EE542
Lecture 18: IIoT for Oil Industry

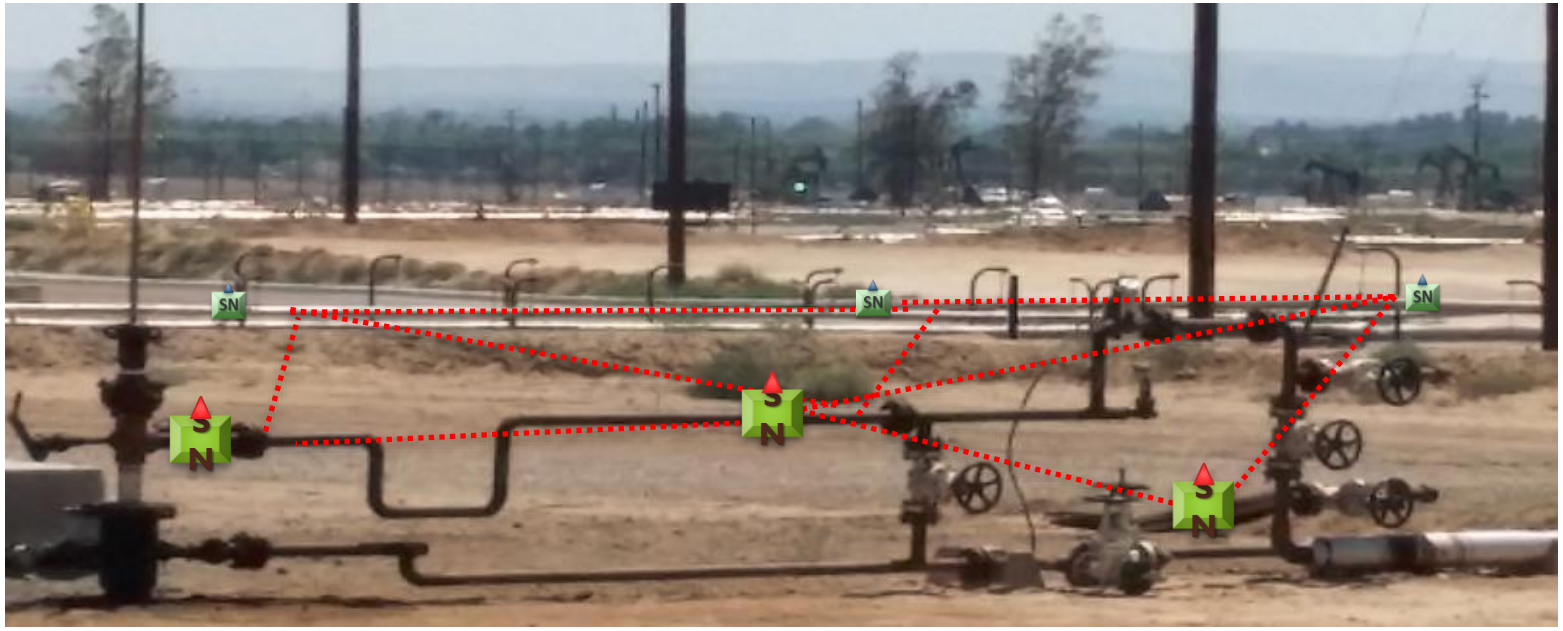
Internet and Cloud Computing

Young Cho
Department of Electrical Engineering
University of Southern California

Non-invasive Condition Monitoring (SEN)

- The Goal
  - Self Sustaining IIoT in the Real World
  - Use of IIoT to Increase Field Security and Oil Production with Lower Cost
- Potentials
  - Potential for application in various remote location and plant environment in place of batteries used today
  - Cost reasons inhibits IIoT type applications, this technology can drive down the cost of smart field implementation
  - Reducing amount of equipment in the field, as existing wireless systems have very low battery life (many not as advertised) or require expensive solar panels that are conducive to theft
  - Non-invasive Sensor Data analysis for inferential information

SEN Vision



- Low cost sensors – redundant sensors
- “Lick and Stick” Sensors – easy installation
- Industrial-standard wireless mesh network – turnkey operation
- Persistent spatial sensing – new type of long term data
- Non-invasive Sensing

Target Equipment

- Industrial Devices
  - Rosemount Wireless Transceivers
  - Permsense Wireless Sensor
  - Continuous Monitoring of Oil Pipes
  - Uses Lithium Battery (10 years self-life)
  - Shorter Life in Practice (1-2 years typical)

- Research Goal
  - Efficiently Harvest Ambient Energy
  - Increase the System Life

Variety of Data Loggers

Instamic
- 4 hours battery
- Only 2 GB
- Bluetooth
- $100

Voice Recorder
- 6 days recording
- 16 GB data
- No upload
- $250

Noise Tutor
- AC powered
- Hard Drives
- WiFi/3G
- $2500

Challenges

- IIoT is a new market
- Limited life and performance
- High Cost
- No commercialized/Industrialized self sustaining solutions

Our Initial Work

March 2010, Bakersfield, CA

Thermal Power Harvestor

Wireless Sensor

- Large Battery Powered Monitoring System Ran Out of Power
- Wireless Sensor Continued to Run Overnight
- Alluding to Pressure using Temperature

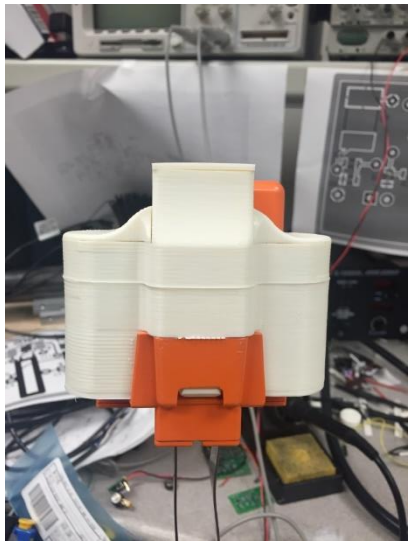
Pervasive Thermoelectric Generation (PTG)

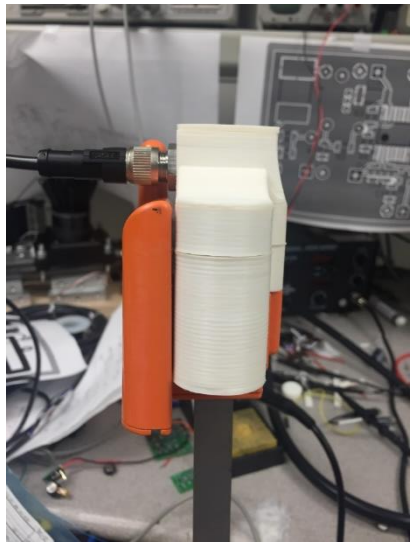
PTG for Permasense Transceivers

Successfully Tested in the Laboratory
Higher Efficiency Conditioner Design
Integrated Perpetua PowerPuck
Integrated Dual Polarity

PTG for Rosemount Transceivers

Successful Field Trials
1+ Years Without Failure
With or Without Batteries
Integrated our TEG design
Integrated Dual Polarity
Integrated Module Chaining

