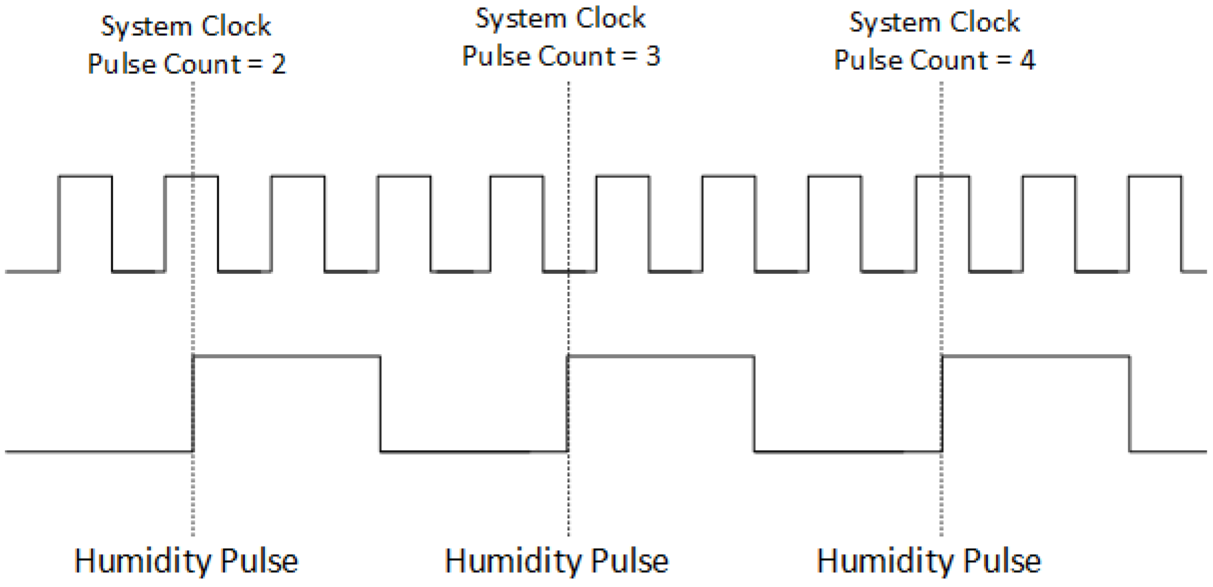
- 555 Timer: TI TLC551CP | $1.84 | Mouser
  - Supply voltage: 1 V to 15 V
  - Requires 4 resistors to configure
- Output frequency of circuit varies in the range of approximately 6 kHz to 7.5 kHz
  - Higher frequency means lower % RH
  - Nearly linear transfer function
  - Low output frequency allows simple oversampling for frequency detection



