Sensor Systems and the Art of Effectively Deploying Sensor Networks

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TechChange – TC111

CellPump:
Using sensors to improve efficacy

30-80% of water pumps fail within 1 year of installation

What happens when a pump fails?

http://www.pdx.edu/sweetlab/cellpump-rwanda
http://www.sweetsensors.com/applications/cellpump/

Stove Usage Monitors: Establishing reliable usage data

How much are free cookstoves *actually* used?

https://www.youtube.com/v/qmY8PRmi3lQ

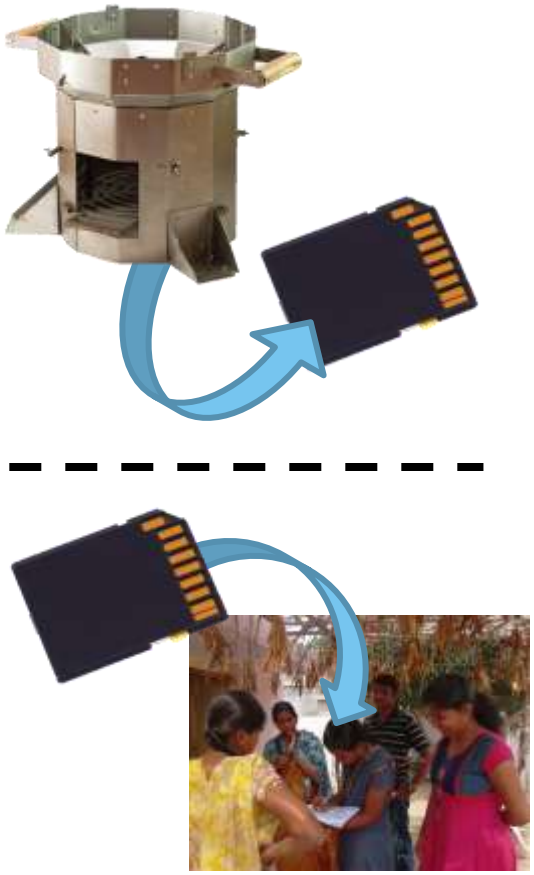
Inspire Living:
Sensors for Immediate Impact

- **Pneumonia can be reliably diagnosed from key signals**
  - Respiration rate is key
- **Hard to train people to diagnose, easy to train a machine**
  - Use sensors to measure and evaluate respiration

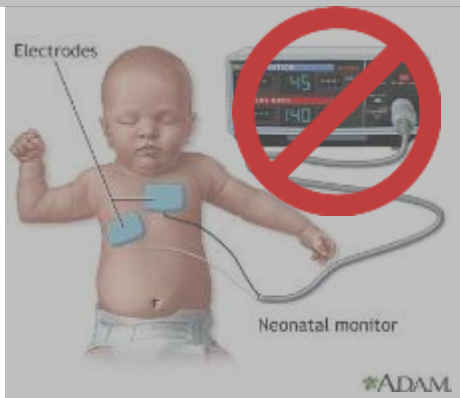
Application requirements define data behavior

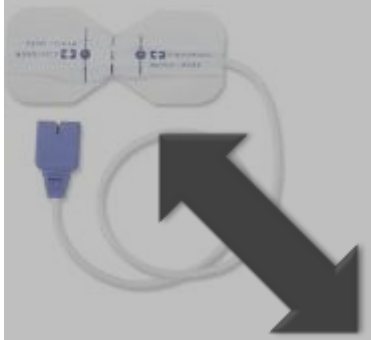
CellPump

Stove Usage Monitors



Inspire Living





Has Pneumonia
Consult Doctor

Real-Time ***Batch*** ***Local Loop***

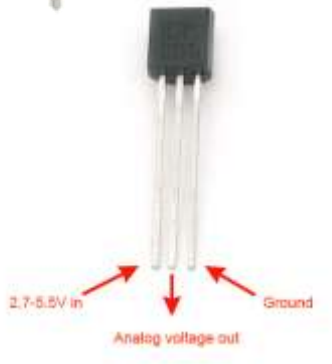
Developing a sensor-based deployment requires understanding…