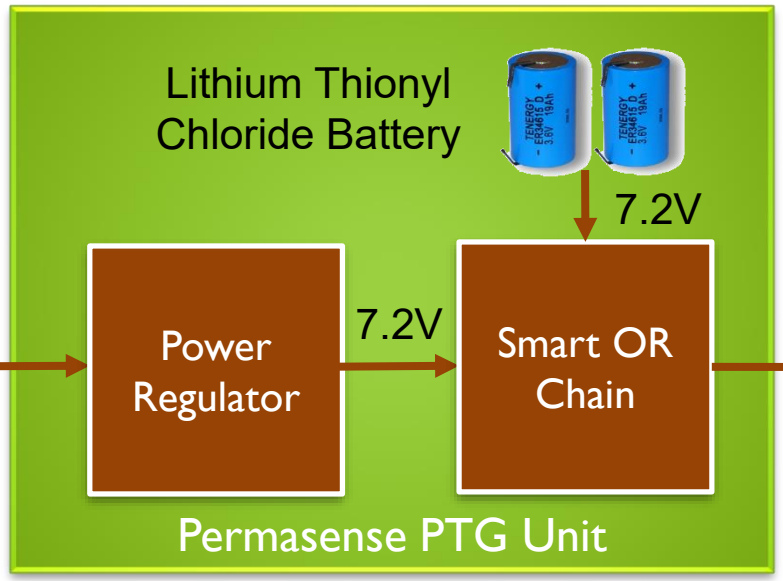




Fully Integrated Battery Unit

0-12V

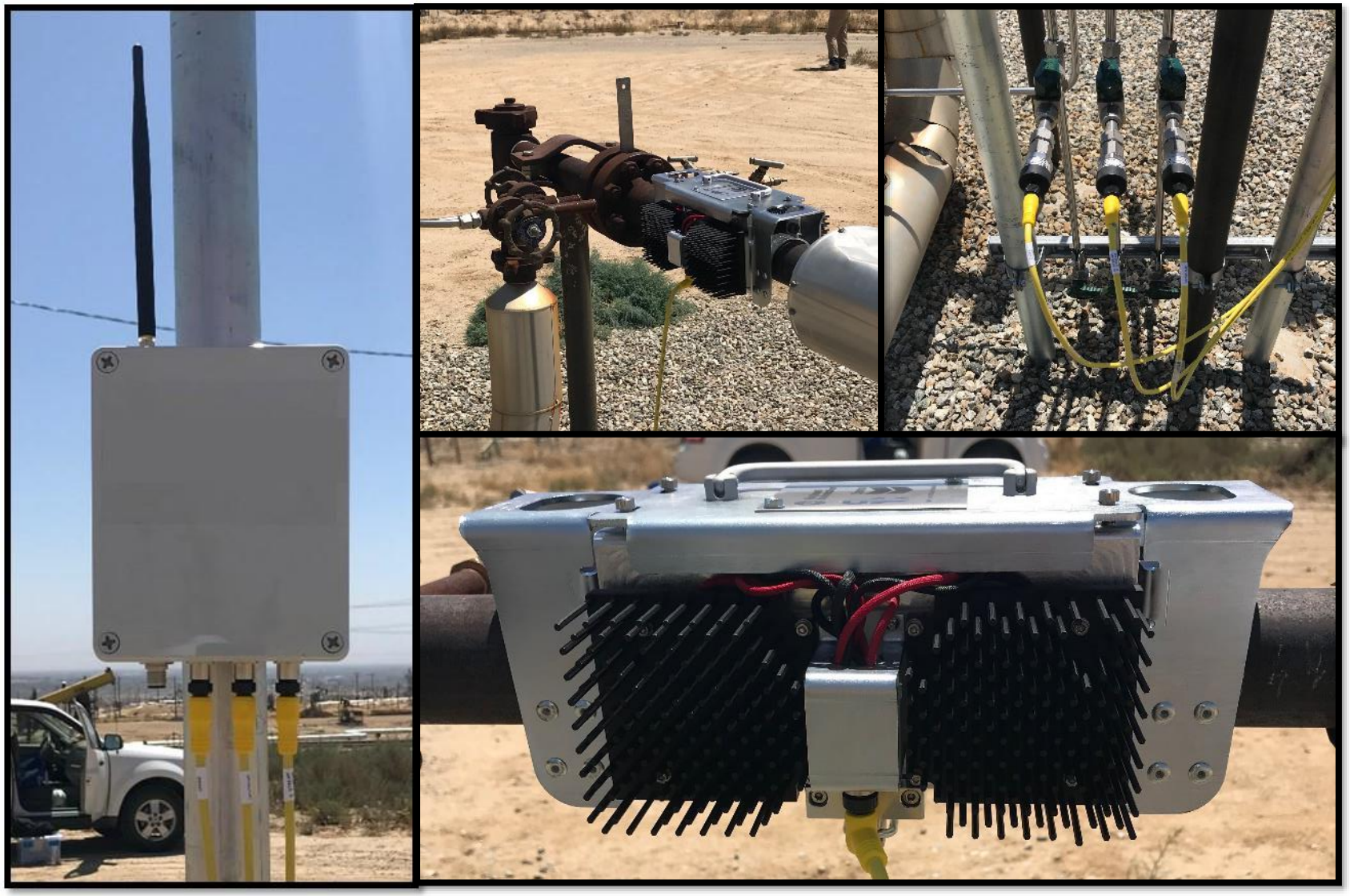
Perpetua
Power Puck