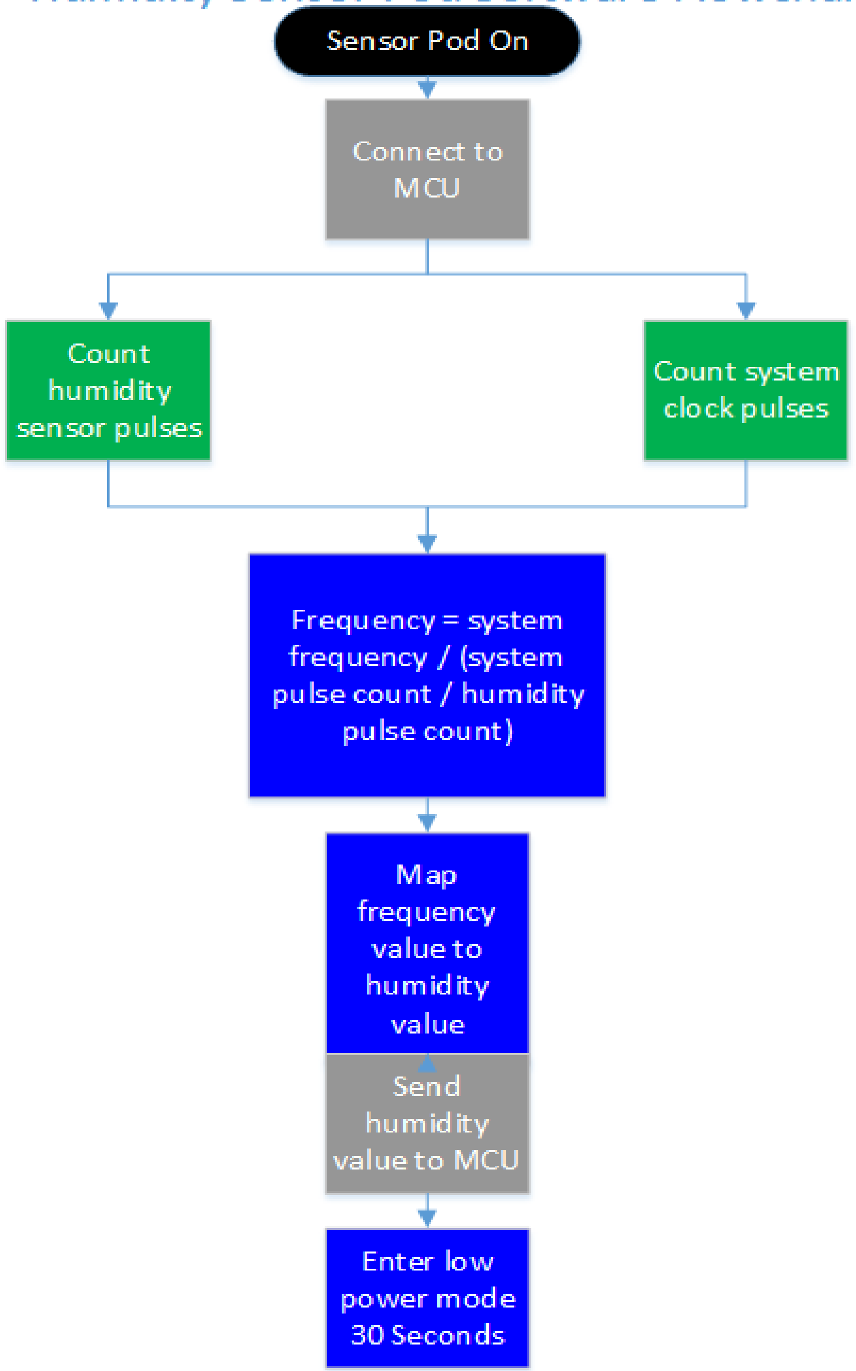


BILL OF MATERIAL AVAILABLE ON REQUEST

Humidity Sensor Frequency Determination


System Clock Pulse Count = 2
System Clock Pulse Count = 3
System Clock Pulse Count = 4
Humidity Pulse
Humidity Pulse
Humidity Pulse

Humidity Sensor Pod Software Flowchart


Sensor Pod On
Connect to MCU
Count humidity sensor pulses
Count system clock pulses
Frequency = system frequency / (system pulse count / humidity pulse count)
Map frequency value to humidity value
Send humidity value to MCU
Enter low power mode 30 Seconds

