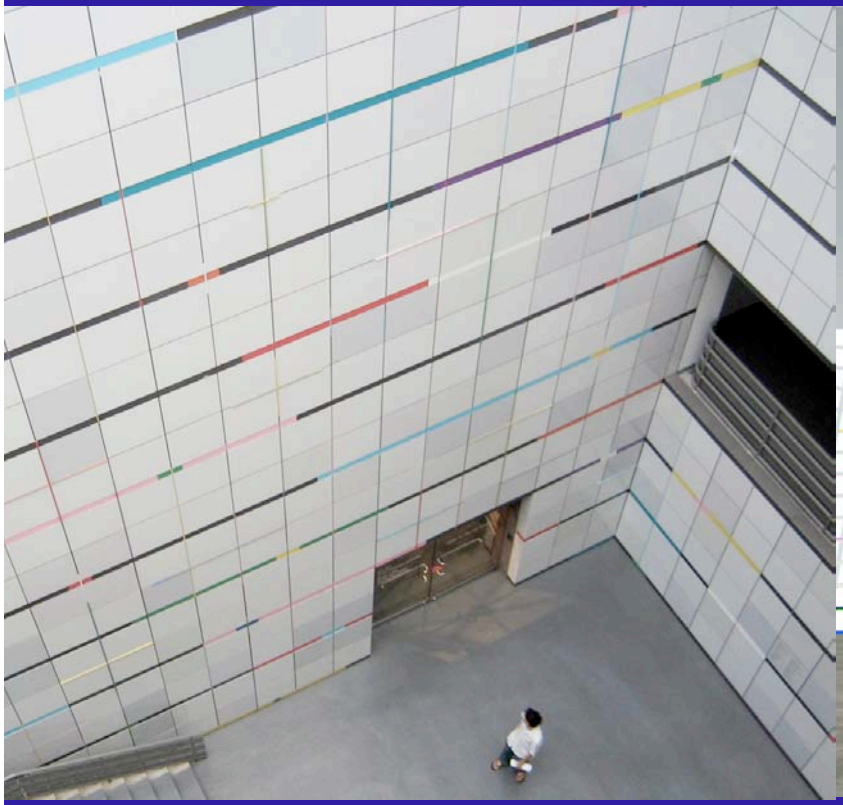
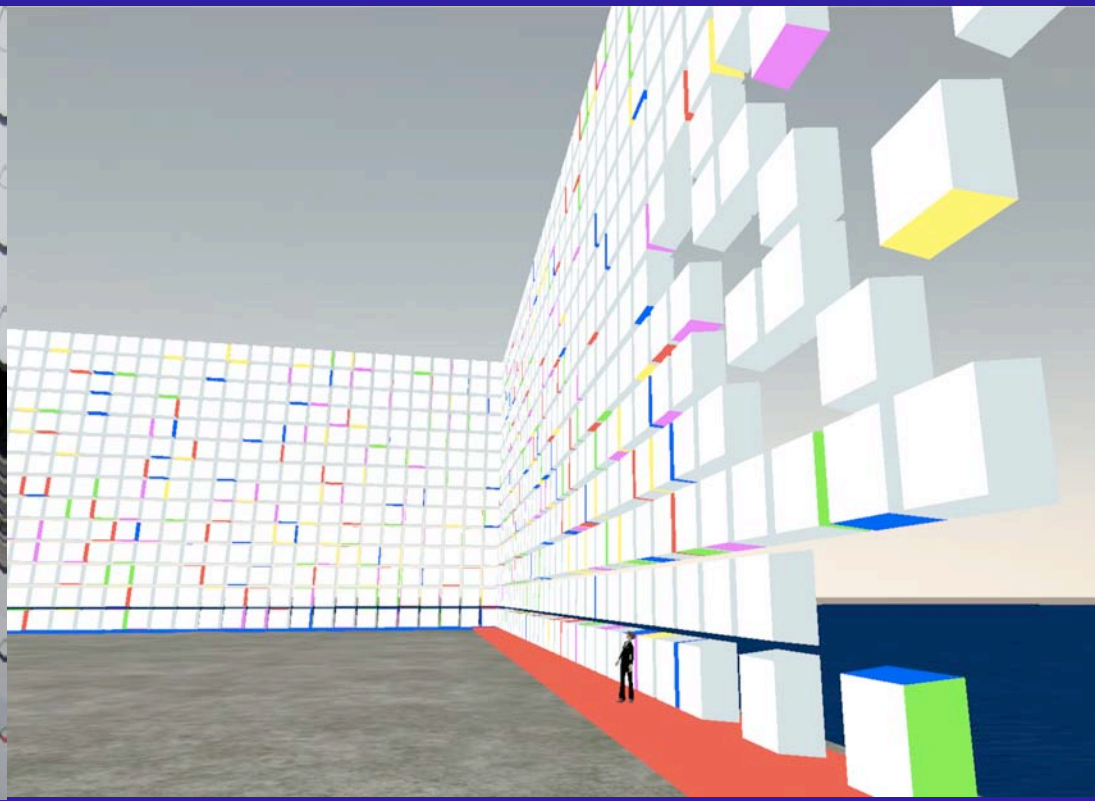
Sensor Networks for Linking Virtual and Real Worlds





Prof. Joe Paradiso
Responsive Environments Group, MIT Media Lab

http://www.media.mit.edu/resenv

Tokyo - 9/08

Topics







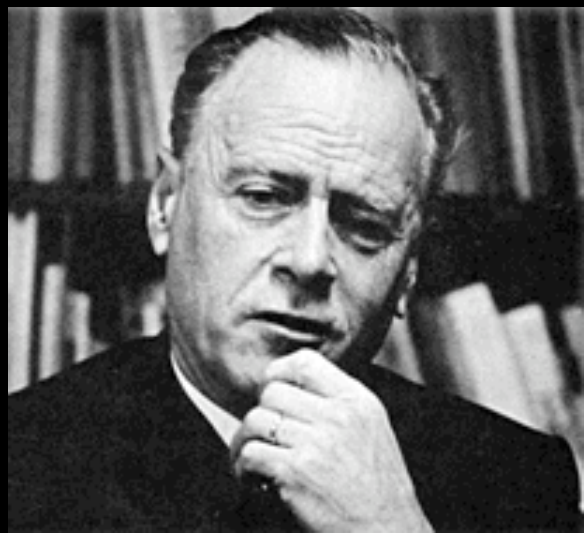
- Cross Reality
  - Sensor networks connect real and virtual spaces
  - Virtual worlds for browsing reality
- Sensor-Enhanced Media Creation
- Wearable Sensors
  - Sports Medicine & Entertainment
- Low Power Techniques
  - Quasi-Passive & Groggy Wakeup
    - Applications in Health and Supply Chain Monitoring
  - Passive RFID Tags for Precise Localization
- Sensor Networks for Social Computing

Marshall McLuhan, 1911-1980

"After three thousand years of explosion, by means of fragmentary and mechanical technologies, the Western world is imploding. During the mechanical ages we had extended our bodies in space. Today, after more than a century of electric technology, we have extended our central nervous system itself in a global embrace, abolishing both space and time as far as our planet is concerned. Rapidly, we approach the final phase of the extensions of man - the technological simulation of consciousness, when the creative process of knowing will be collectively and corporately extended to the whole of human society, much as we have already extended our senses and our nerves by the various media."