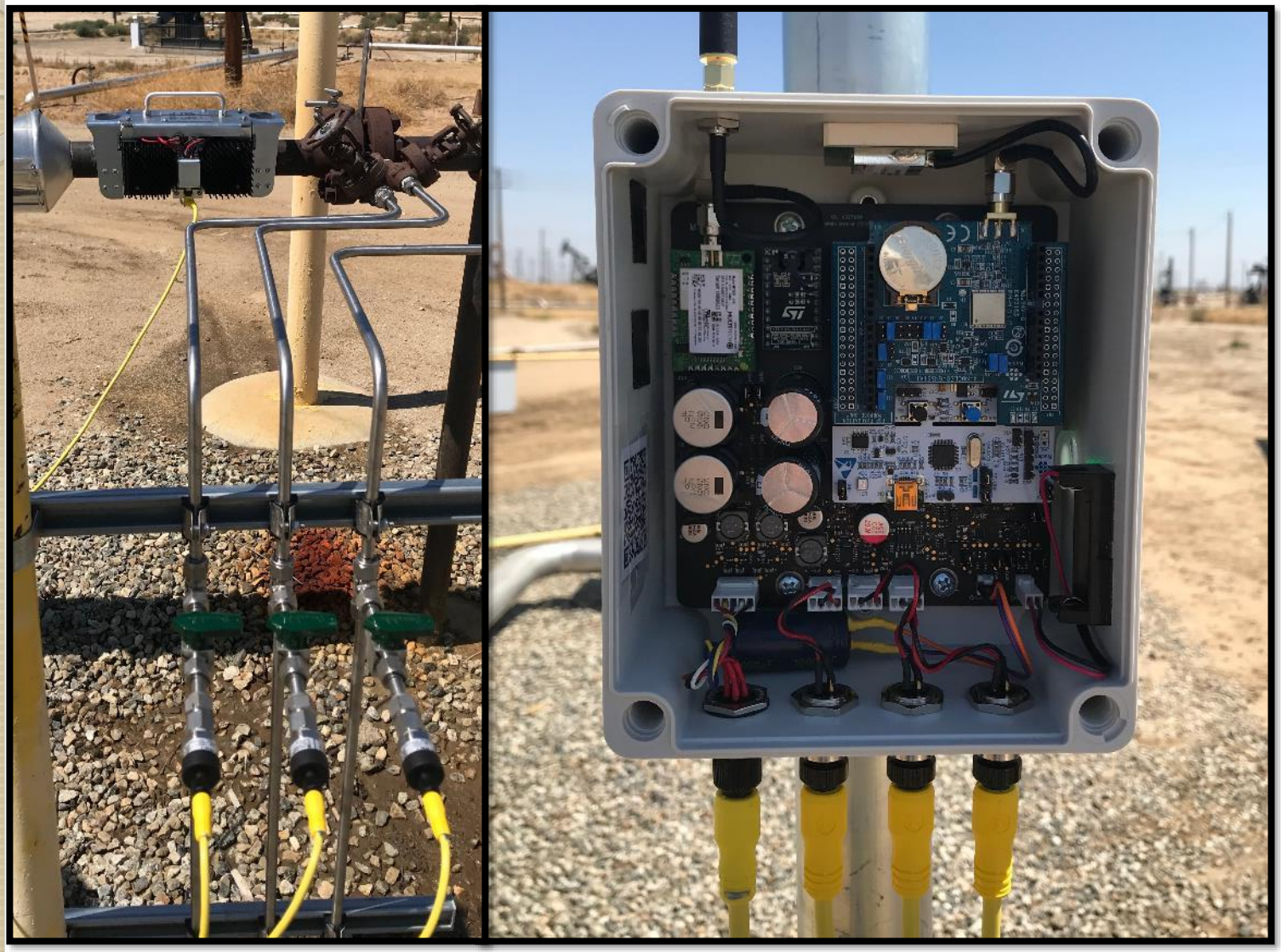
7.2V

Permasense
Sensor

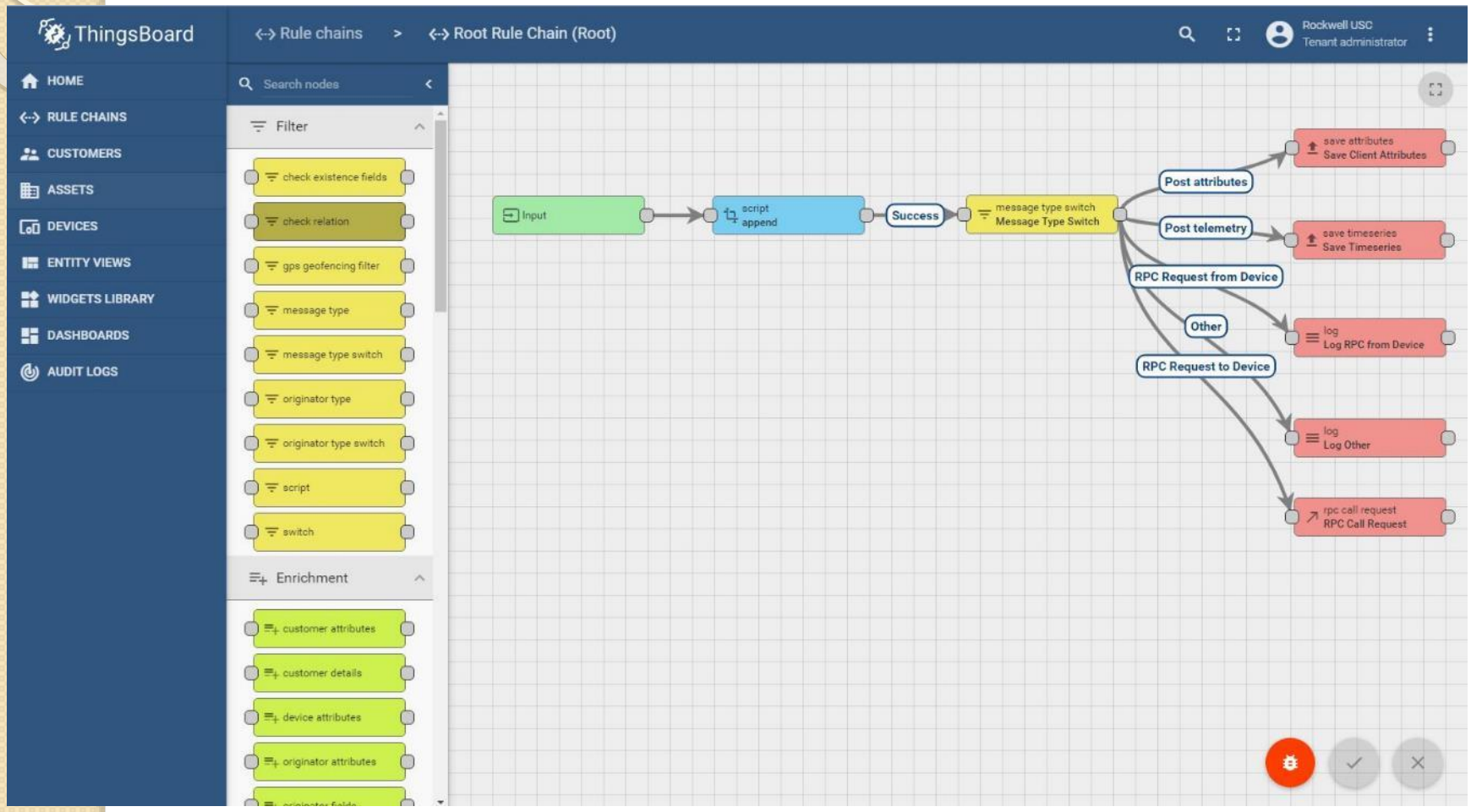
SSIIoT in the Field (Feb 2019)