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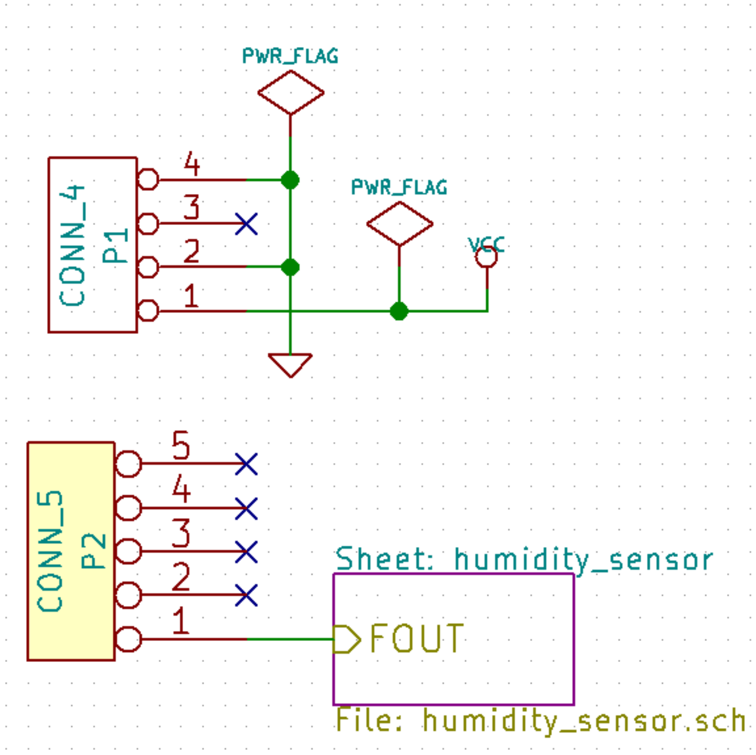
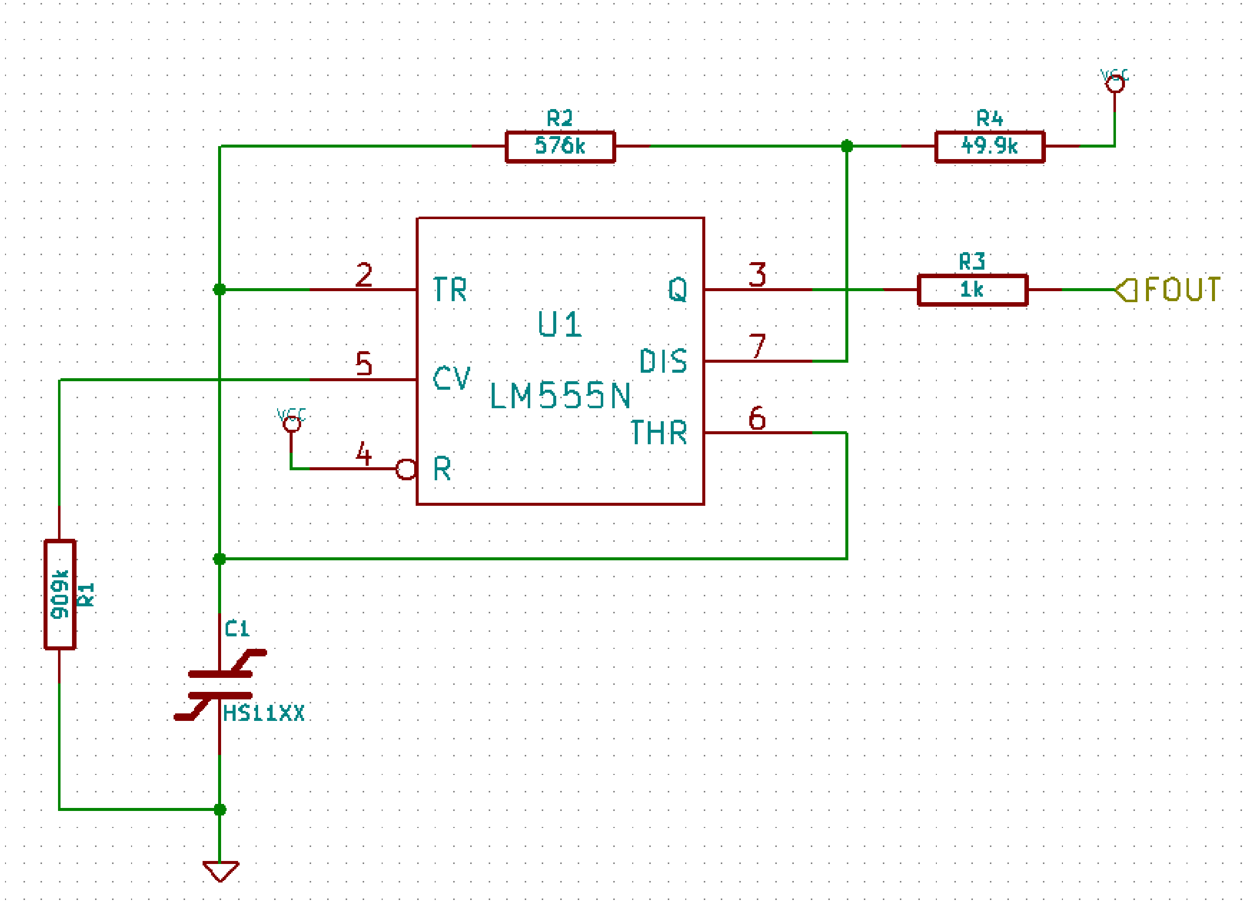
Humidity Sensor Schematic