Marshall McLuhan - Understanding Media (1964)

Electronic media (a.k.a. television) as an extension of the central nervous system



Sensor Networks as Extension of the Nervous System

Cast our awareness across space, time, scale, modality…

Bootstrapping a Ubiquitous Sensor Infrastructure



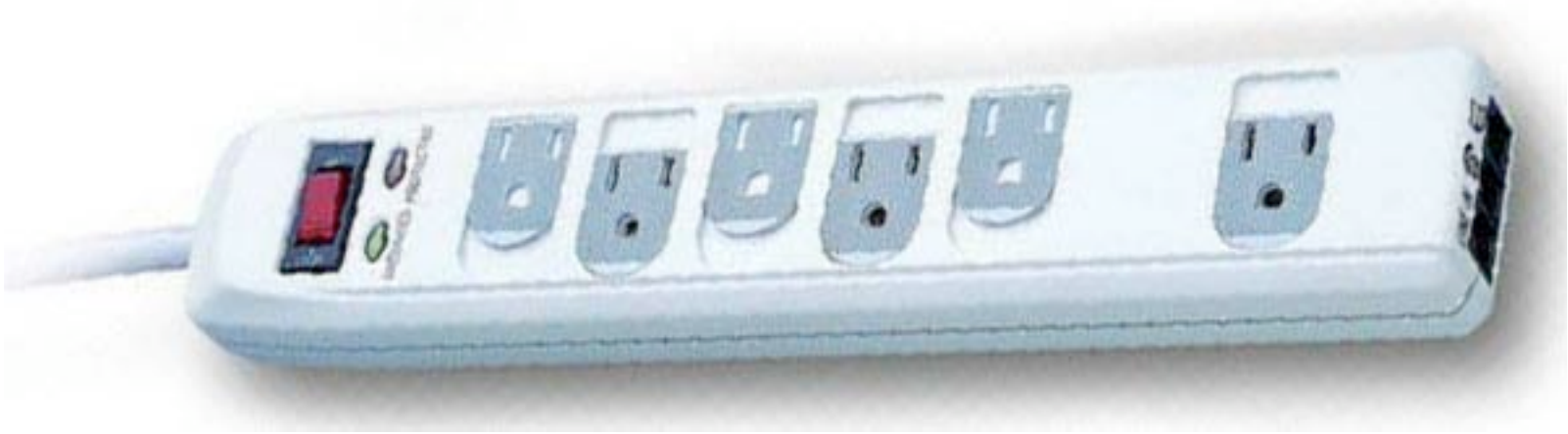




- Sensor networks are the foot soldiers at the front lines of ubiquitous computing
- At this point, few if any customers will buy an ensemble of "UbiComp" sensors
- They will aggregate from established devices
  - Home security, appliances, utility devices, entertainment…

Just as the web sprouted from a networked ensemble of personal computers, true "ubicomp" will arise from an armada of networked devices installed for other purposes.

Power Strips are Everywhere



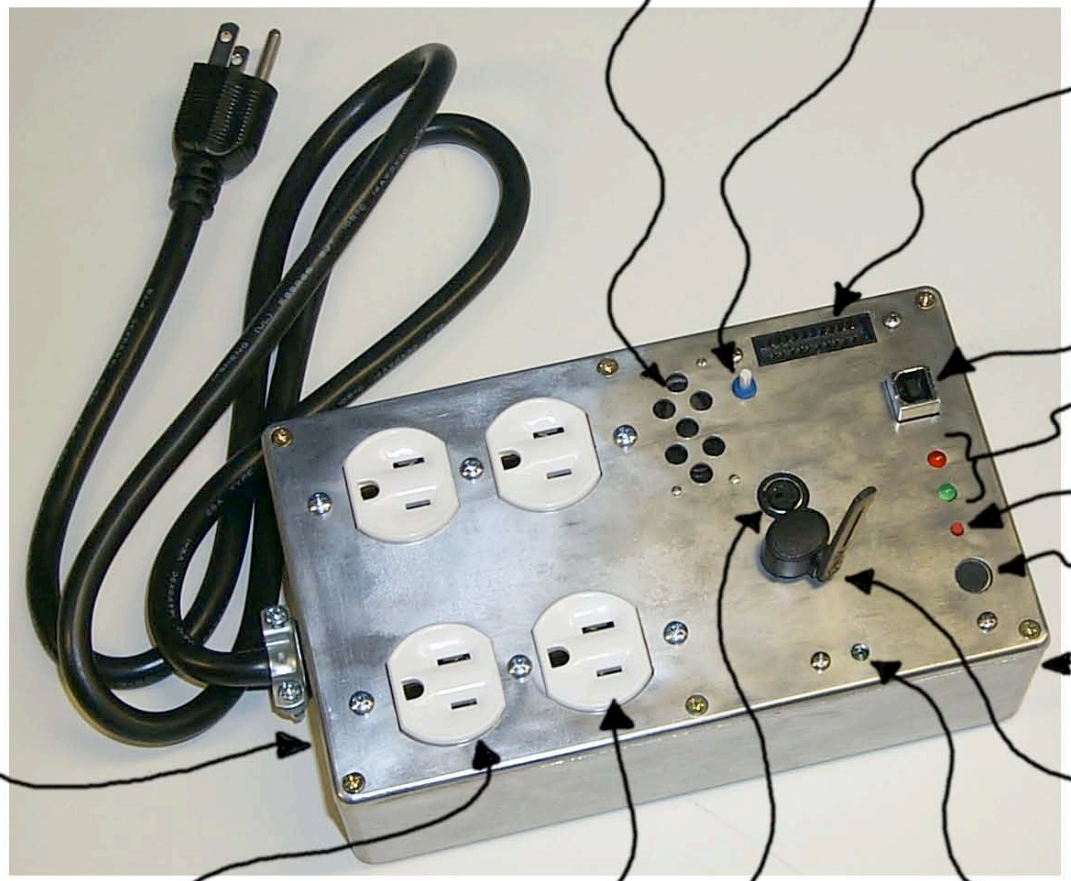
- Needed in Homes, offices, especially the Media Lab!
- Sensors are becoming commodity items
  - Cost of adding sensors to a design is becoming incremental
- Power strips are ideal base platforms for hosting a sensor network
  - Ready access to power
  - Power line can be a network port
  - Can monitor the status of devices that are plugged in

PlugPoint – Power Strips as the backbone of a UbiComp Sensor Infrastructure

J. Lifton, M. Feldmeier, Y. Ono (Ricoh)

Collaboration with Ricoh Research

Power Line provides energy & comm
Monitor current profiles, Switch individual sockets
Hosts basic sensors (mic, light, motion)
Expansion Port for others
Hub for wireless sensor network