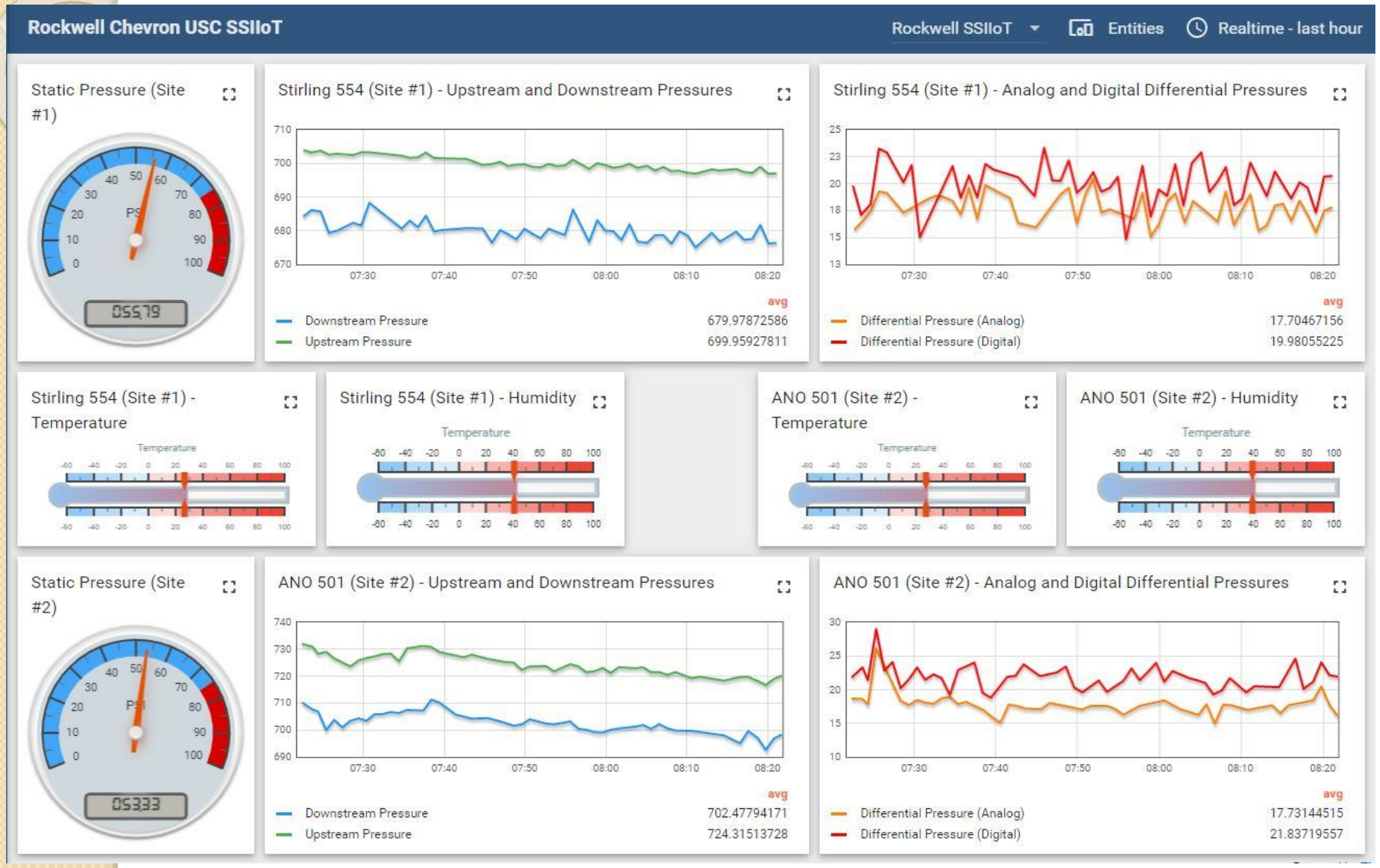
SSIIoT in the Field



Data Collection



Data Collection



Cell Phone based SSIIoT Platform

Continuous Audio Recording

Audio Upload using Cellular

Efficient power optimization

Remote Access

Robust

Solar Powered

Audio Processing

Cost: ~$250

- Smartphone – Various Sensors
- Flash Ubuntu Touch OS
- Reconfigure to use only the essential parts

Self-Sufficient System

Efficient power optimization

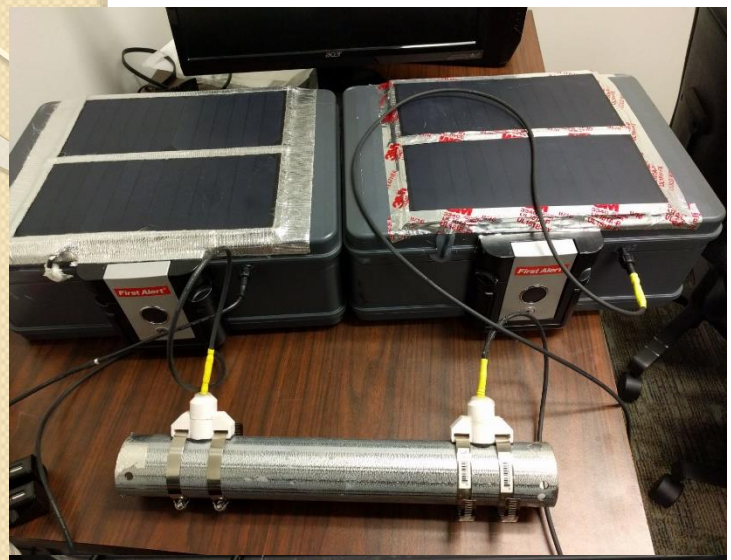
- Display is always off
- Battery monitored every half an hour
- Data turned on only when uploading and remote access
- Goes into critical state when battery falls below 10%

Solar Powered and Robust

- Charges up during day
- Battery big enough to last 2 days without sun
- Sturdy case – Withstands high temperatures and water-proof

```
Wed Aug 24 14:45:03 PDT 2016 Battery capacity is 93 %
Wed Aug 24 14:45:03 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 15:15:02 PDT 2016 Battery capacity is 95 %
Wed Aug 24 15:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 15:45:04 PDT 2016 Battery capacity is 100 %
Wed Aug 24 15:45:04 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 16:15:02 PDT 2016 Battery capacity is 77 %
Wed Aug 24 16:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 16:45:03 PDT 2016 Battery capacity is 75 %
Wed Aug 24 16:45:03 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 17:15:02 PDT 2016 Battery capacity is 75 %
Wed Aug 24 17:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 17:45:02 PDT 2016 Battery capacity is 72 %
Wed Aug 24 17:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 18:15:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 18:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 18:45:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 18:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 19:15:02 PDT 2016 Battery capacity is 70 %
Wed Aug 24 19:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 19:45:02 PDT 2016 Battery capacity is 69 %
Wed Aug 24 19:45:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 20:15:02 PDT 2016 Battery capacity is 76 %
Wed Aug 24 20:15:02 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 20:45:01 PDT 2016 Battery capacity is 86 %
Wed Aug 24 20:45:01 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 21:15:01 PDT 2016 Battery capacity is 95 %
Wed Aug 24 21:15:01 PDT 2016 in NORMAL mode, came from higher percentage or charging up
Wed Aug 24 21:45:02 PDT 2016 Battery capacity is 95 %
```

Two Working SEN Platforms



Field Trial in Bakersfield

Nexus 4 Platform

- Functionality
  - Various Built-in Sensors
  - Customizable Ubuntu Touch Linux OS
  - Reconfigure to use only the essential parts
- Custom Nexus 4G Phone
  - Customized Linux
  - Lower Clock Frequency
  - Turn off 2 of 4 Cores
  - Record Audio
  - Transmit Data via Cellular Nextwork

- Power Consumption: ~ 350mW (May be reduced)

Remote Data Collection Server

Continuous Audio Recording

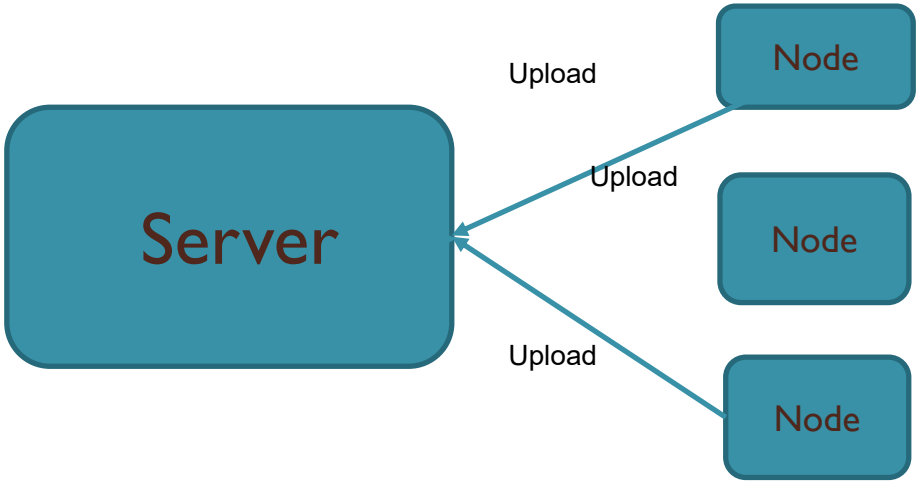
- 44.1KHz sampling rate
- 24 hours/7 days
- Audio samples of configurable length using Vorbis tools