Software Design

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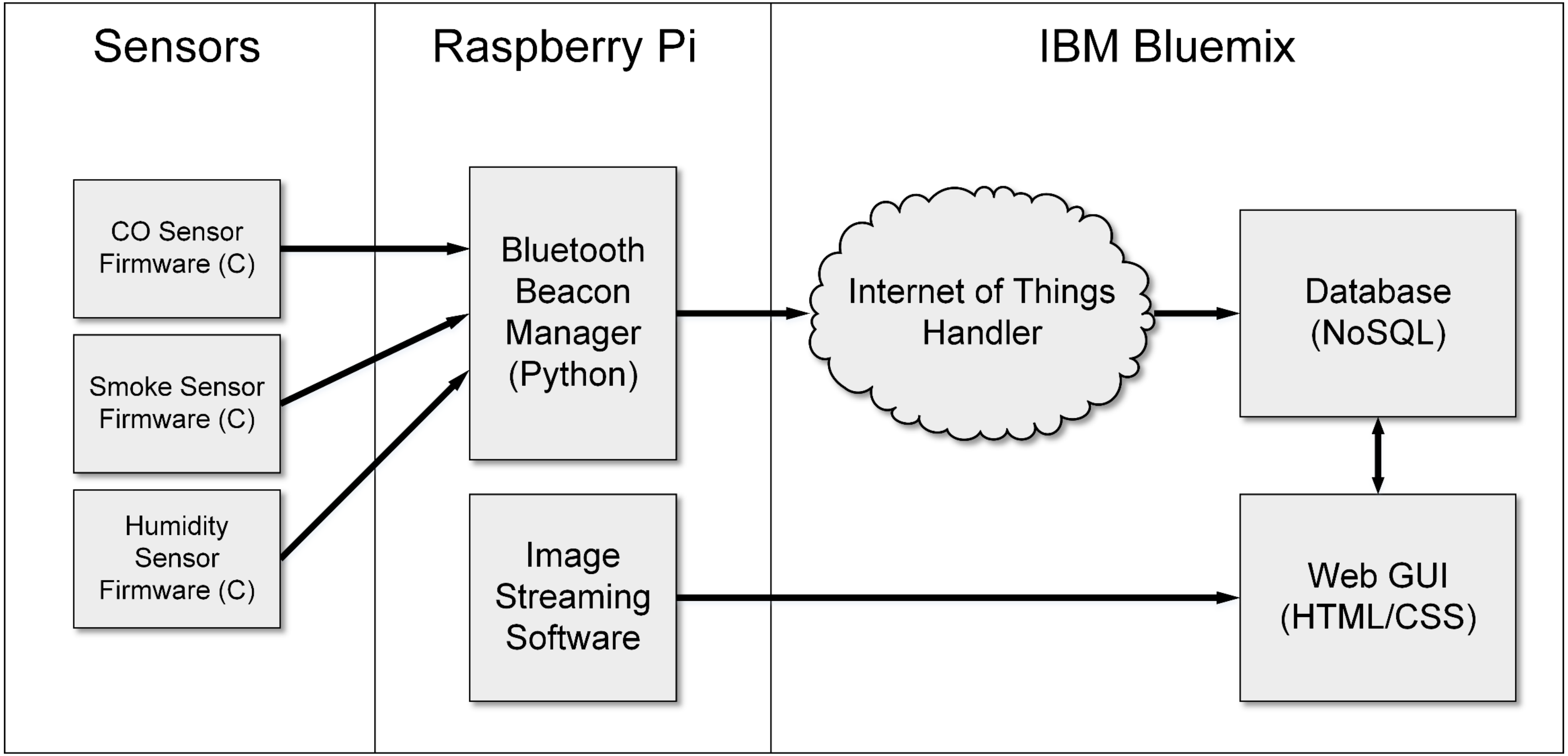
Software Block Diagram



Sensors

Raspberry Pi

IBM Bluemix

CO Sensor Firmware (C)

Smoke Sensor Firmware (C)

Humidity Sensor Firmware (C)

Bluetooth Beacon Manager (Python)

Image Streaming Software

Internet of Things Handler

Database (NoSQL)

Web GUI (HTML/CSS)