1.5W Speaker

Volume Control

Expansion Port
- SPI
- analog-to-digital
- PWM
- GPIO
- and more

USB 2.0

LED Indicators

Control Button

Microphone

Vibration Detector

2.4 GHz 500 kbps Wireless Transceiver

Light Sensor

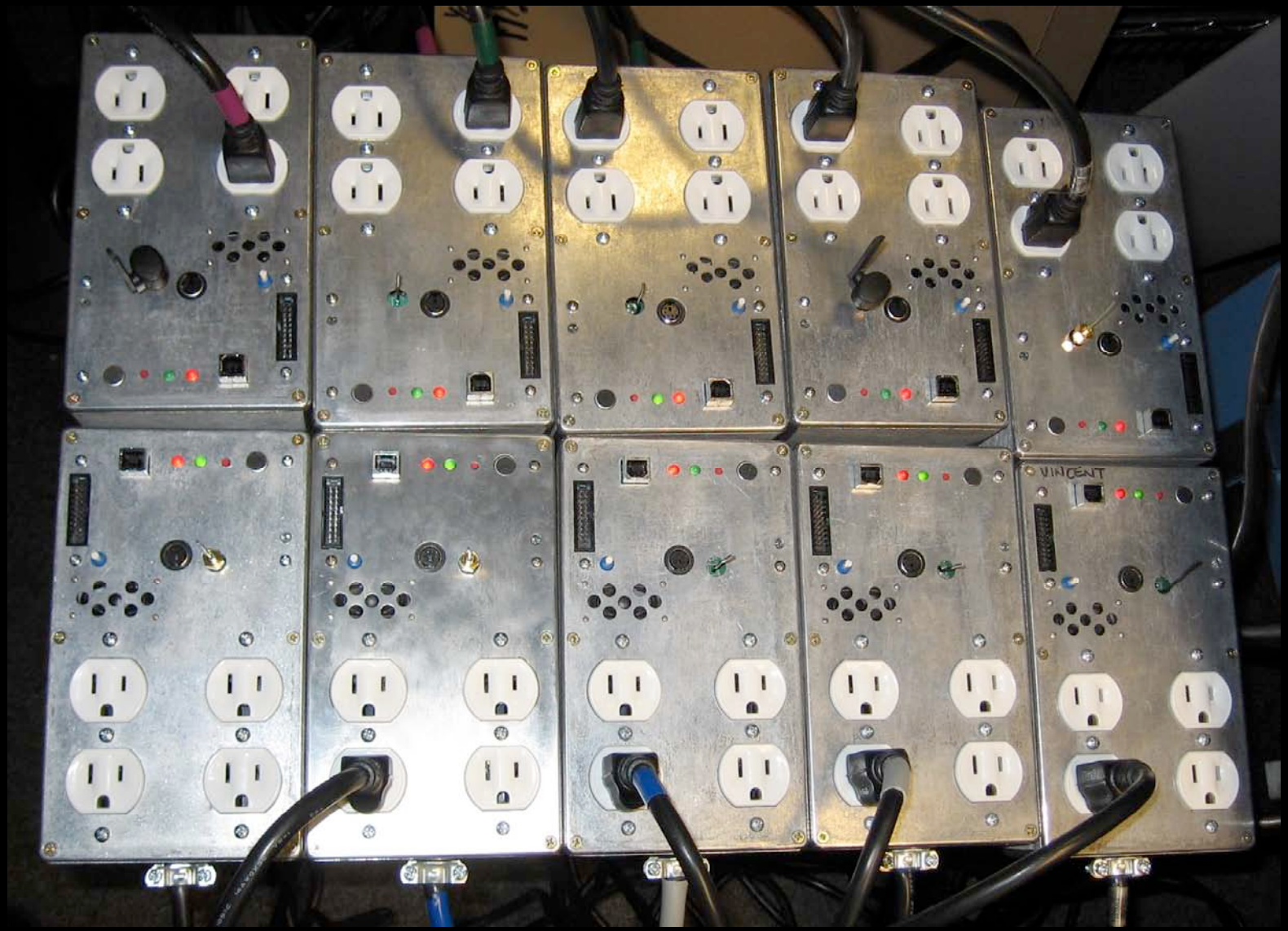
Microcontroller
- 48 MHz
- 32 bit
- 64 KB flash
- 16 KB SRAM

4 Independent Outlets With Current Sensors & Digitally Controlled Switches

Input Voltage Sensor & Over-voltage Protection

JTAG Debugging & Programming Interface

Army of Plugs



35 ON MEDIA LAB THIRD FLOOR

Distributed Acoustic Conversation Shielding

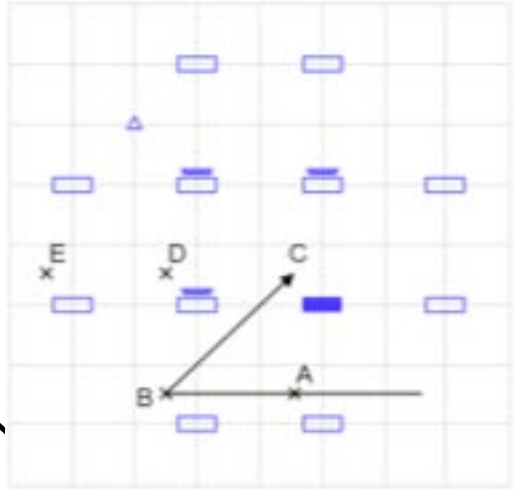
-People are sitting closer in open office environments

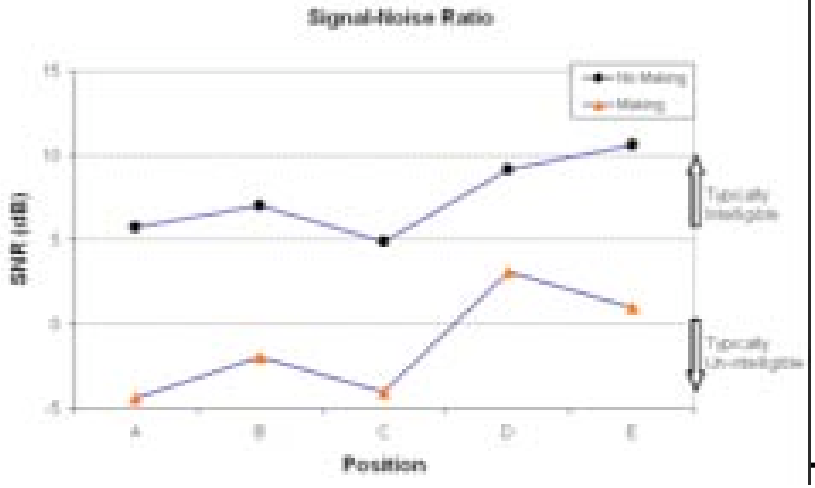
-Privacy is lacking…

-White noise, babble, etc. are often used for conversation screening

-Not optimal (preset volume, constant presence, etc.)

-Why not use a sensor/actuator network to sense locations of conversations and potential eavesdroppers, then fade up appropriate acoustic background on appropriate speakers to optimally shield the conversation from listeners without making the volume too loud at any one location