Audio Upload to Server

- Accessible via web page
- Every 6 hours
- Power efficient

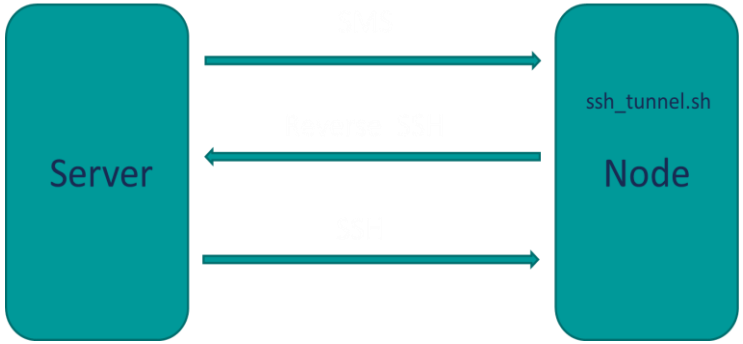
Index of /test/audio_files/node_alpha

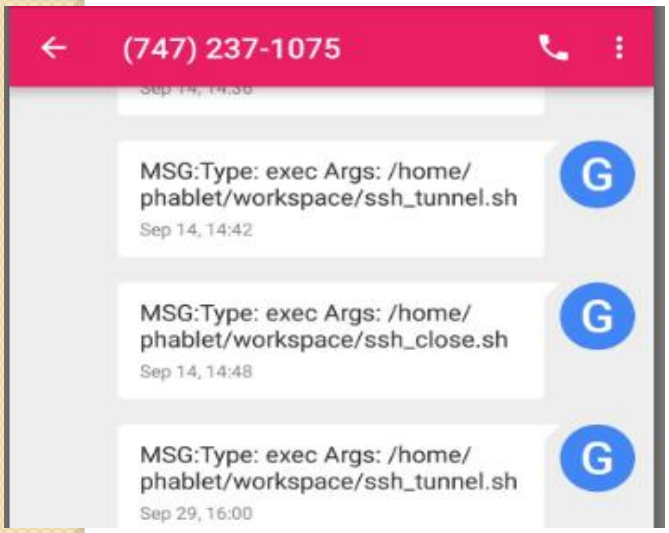
Name	Last modified	Size	Description
Parent Directory		-	
160914-130720-291376521.ogg	2016-09-14 18:01	158K	
160914-130740-846616714.ogg	2016-09-14 18:01	158K	
160914-130801-472994867.ogg	2016-09-14 18:01	157K	
160914-130822-162122069.ogg	2016-09-14 18:01	157K	
160914-130903-364209356.ogg	2016-09-14 18:01	158K	
160914-130923-932902311.ogg	2016-09-14 18:02	158K	
160914-130944-564130780.ogg	2016-09-14 18:02	158K	
160914-131005-062082341.ogg	2016-09-14 18:02	158K	



Remote Access to Nexus 4 via Web

- Three step process
  - SMS to initialize reverse SSH from node
  - Node SSH to the server
  - Server can access node through local port
- SMS used as a side channel



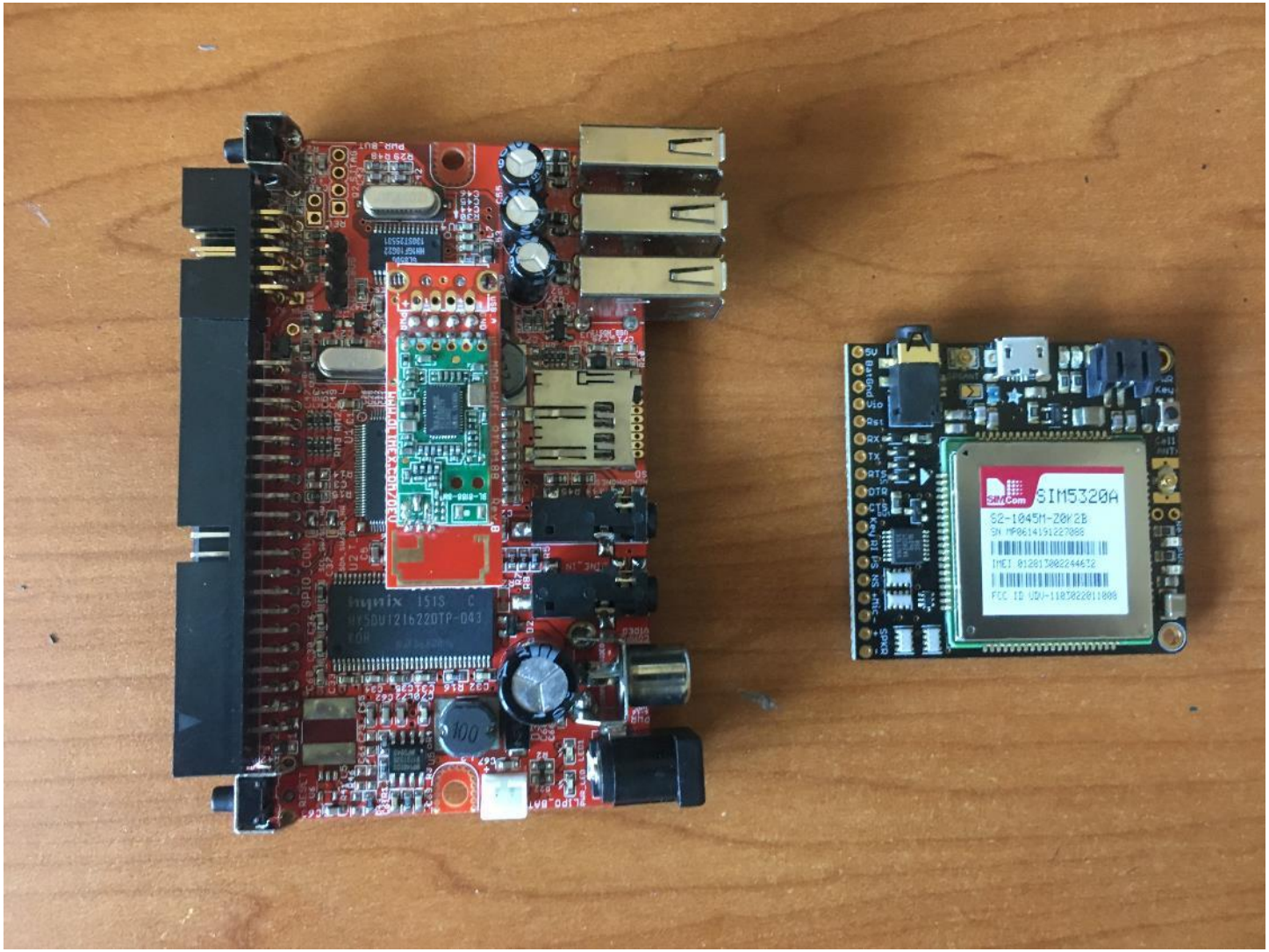


Access to Audio data via Web

Index of /test/audio_files/test_node

Name	Last modified	Size	Description
Parent Directory		-	
160728-103736-540148032.ogg	2016-07-28 11:01	23K	
160728-103747-394244983.ogg	2016-07-28 11:01	163K	
160728-103825-440135265.ogg	2016-07-28 11:01	246K	
160728-103907-550491171.ogg	2016-07-28 11:01	250K	
160728-104736-992789328.ogg	2016-07-28 11:01	248K	
160728-104807-545147024.ogg	2016-07-28 11:01	84K	
160728-105352-683773779.ogg	2016-07-28 11:01	262K	
160728-105425-709408733.ogg	2016-07-28 11:02	252K	
160728-105456-337975798.ogg	2016-07-28 11:02	254K	

Others: iMX233-OLinuXino-MINI + FONA 3G



i.mx233 Olimex-Mini

- Embedded Linux
  - Custom drivers installed (audio, I2C, SPI)
  - Compiled and functioning
- Audio
  - Able to play stereo audio
  - Able to record stereo audio using ARECORD into WAV
  - Need to compress audio before transmission
- Communication
  - Driver for 3G UART needs to be written
  - Need to test and evaluate

Nokia 8110 4G Phone

- Installed Custom OS
  - (GerdaOS – derivative of KaiOS)
  - Rooted
- Telnet
  - Telnet server installed
  - Successful telnet to phone's root

Nokia 8110 4G Power Control

- Processor Speed
  - Root shell to reduce the operating frequency of the processor from 800 MHz down to 200 MHz (minimum functional operating frequency)

```
[t /sys/devices/system/cpu/cpu0/cpufreq/cpuinfo_cur_freq
200000
root@Nokia 8110 4G:/ #
```