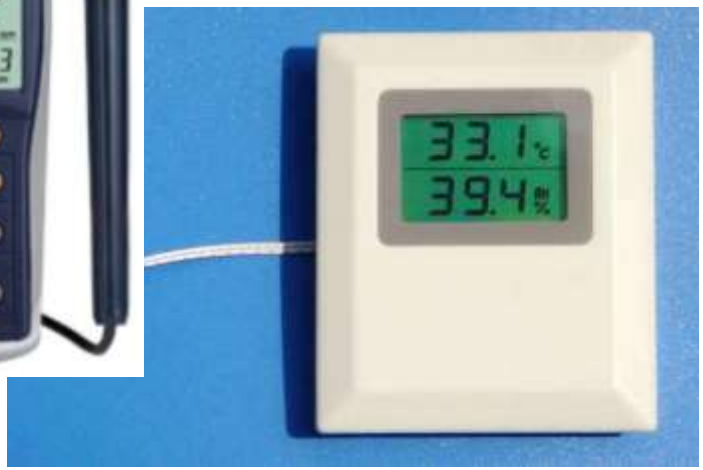
- **What semantic data you need?**
  - What is the question you're actually trying to answer?
- **What physical data you need?**
  - What can you actually sense about the world?
- **What do you have available?**
  - Existing data sources, infrastructure
- **How is the data intended to be used?**
  - Which informs how the data is collected, disseminated

A sensor deployment is a series of interconnected tradeoffs

Sometimes semantic and physical data requirements line up

- **How does interior temperature change through the day?**
  - Use a temperature sensor
- **What about humidity, carbon dioxide, air particulates…?**
  - In general, there are sensors for environmental monitoring





Many times we have to look at side effects to sense phenomenon

Simple Example

Did I close the window → Contact sensor

Did I close the blinds → Ambient light sensor

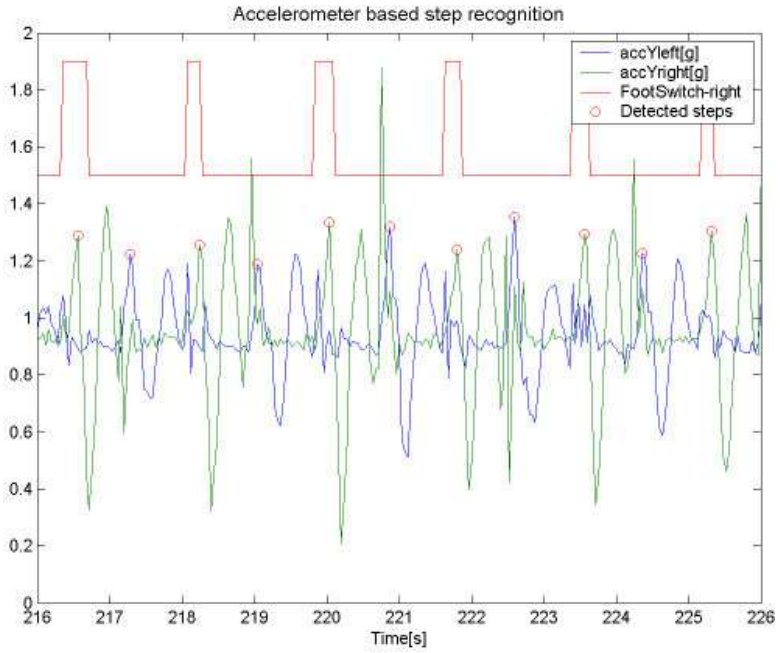
Complex Example

Fitbit “counts steps”

Measures accelerometer data

Classifies motion traces

(machine learning usually)



Choosing a means to sense can be non-obvious

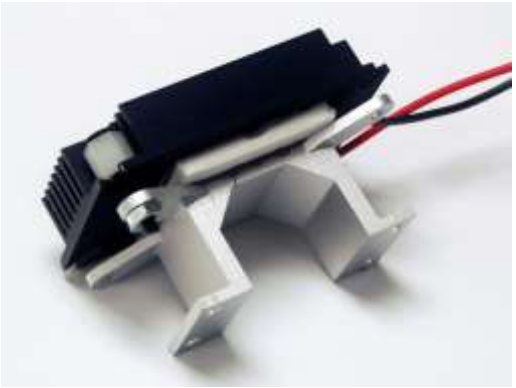
“I need a sensor that measures water flow”

+ Mechanically challenging

“It needs to be wireless and last for several months”

“I want to measure if people wash their hands after they use the toilet”

You actually want a temperature sensor



Paul Martin, Zainul Charbiwala, Mani B. Srivastava
DoubleDip: leveraging thermoelectric harvesting for low power monitoring of sporadic water use
In Sensys’10

Group Question: How can we answer the same question without plumbing?