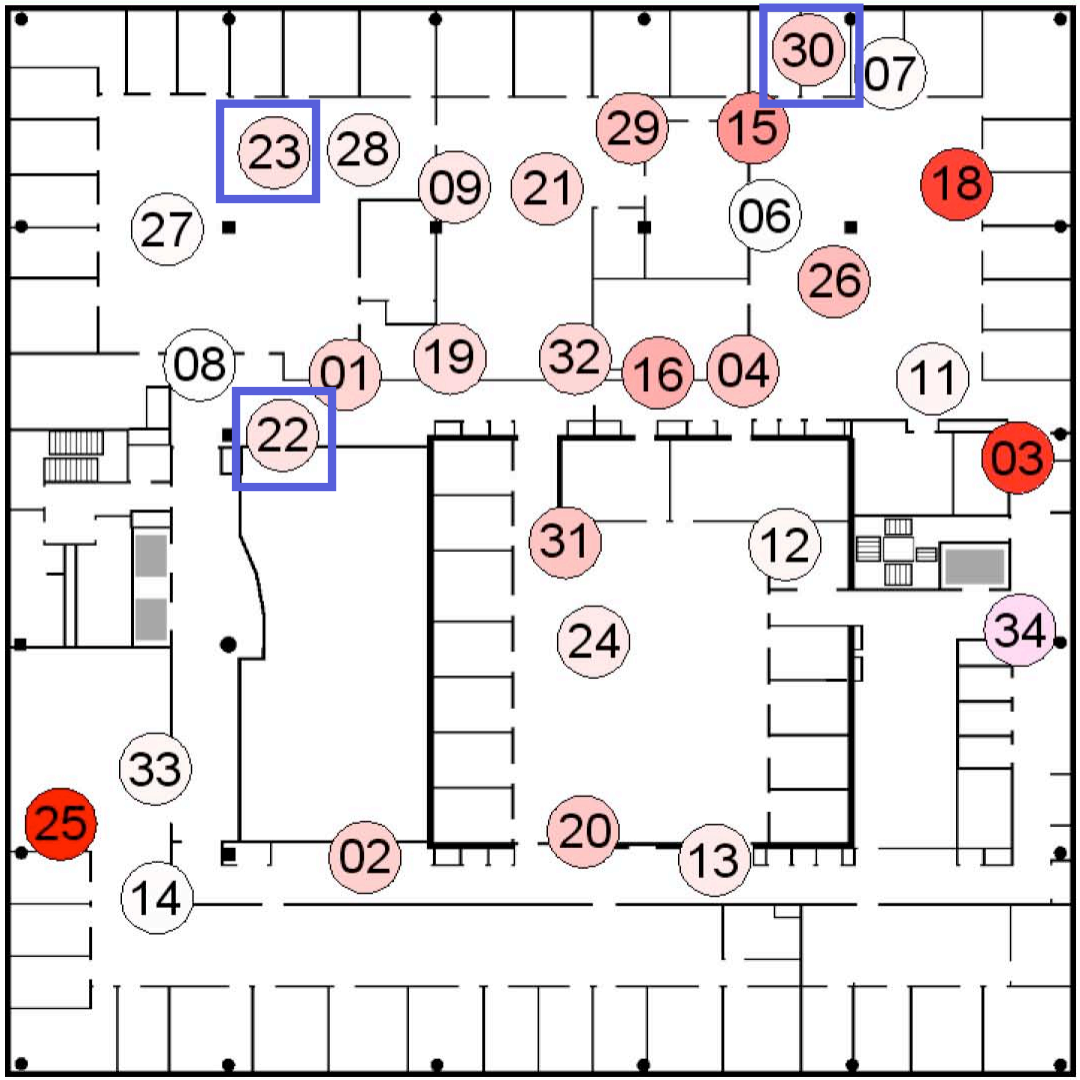




Yasuhiro Ono

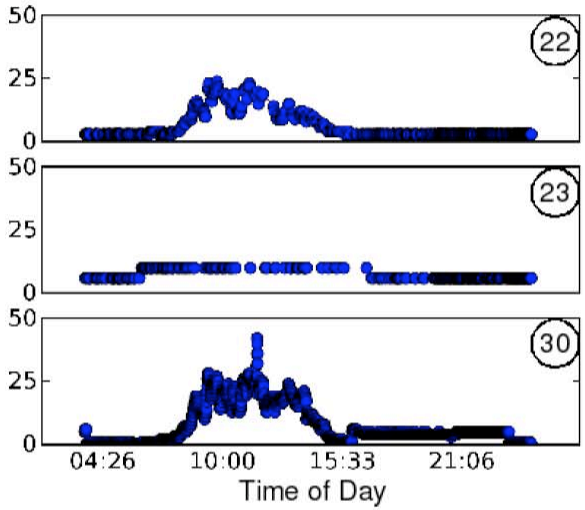
Ricoh ML affiliate

Rhythm of Lab

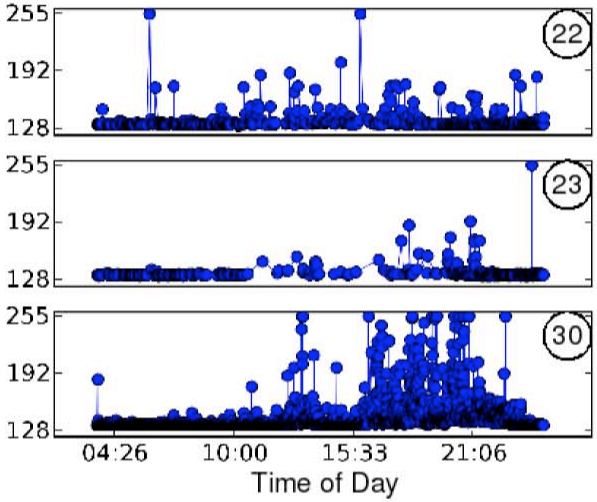


Darker implies more sound & movement

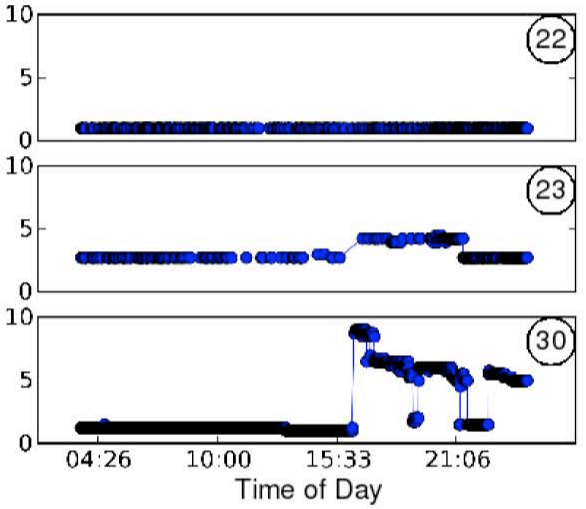
Rhythm of Lab



Incident Light



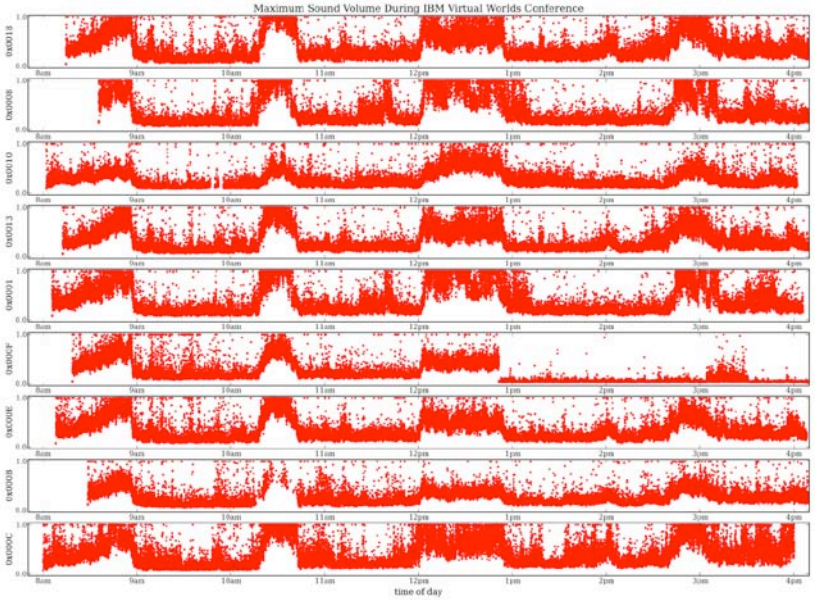
Sound Volume