- Core Activation/Deactivation
  - Implemented a method via the root shell to turn off one of the CPU's cores
  - Below are screenshots showing the second core (cpu1) becoming offline

```
[root@Nokia 8110 4G:/sys/devices/system/cpu # cat online
0-1
[root@Nokia 8110 4G:/sys/devices/system/cpu # cat offline
```

```
[root@Nokia 8110 4G:/sys/devices/system/cpu # cat online
0
[root@Nokia 8110 4G:/sys/devices/system/cpu # cat offline
1
```

Nokia 8110 4G Remote Access

- No Static IP Address for Phone
  - Most phone plans do not give static IP
  - Need a work around to access phone remotely
  - Use of VPN Tunnel will enable this access
- Enabling VPN to Phone
  - Successfully initialized a VPN connection between the phone and a remote node
  - Currently searching for a method to disable/bypass a firewall on the phone that is blocking VPN outgoing messages

Inference with Non-invasive Sensors

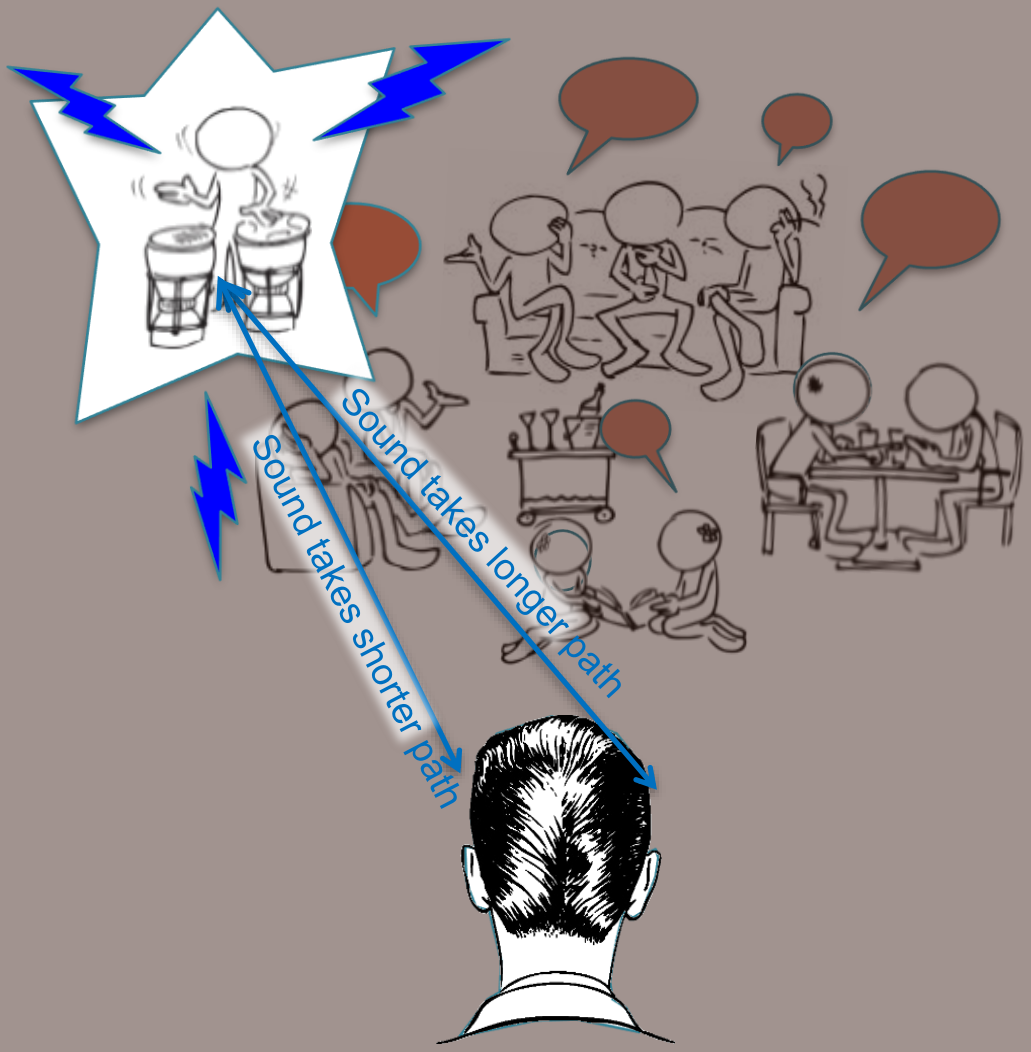
- Ambient Conditions
  - Temperature
  - Pressure
  - Light
  - Sound/Vibration
  - Magnetic Fields
  - Complex phenomenon such as video and gas composition, and etc.
- Inferential Information
  - Determine internal conditions with above?
  - Modeling (internal parameters for accuracy and even prediction)
- Big Data

Example: Human Ears

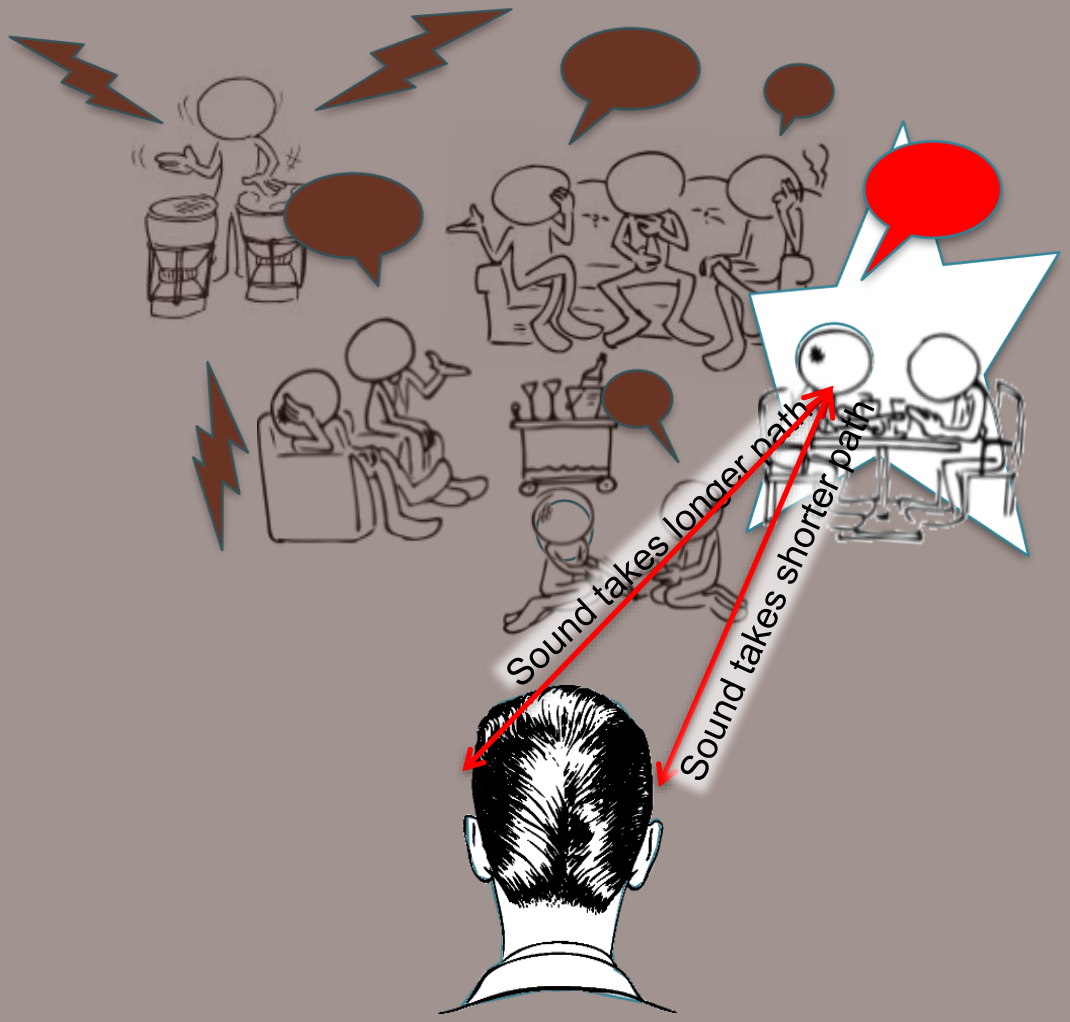
- Humans are Better than Machines in Audio Processing
  - Locating and Isolating Sounds
    - Focus on a single stream of audio to interpret in a noise room
  - Sound Pattern Recognition
    - Differentiating subtle differences in voice colors
- Mimicking Human Capability
  - Single audio stream can be processed to give result
  - Improved result can be attained given multiple recordings
  - Localization of the sound is also possible with multiple recordings