Goal: Measure hand washing rate after bathroom usage

Stretch goal: Distinguish by bathroom activity

Restrictions:

- No plumbing
- No power
- No direct user involvement (“push here after washing”)

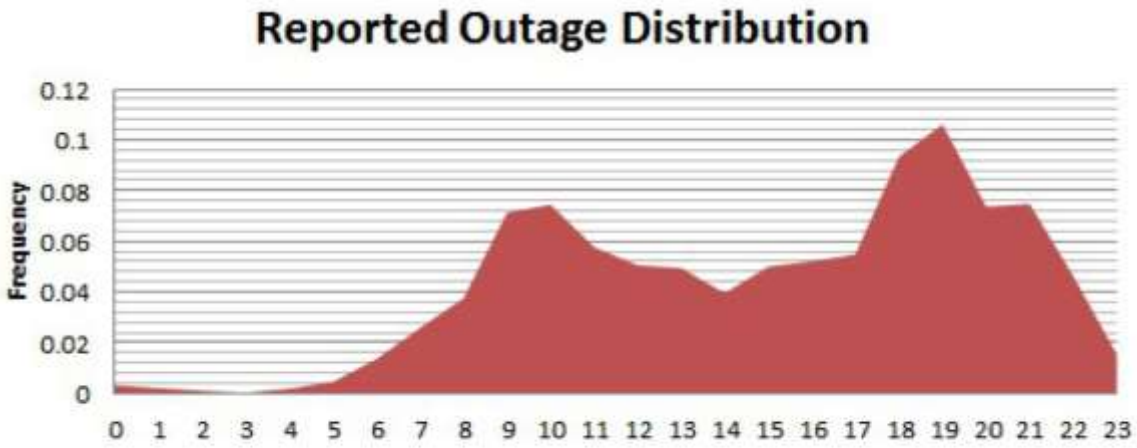
What data sources are already available?

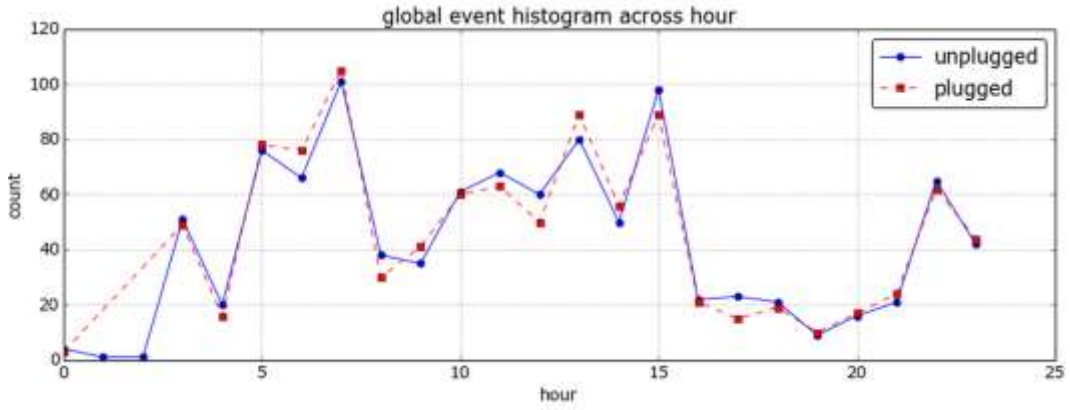
- **Sometimes what you want is collected and published**
  - KPLC weekly power outage reports