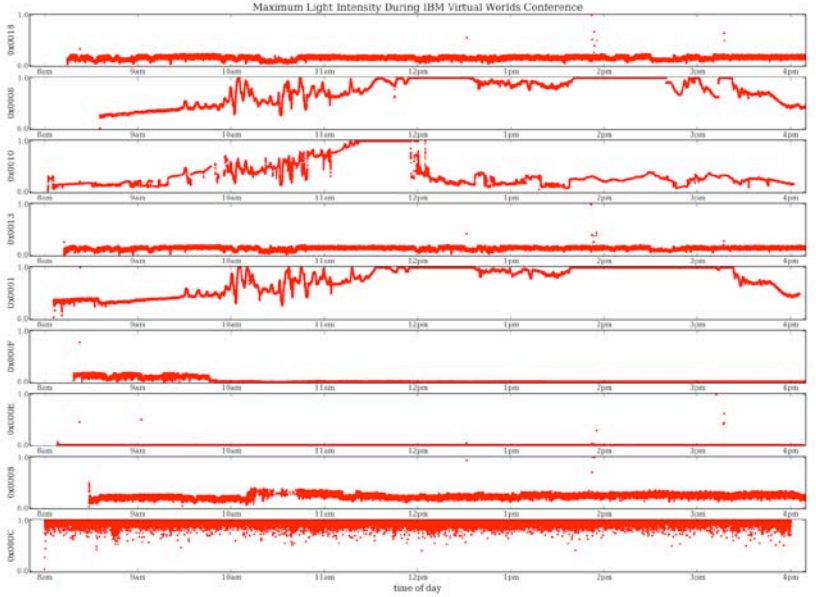
Outlet Current

PLUG Data from Demo Stations @ IBM Virtual Worlds Event, 5/07

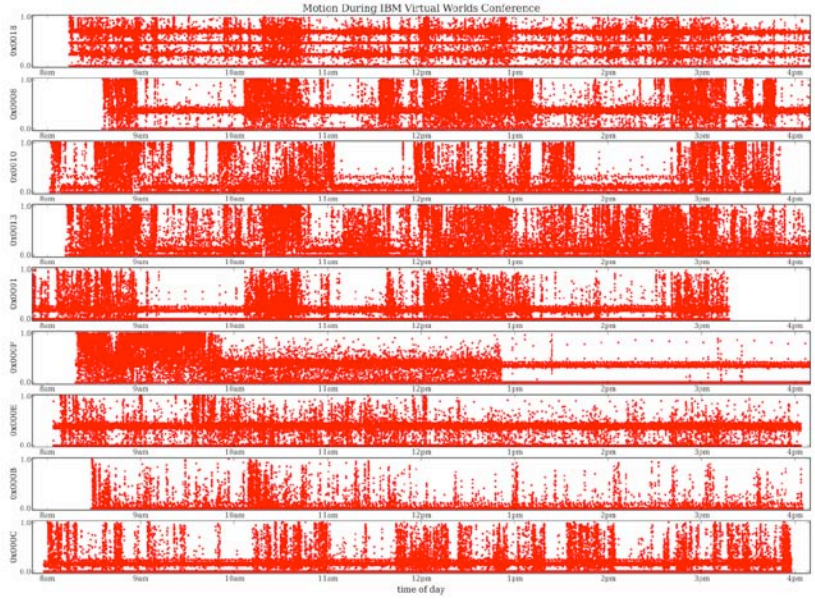
Sound Amplitude



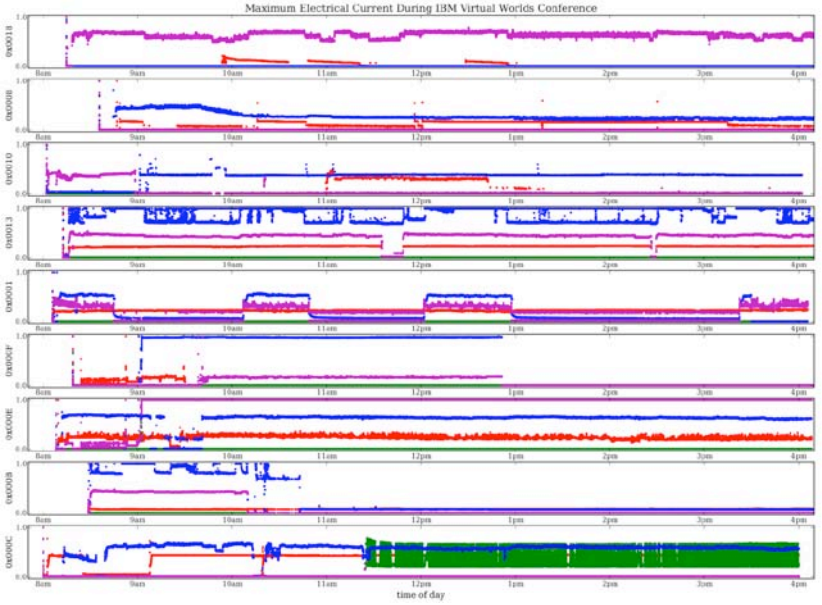
Light Intensity



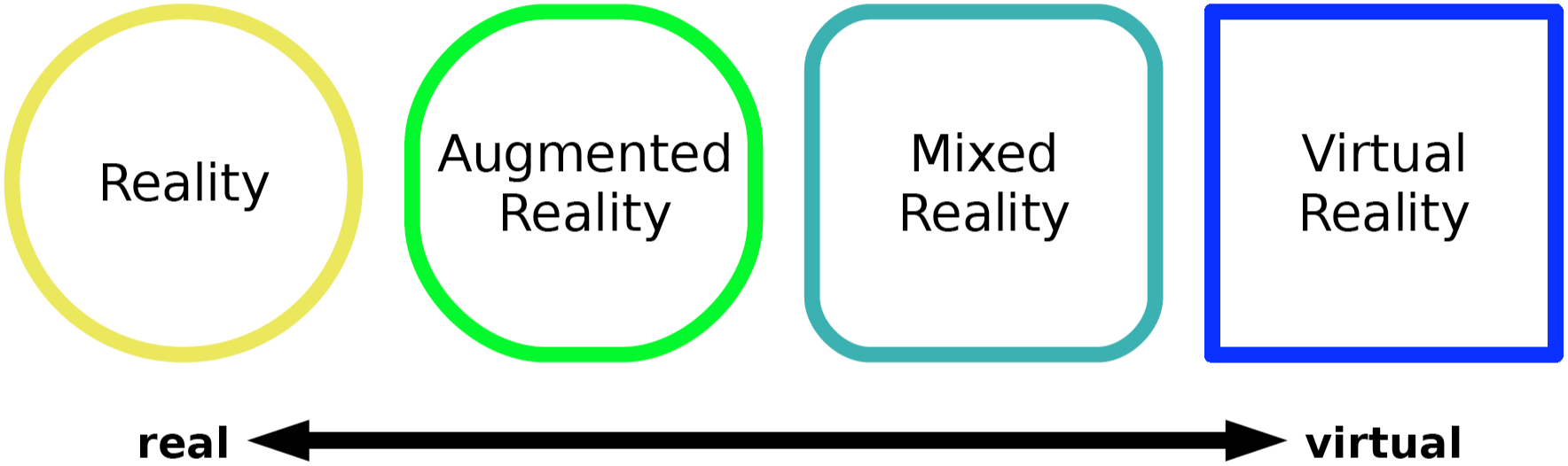
Motion Sensor



Electric Current

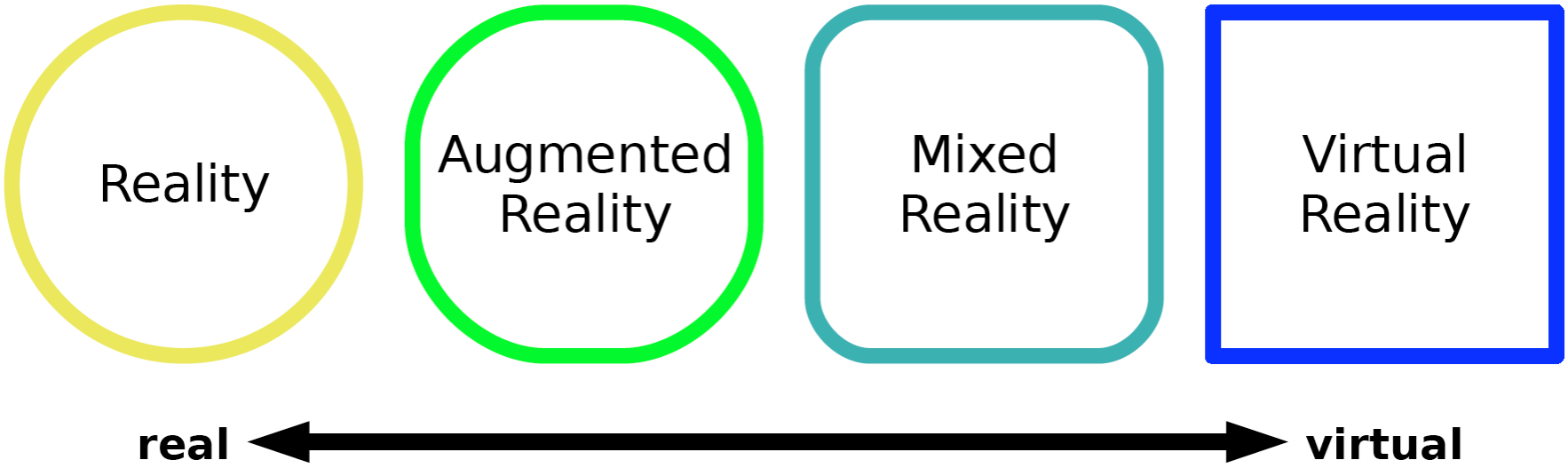


Reality Taxonomy