Listening Capability

Listening Capability



Listening Capability



Enhanced Frequency And Time Hybrid Analysis Audio Separation Examples

Overlapping Clarinets: 

Extracted 1st Clarinet: 

Extracted 2nd Clarinet: 

Woman and Man: 

Extracted Woman's Voice: 

Extracted Man's Voice: 

Human Voice & Noise: 

Extracted Voice: 

Extracted Noise: 

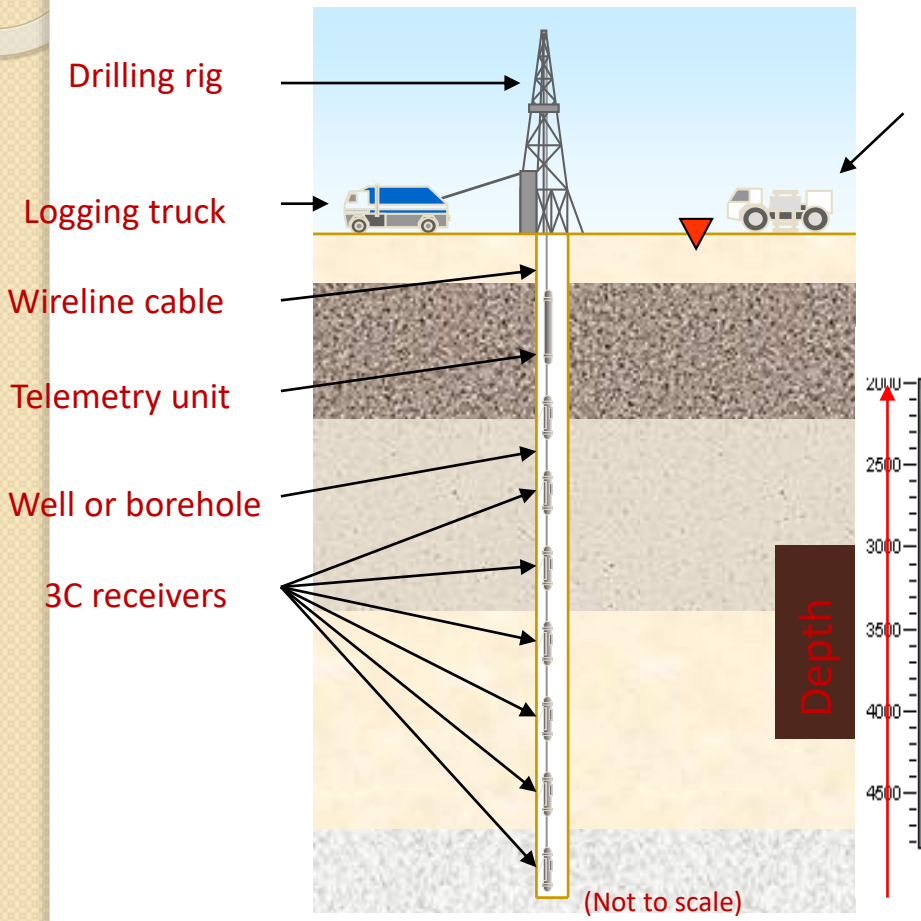
Two Men and Music: 

Extracted 1st Voice: 

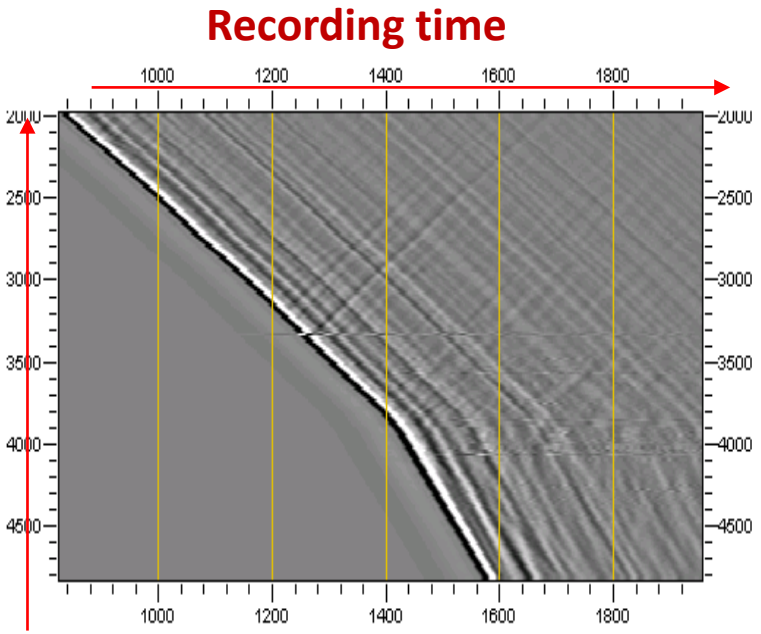
Extracted 2nd Voice: 