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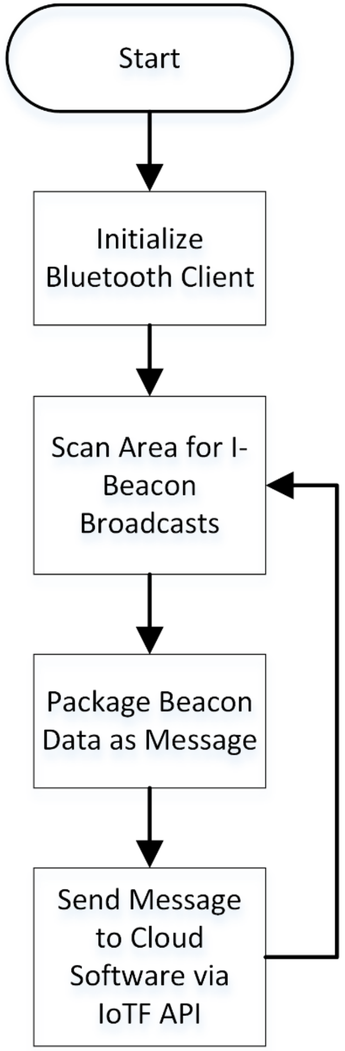
Bluetooth Beacon Manager

- Python Script
- Bluez C Library, Pybluez BLE python wrapper
- Takes in Sensor information via BLE I-Beacon Protocol
- Sends out specific sensor data to IoT handler via WiFi
- No data filtering, all data passed to Cloud Application for interpreting

MCU Communication Software Flowchart



Start

Initialize Bluetooth Client

Scan Area for I-Beacon Broadcasts

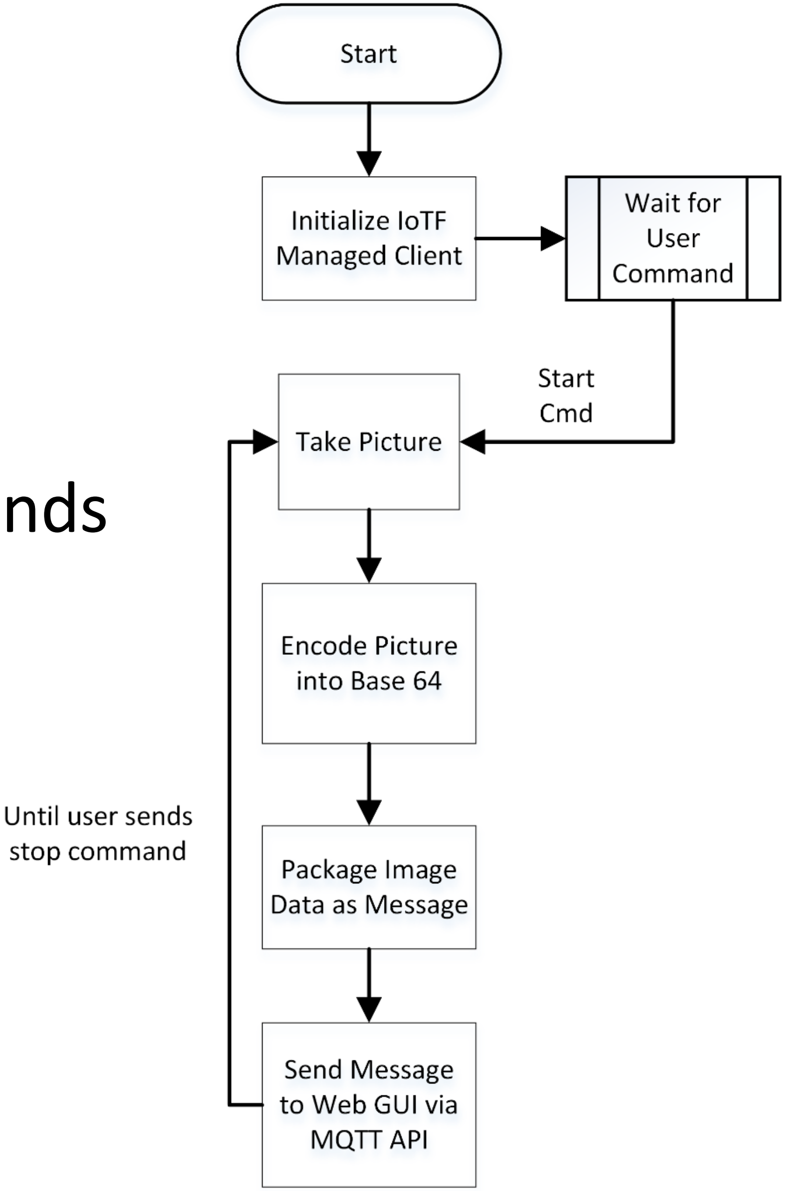
Package Beacon Data as Message

Send Message to Cloud Software via IoTF API

CAMERA STREAMING MANAGER

- Custom Python Script
- User controls when to start the Camera Stream
- Takes picture, encodes image into Base64 then sends to Web GUI for decoding and display over IoTF
- Complete control over resolution and FPS
- Explored options:
  - Raspvid
  - MJPEG-Streamer