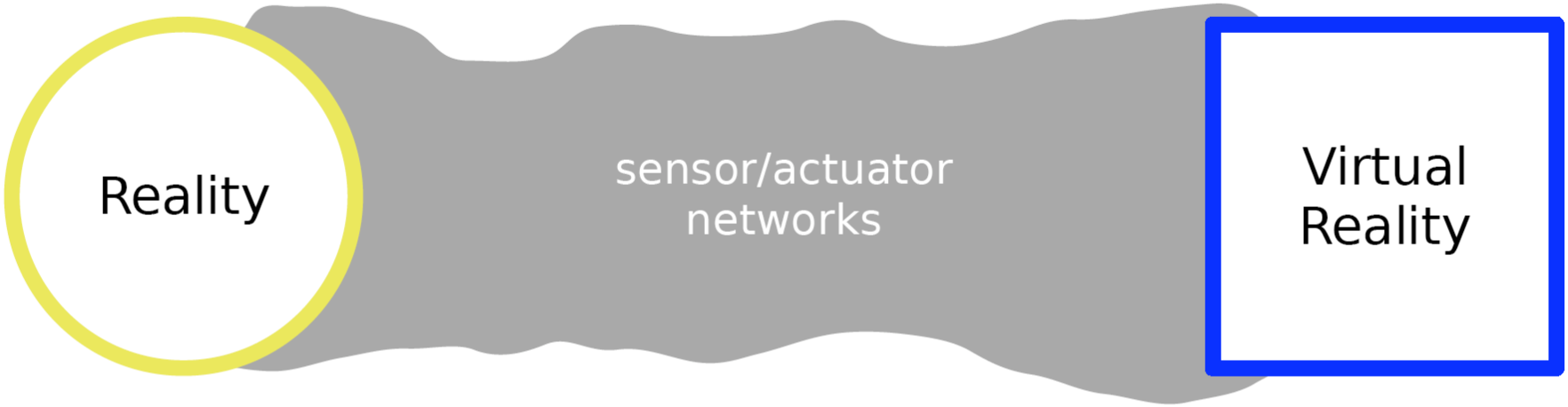
Josh Lifton's PhD Thesis - 8/07

Reality Taxonomy



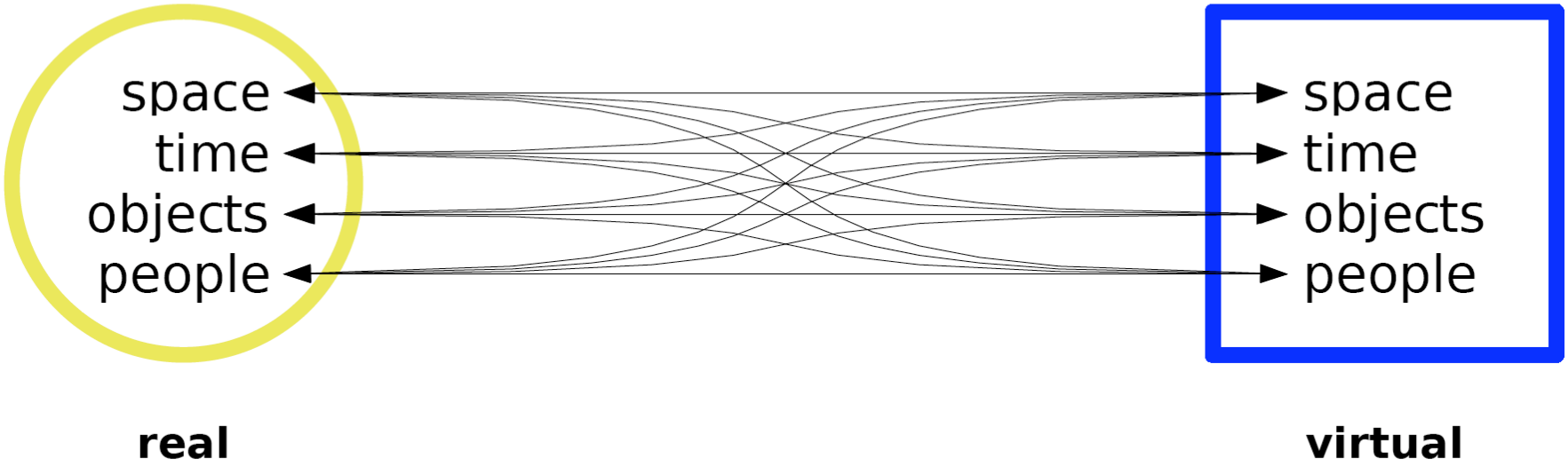
All single realities.

Dual Reality



Two complete realities that influence and leak into each other by means of ubiquitous sensor/actuator networks.

Reality Mappings



Allow for distortion, exaggeration, and metaphor.