Borehole Seismic Audio Analysis

- Borehole Seismic Audio Analysis
  - Key Technology for Discovery



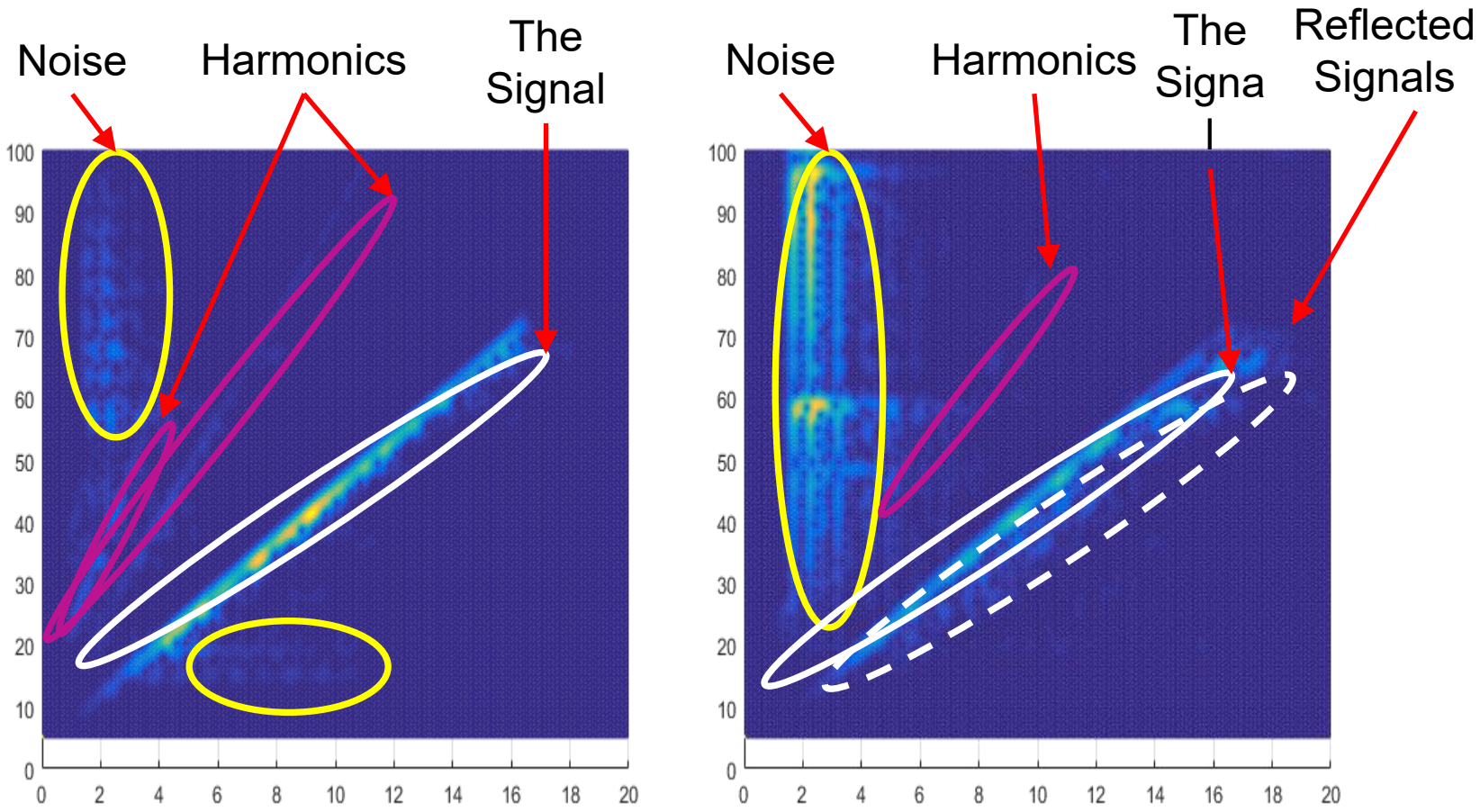
Seismic source (Airgun, dynamite, vibroseis) and reference sensor



Recovering Phase of Audio

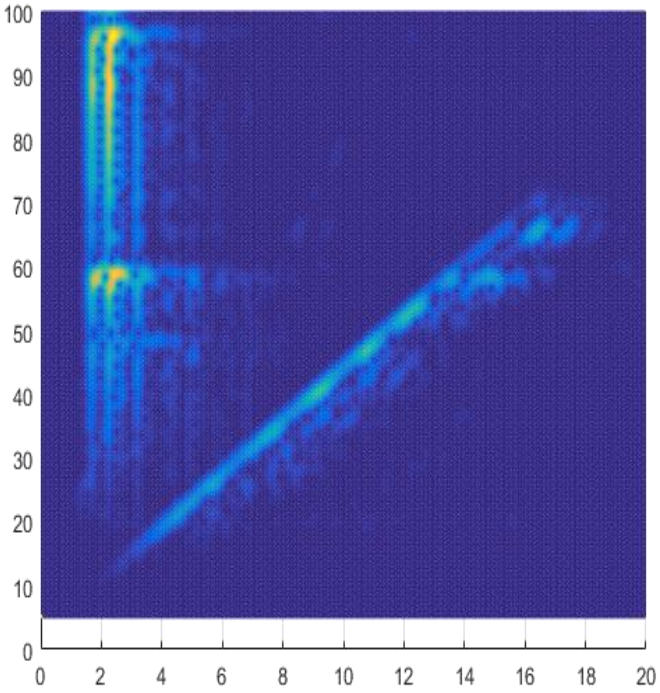
- Method
  - Generate Frequency/Amplitude Hybrid Map
  - Use Frequency and Amplitude as Guide
  - Efficiently Search for the Correct Phase
- Experiments
  - One Sine of a fixed frequency and a starting phase
  - Two Sine of fixed frequencies and a starting phase

Sensor Data with Noise

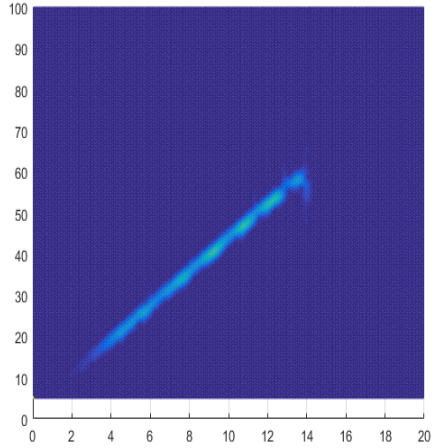


Hybrid representation of Sensor 1 (closest to surface) and Sensor 80 (farthest to surface)

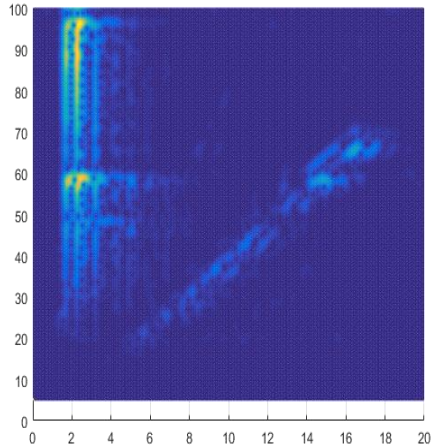
Taking a Signal Apart



Sensor 80 Data



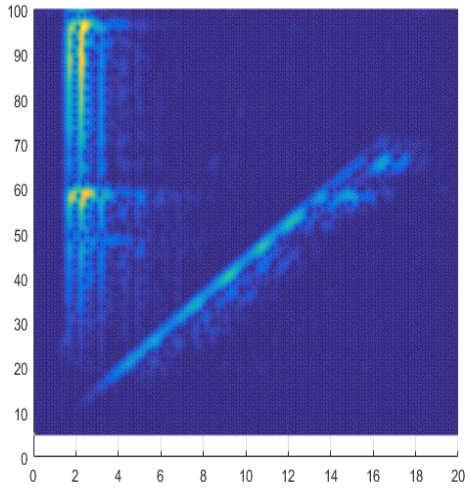
The Main Signal



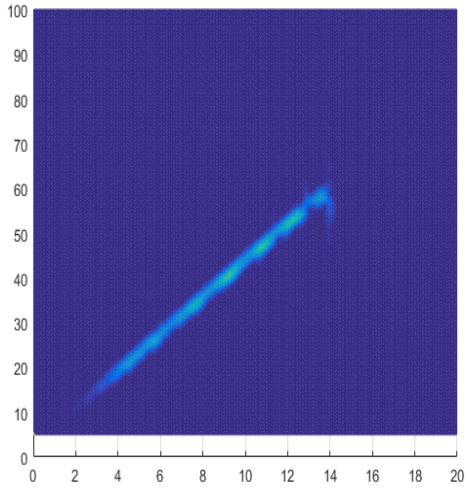
The Rest of the Signal

Result

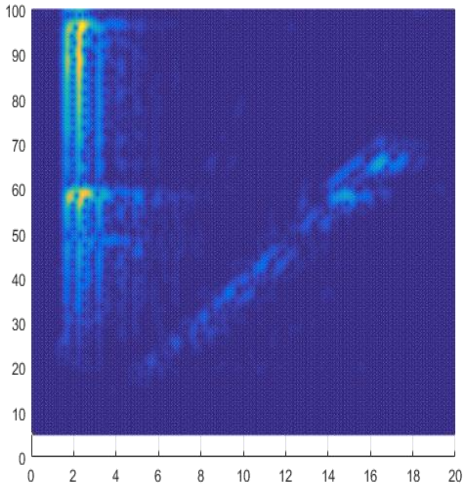
- The Baseline Pitch has been Increased to make the Result Audible



The Original Signal



Detected Signal



Leftover Signal