MCU Camera Stream Flowchart


Start
Initialize IoTF Managed Client
Wait for User Command
Start Cmd
Take Picture
Encode Picture into Base 64
Package Image Data as Message
Send Message to Web GUI via MQTT API
Until user sends stop command

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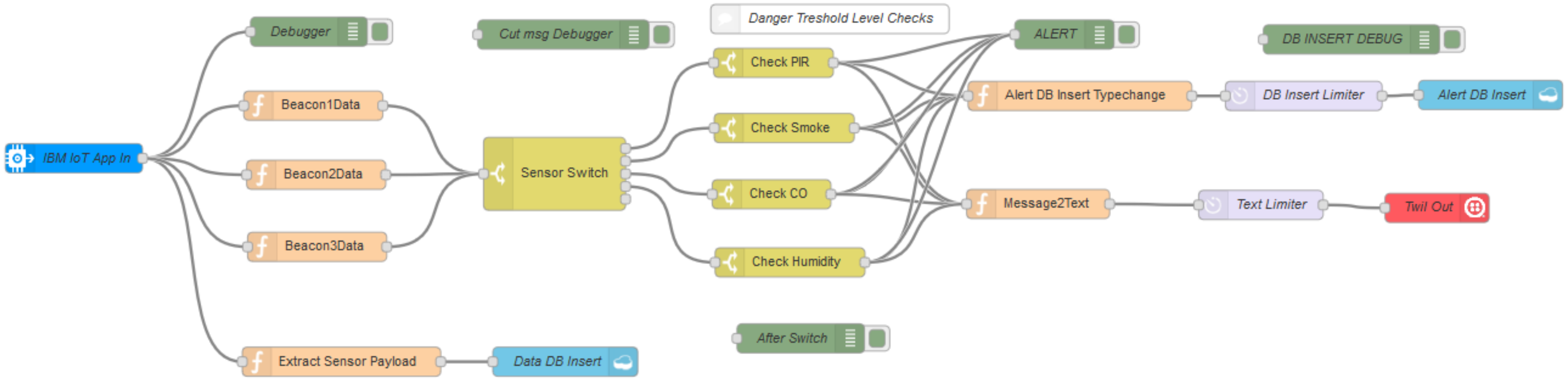
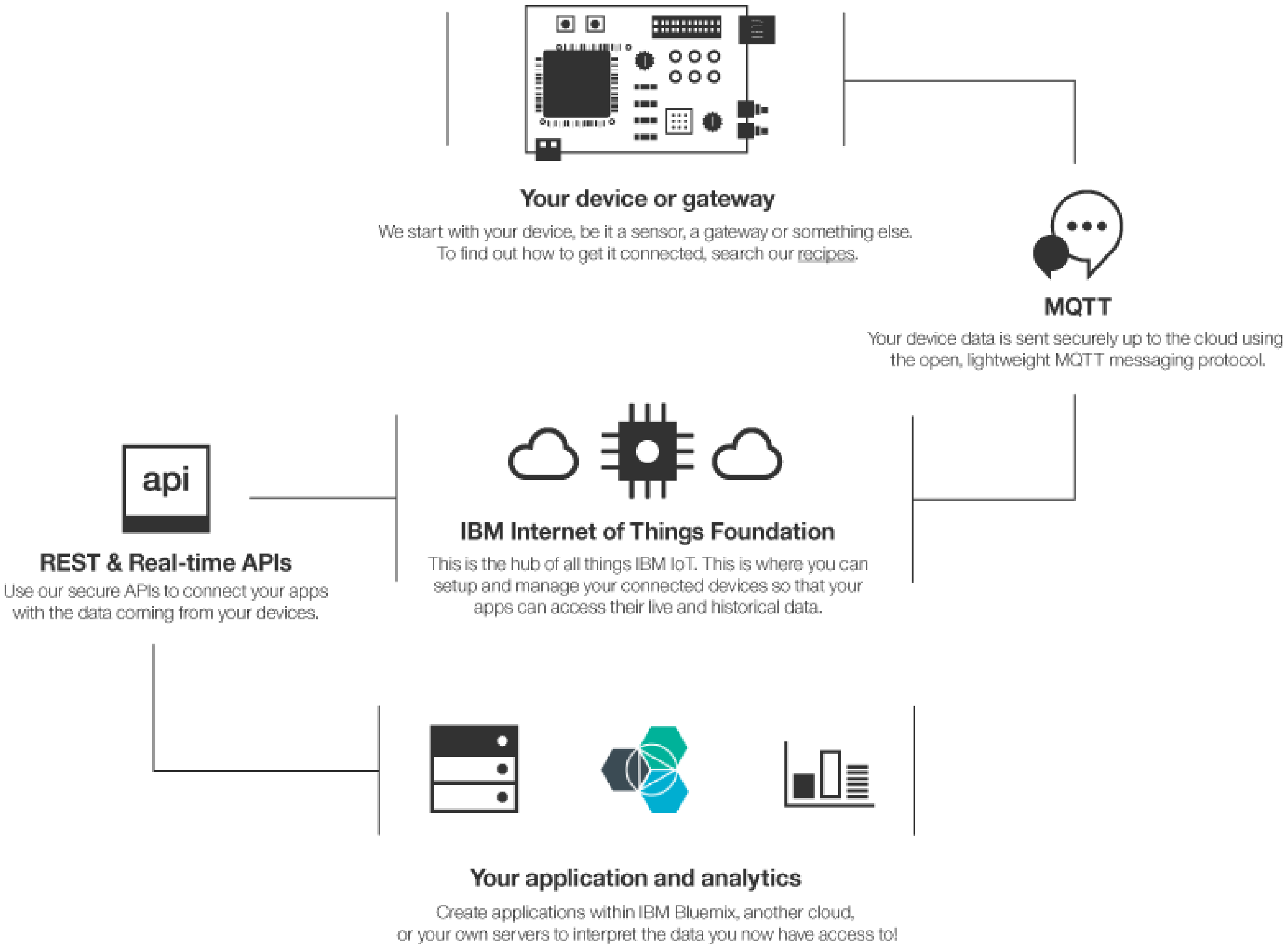
Internet of Things Handler