- **Use partial information to confirm or question measurements**

Think a little outside the box for possible data sources

- **Kenya: people tweet to notify / complain of power outages**





Preliminary results from a deployment in Kenya

Drilling into data collection and tradeoffs

- **What semantic data you need?**
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A sensor deployment is a series of interconnected tradeoffs

Define the data you intend to collect

- **How much data?**
  - Synchrophasor (power grid health): 1000's samples / sec
  - Soil Moisture: 1-10 samples / day
  - Mudslide Detection[1]: 1 sample / 5 min <> 10 samples / sec

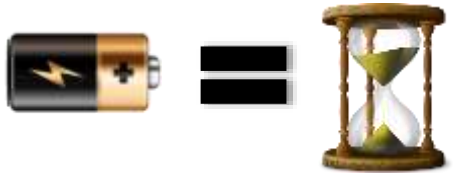
- **And what data do you actually *need*?**
  - `12:00 AM – It's 74 degrees.`
  - `12:01 AM – It's 74 degrees.`
  - `12:02 AM – It's 74 degrees.`
  - "Compressive sensing"
    - Lots of research: Report differences, trends, fit variables…

[1]*Real-time Wireless Sensor Network for Landslide Detection. Ramesh, M. V. SenSys'13*

Energy budget defines capabilities (and requirements dictate energy budget)

- **Plug it in!**
  - Power grid can be unreliable
  - Requires nearby available wiring
  - Who pays?

- **Put a battery in it**
  - Battery == Lifetime
  - Low-power design or a big battery



- **What about solar?**
  - Energy harvesting often most expensive
  - Requires lowest-power design

The cost / performance tradeoff spans 2-3 orders of magnitude

"An embedded sensor is like a computer from the '70s with some neat sensors attached"

and lasts a year+ on a battery

"A smartphone is like a mini-PC in your pocket"

and lasts a day on a battery

The cost / performance tradeoff spans 2-3 orders of magnitude

"An embedded sensor is like a computer from the '70s with some neat sensors attached"

"A smartphone is like a mini-PC in your pocket"

They are priced appropriately

Smartphones have a diverse array of powerful sensors

Smartphones have a diverse array of powerful sensors

Accelerometer, Gyroscope, Magnetometer, GPS, camera…

And communication (cellular, WiFi, Bluetooth, NFC) is built in

Pentland ‘06 Pentland ‘07 Pentland ‘09

HiJack: Augmenting smartphones to add "missing" sensors

Geiger Counter

EKG Monitor

Thermometer

CC Terminal

CO Sensor

Soil Moisture

[slide courtesy Prabal Dutta]

HiJack → QuickJack → PhoneWorks

Commercial development kit available, mass market products

Images from NXP, Home Depot

Smartphones are expensive to deploy

- **General purpose device: you pay for what you don't use**
- **Power limitations means the phone is tethered**
  - Unless "attached" to a user, that is, crowdsourcing
- **Communication options *only* cellular, Wi-Fi, Bluetooth**
- **Make sense in 10s-100s, maybe not 1000s**
  - But can be re-used / re-purposed

How to think like an embedded systems engineer

Or, how to do better than a smartphone for less money?

Goal: Understand the tradeoffs in the embedded design space, what is feasible, what isn't feasible.

How much local storage do you need?

- **It's never zero**
  - How much data are you willing to lose?
  - "Batch", "Delay-Tolerant", "Best-Effort"
- **Memory quickly drives microcontroller cost**
  - RAM from 16~128 *kilobytes*
- **Flash memory**
  - SD cards are cheap, easy to interface with
  - Flash chips can be cheaper, more work to integrate; read
- **What do you do when you run out of space?**

How do you get continuous data off of devices?

- **What data backhaul is available?**
  - Ethernet? Wi-Fi? Cellular (data, voice, text)? Satellite?
  - How reliable is it?
    - (again, how much data are you willing to lose?)

- **Who Pays??**

- **Communication is often 80%+ of energy budget**
  - Defines battery size / system lifetime

Is there anything that can make communication more efficient?