Real World can be "browsed" in virtual space

MIT Media Lab

Second Life as a the Virtual End of Dual Reality

Shadow Lab - Binding real sensor data to virtual worlds

Third floor of ML built in Second Life

ResEnv Lab rendered in detail - other areas currently derived from map

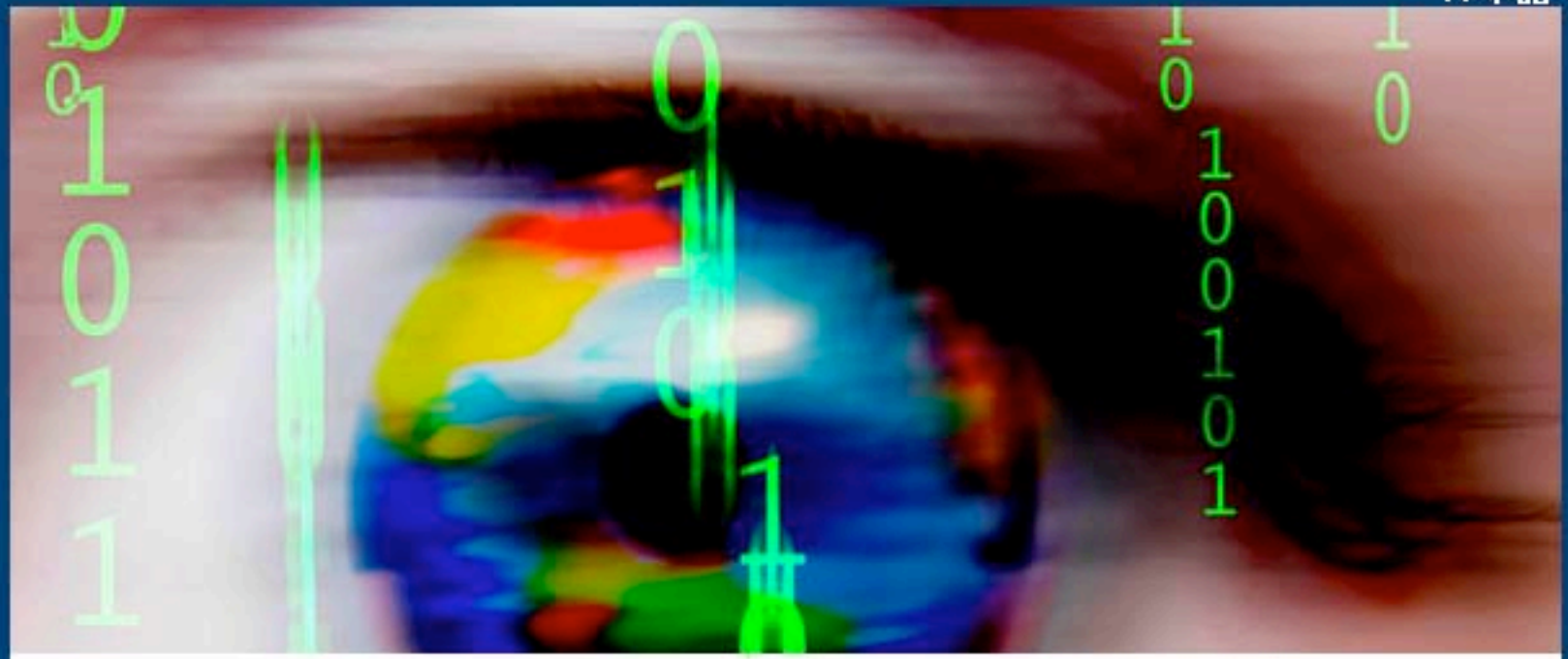
Sensor data piped in and interpreted as real-time graphic phenomena

Simple sensor apparitions to explore basic ideas

- Energy use ➔ height of fire
- Activity (sound, motion) ➔ whirlwinds
- Active regions ➔ higher walls
- "Ghost" face ➔ individual presence

Lifton 07

日本語



The MIT Media Lab and Frank Moss invite you to the Fall Sponsor Meeting

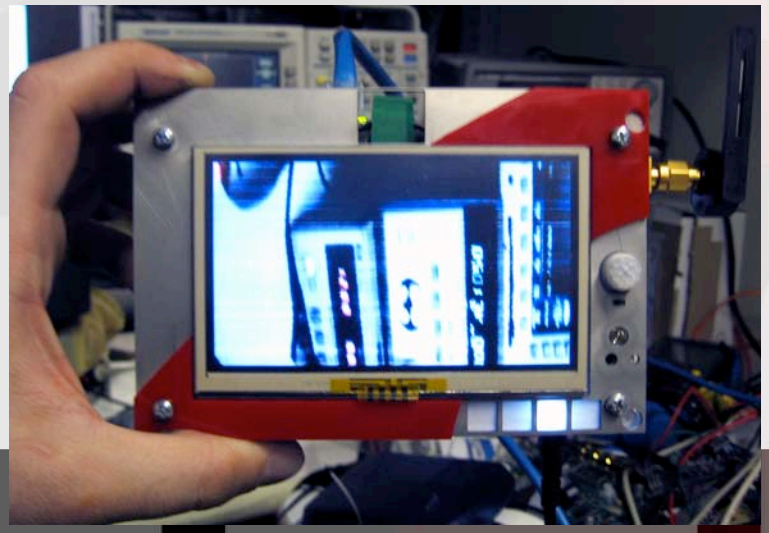
WEDNESDAY PM - FRIDAY AM
OCTOBER 29-31, 2008

Awareness

As citizens of the information age, we are leaving behind more and more digital "breadcrumbs" wherever we go. This new wealth of information enables us to build a truly transparent environment—one with an astonishing awareness of who we are, what we are doing, and how our society is evolving. The Media Lab's "Awareness" symposium will explore the unprecedented opportunities—and hidden dangers—of this new world.

Device Details – Camera System

- Deployed to cover entire building (>100 nodes)
- 3MP Camera
- Motorized Panning and Focus
- Dedicated Video DSP/ARM
  - (TI DaVinci chip)
- Real-time Linux OS
- LCD display (Touchscreen)
- Contains Spinner Gateway/Sensor board (detailed on next slide)