- IBM Bluemix’s Internet of Things Foundation
- Twilio for text message API
- Allows for simple message transfer over MQTT protocol
- Chosen because:
  - Familiarity with the IBM Bluemix Platform
  - Node-Red to create dataflow



IBM Bluemix™

How it works



Your device or gateway

We start with your device, be it a sensor, a gateway or something else. To find out how to get it connected, search our recipes.

MQTT

Your device data is sent securely up to the cloud using the open, lightweight MQTT messaging protocol.

IBM Internet of Things Foundation

This is the hub of all things IBM IoT. This is where you can setup and manage your connected devices so that your apps can access their live and historical data.

REST & Real-time APIs

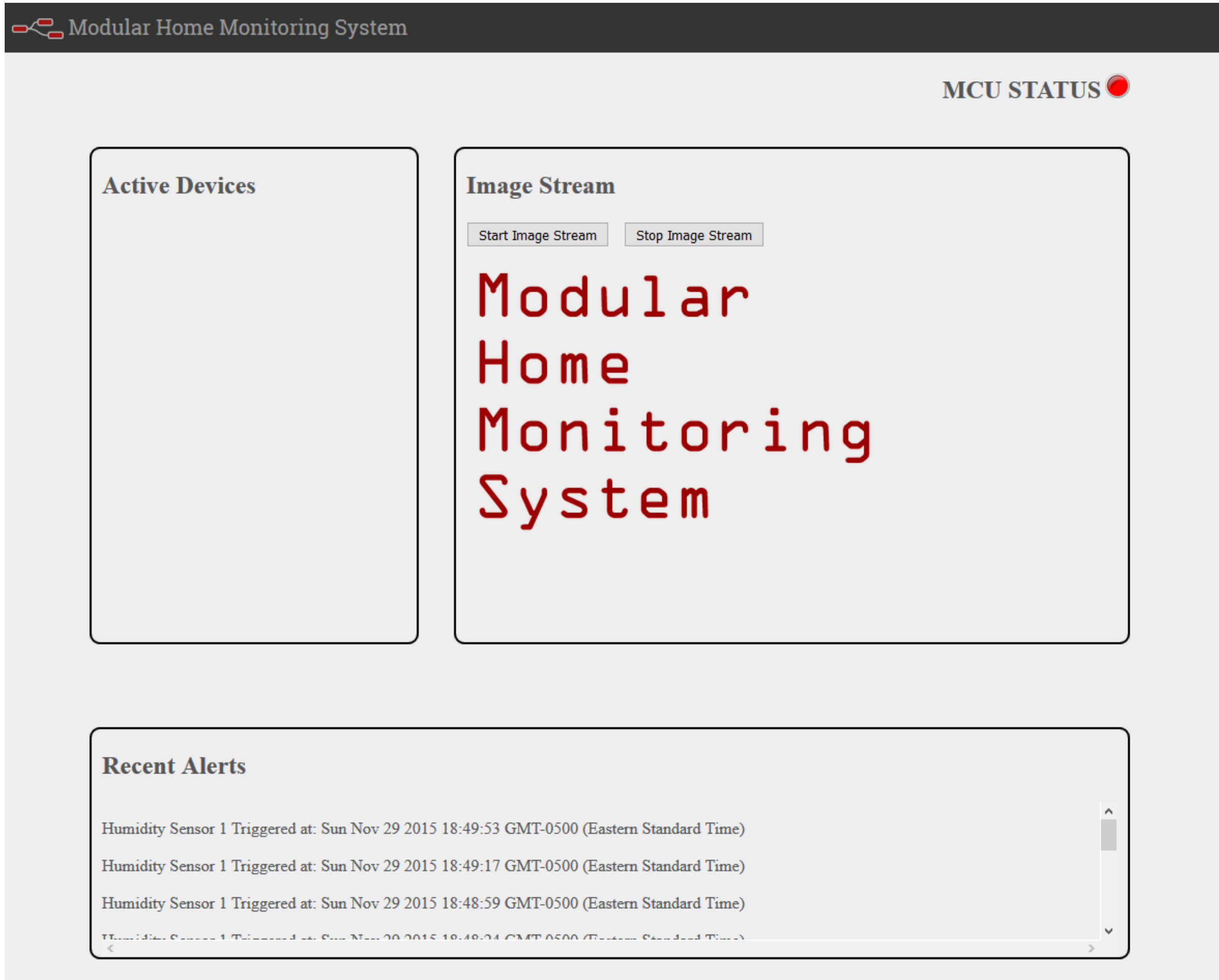
Use our secure APIs to connect your apps with the data coming from your devices.

Your application and analytics

Create applications within IBM Bluemix, another cloud, or your own servers to interpret the data you now have access to!

Web GUI

- Hosted on Bluemix as part of the cloud application
- Developed with HTML and CSS for styling
- Regular Javascript used to query the NoSQL Database
- Everything on one page
  - Status, Alerts and Feed