- **Costs less energy to send a smaller distance (usually)**
  - e.g. Wi-Fi uses less energy than cellular
- **Mesh Networks**
  - Popular in wireless sensor network research
    - Hard to make reliable in practice for battery-backed devices
  - iOS 7 adds support for Wi-Fi based mesh networking
    - Not used much yet, something to watch
    - Early reports are many of the same difficulties as WSNs

Taking it to the extreme: Full-custom design of a $25 “radio DVR”

FM receiver that records broadcast lessons

Users can record programs and share them

http://www.bbc.com/news/technology-30127578
http://web.eecs.umich.edu/~prabal/pubs/papers/foo13lit.pdf

Taking it to the extreme: Full-custom design of a $25 “radio DVR”

Component Name	Cost
Chip	
Speaker Inductor	$0.0245

A Low-Cost Audio Computer for Information Dissemination Among Illiterate People Groups

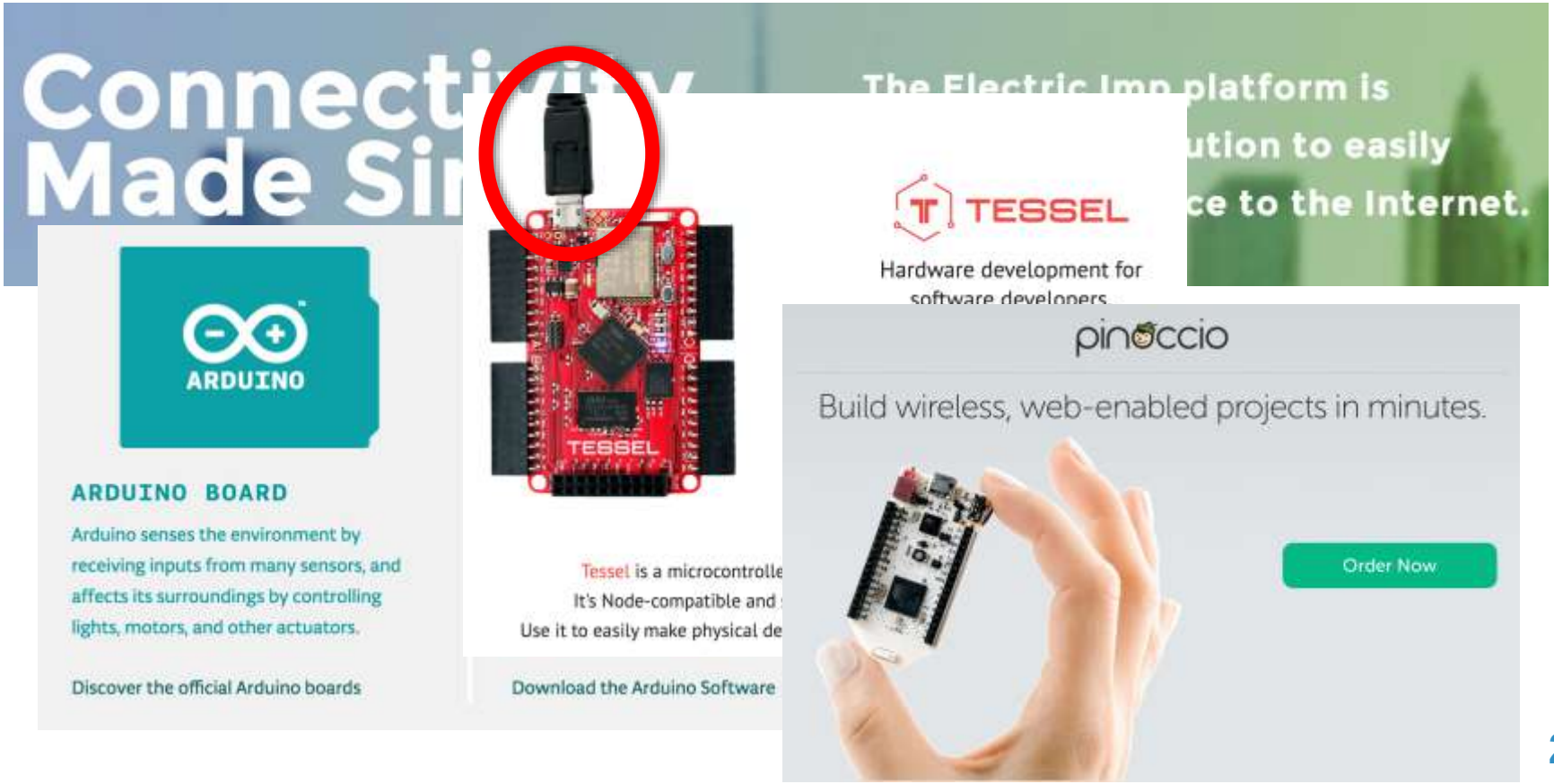
ZhiYoong Foo, David Devescery, Mohammad Hassan Ghaed, *Student Member, IEEE*, Inhee Lee, *Student Member, IEEE*, Abishek Madhavan, Youn Sung Park, *Student Member, IEEE*, Aswin S. Rao, Zach Renner, Nathan E. Roberts, Aaron D. Schulman, Vikas S. Vinay, Michael Wieckowski, Dongmin Yoon, Cliff Schmidt, Thomas Schmid, Prabal Dutta, Peter M. Chen, *Fellow, IEEE*, and David Blaauw, *Fellow, IEEE*

Microphone	$0.0955
PCB	$1.0000 (est.)
NAND Flash	$2.0000
Radio	$1.0395
Total Board Cost	**$5.5980**
System	
Board	$5.5980
Casing	$1.0000(est.)
Test & Assemble	$1.0000 (est.)
Total System Cost	**$7.5980**

http://www.bbc.com/news/technology-30127578
http://web.eecs.umich.edu/~prabal/pubs/papers/foo13lit.pdf

Wireless sensor networks are young technology

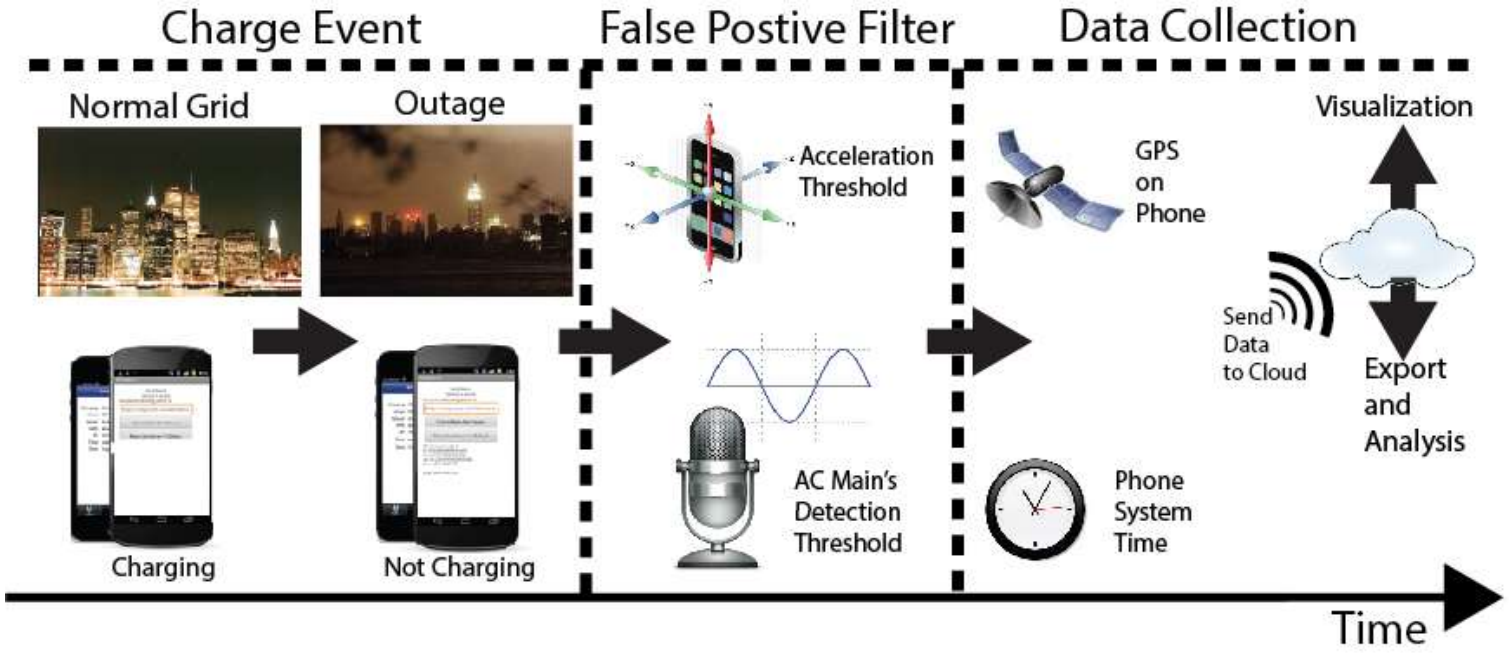
- The field is 15-20 years old
- Maker culture creating some accessible technology