Humidity Sensor 1 Triggered at: Sun Nov 29 2015 18:49:53 GMT-0500 (Eastern Standard Time)

Humidity Sensor 1 Triggered at: Sun Nov 29 2015 18:49:17 GMT-0500 (Eastern Standard Time)

Humidity Sensor 1 Triggered at: Sun Nov 29 2015 18:48:59 GMT-0500 (Eastern Standard Time)

Humidity Sensor 1 Triggered at: Sun Nov 29 2015 18:48:24 GMT-0500 (Eastern Standard Time)

SOFTWARE CHALLENGES

- Unfamiliarity with Python, HTML/CSS, Javascript
- Inexperience with web design in general
- Getting camera stream to non-local web page
- Keeping data usage low and efficient

Administrative Content

WORK DISTRIBUTION

	Interface Board HW Design	CO Sensor Board Design	Smoke Sensor Board Design	Humidity Sensor Board Design	RFDuino Firmware	Bluetooth Comm.	Camera Integration	Cloud Application Development	Procurement
Gary Leutheuser	✓	✓	✓	✓	✓		✓	✓	✓
Robert Short	✓	✓		✓	✓	✓			✓
Robert Simon			✓			✓	✓	✓	

FINANCING

- No sponsorships or financial assistance
- Cost of project split into thirds between group members
  - Incentive to keep component costs low

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Budget

Item	Actual Cost
Raspberry Pi 2 B kit	$93
Pi Camera	$26
3x Interface Board	$102
Sensor Boards	$47
Test Equipment	$50
Development Equipment	$45

Total Cost: $363

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