GridWatch: Crowdsourcing power grid health monitoring

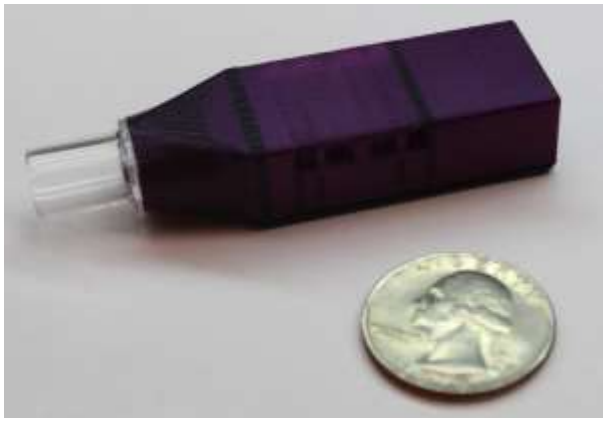
Insight: **You pick up your phone to unplug it**

+ Power loss without motion is likely a power outage



Smoking Cessation with Monoxalyze

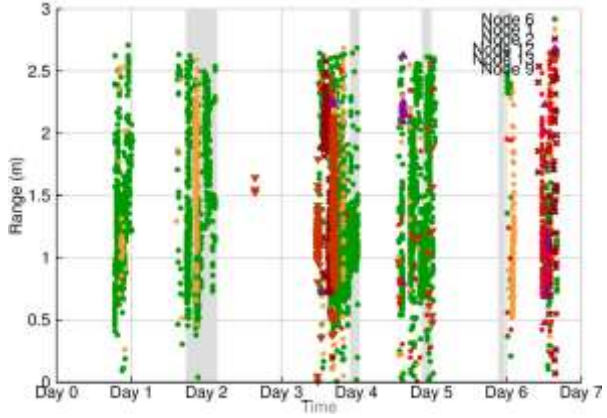
- **Smoking Cessation programs lack feedback**
  - Q: Did you smoke today?
  - A: No, of course not!
- **Carbon Monoxide levels reveal smoking within 4-6 hours**



Gen 2: Wireless (BLE), Authenticated

Human interaction tracking and social graph building with Opo

- **Fine-grained human interaction data**
  - Who did you talk to today?
  - For how long?
  - 10 cm accuracy with 1 week battery
- **Applications in sociology, immunology**

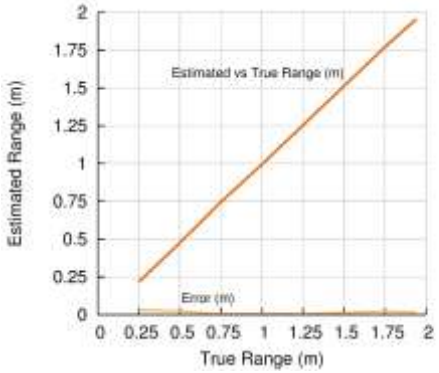


A Week as a PhD Student

Wearable

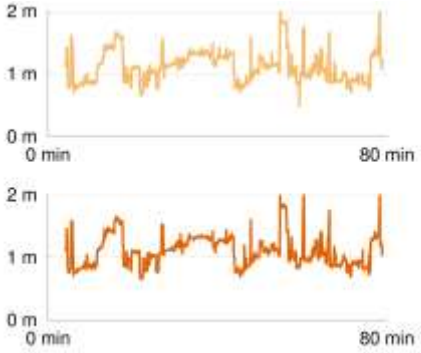
Small form factor

Accurate



Ranging Accuracy Test

Detailed

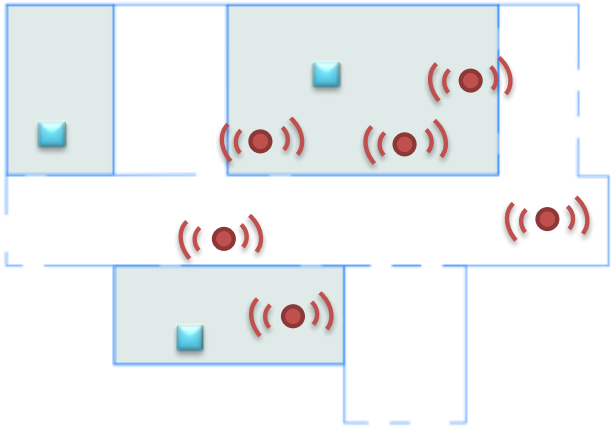


Two Person Interaction

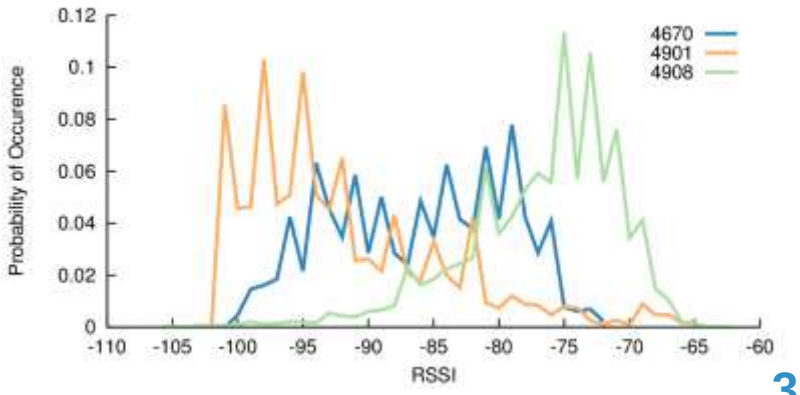
Wearabouts: Leveraging wearable electronics for building occupancy

Wearables are everywhere….

Most emit beacons we can listen for



Which we use to locate people in space

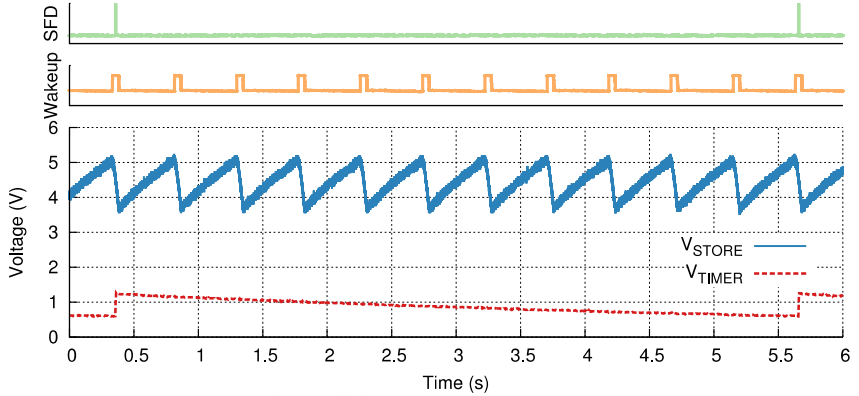


The Monjolo Principle

Combining non-traditional sensing and energy harvesting

Harvest side-channels of energy – wakeup frequency is the sensor

[Monjolo, Sensys '13]



Takeaways

Anything can be sensed, but it may require creativity

Distinguish what you want to know from what you need to measure to answer the question

Constraints on data-collection define the rest of your system

Or at the least are a very good place to start

Smartphones are useful, but not a panacea

And can be costly (though re- and multi-purposeable)

Contact and More Information

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[slides on my website]

Lab11

http://lab11.eecs.umich.edu

http://github.com/lab11

Prabal Dutta

http://eecs.umich.edu/~prabal