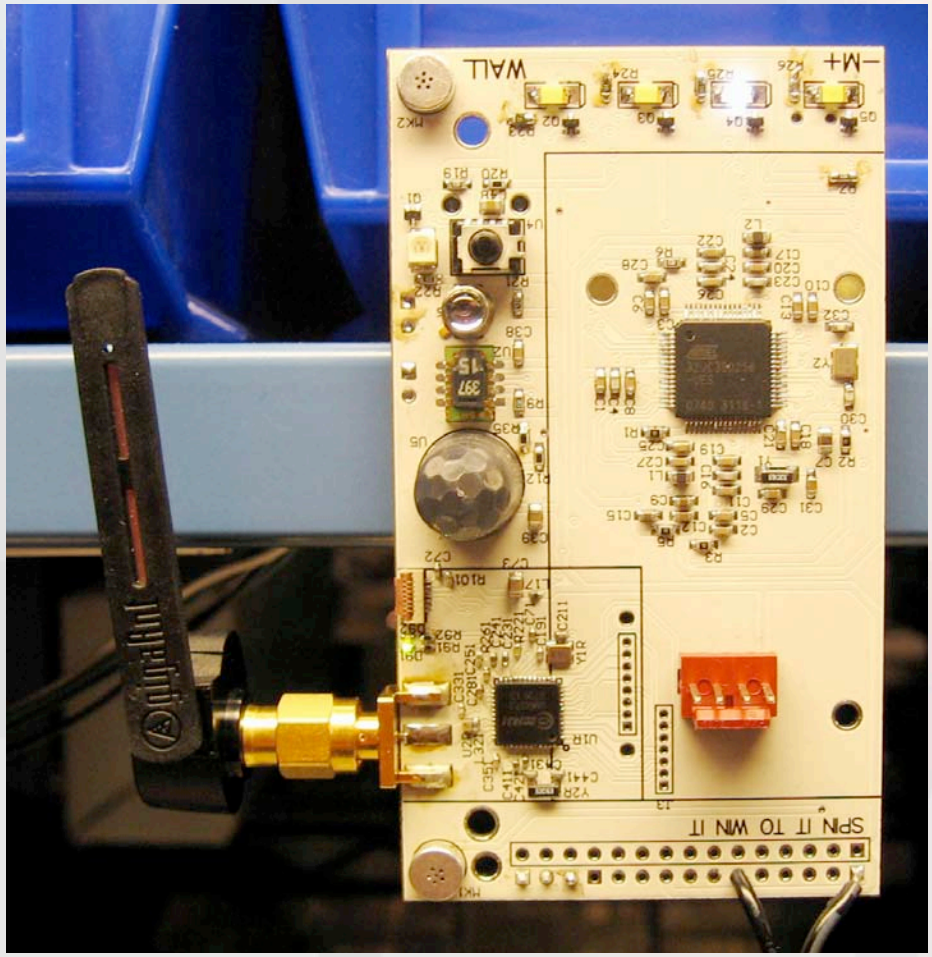


Mat Laibowitz

45 distributed across Media Lab for October 08

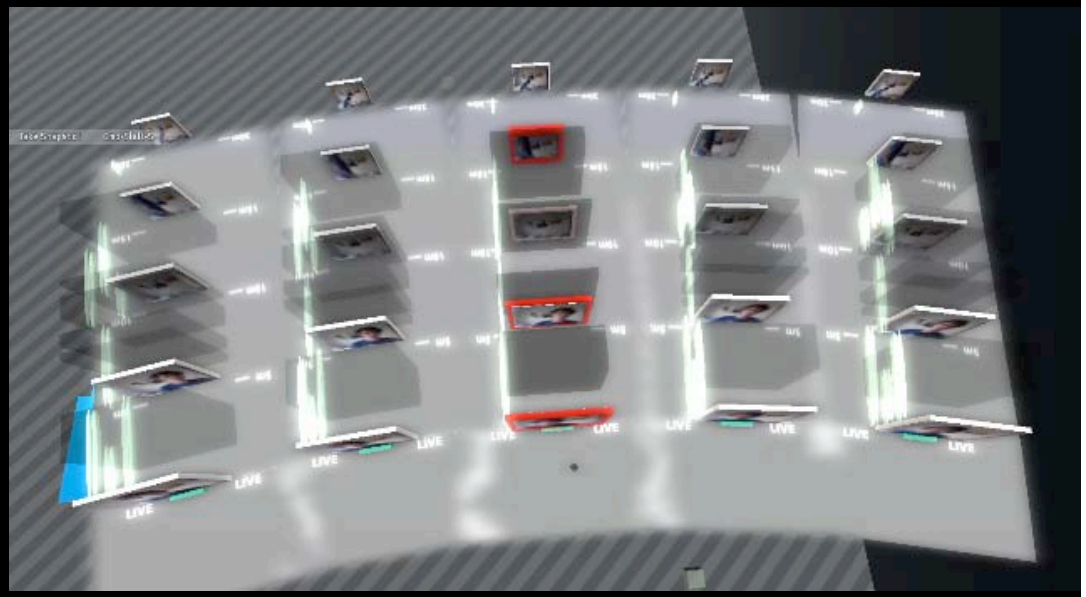
Device Details – Spinner Gateway

- Works with or without camera board
- Communicates with wearable/mobile devices in mesh network
- Serves as reference beacon for location system
- Ethernet
- Audio system with DSP
  - AVR32
- Environmental Sensing
  - Motion
  - Humidity and Temperature
  - Light
  - Infrared Communication and Detection/Proximity
  - Talks to badge systems



October 2008 Demos Planned

- Video node identifies badged participants
- Automatic connection to other participants with common interests (or tunneling into spaces where you have potential interest)
- Explore spaces with high activity, look for colleagues
- Portal into virtual world…



SecondLife Representation

Drew Harry

Scalable Virtuality

Going beyond "Dual Reality" (using sensor/actuator networks to blend real and virtual worlds) is "Scalable Virtuality," where the manifestation of virtual phenomena in the real world becomes a function of available and appropriate information portals. We see a unified digital information space that the artifacts of ubiquitous computing project onto, ranging from a flashing light, to a cellphone, to full-up immersive 3D virtual world.

Mobile User Interfaces for Sensor Networks

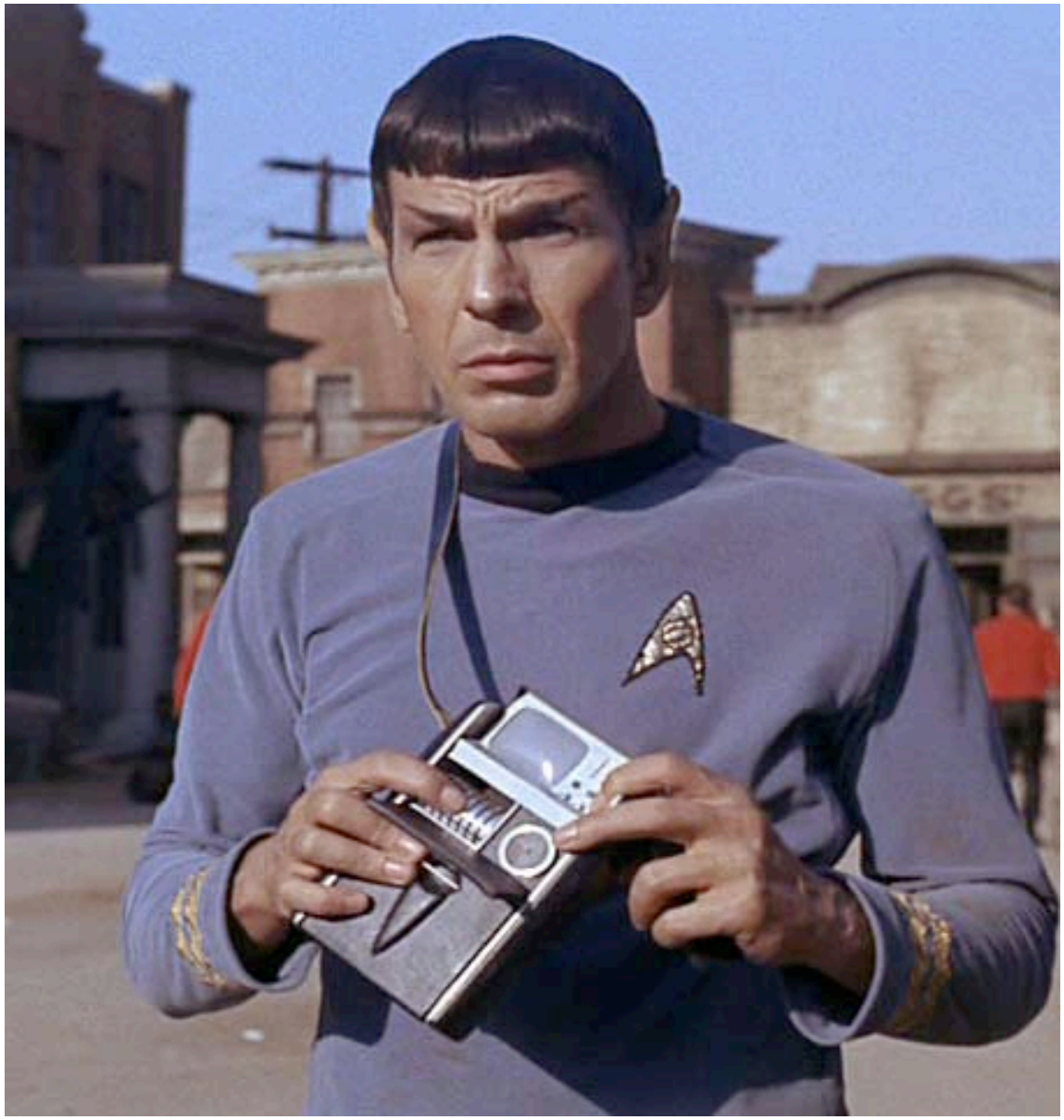
Browsing, querying, navigating through sensor net data

What are the interface affordances, displays, interaction modalities?

Privacy & Security?

Mobile platform inside of network vs fixed platform outside?

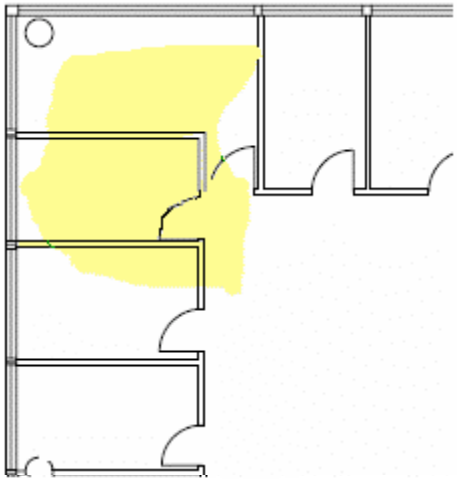
McLuhan Extension of human senses

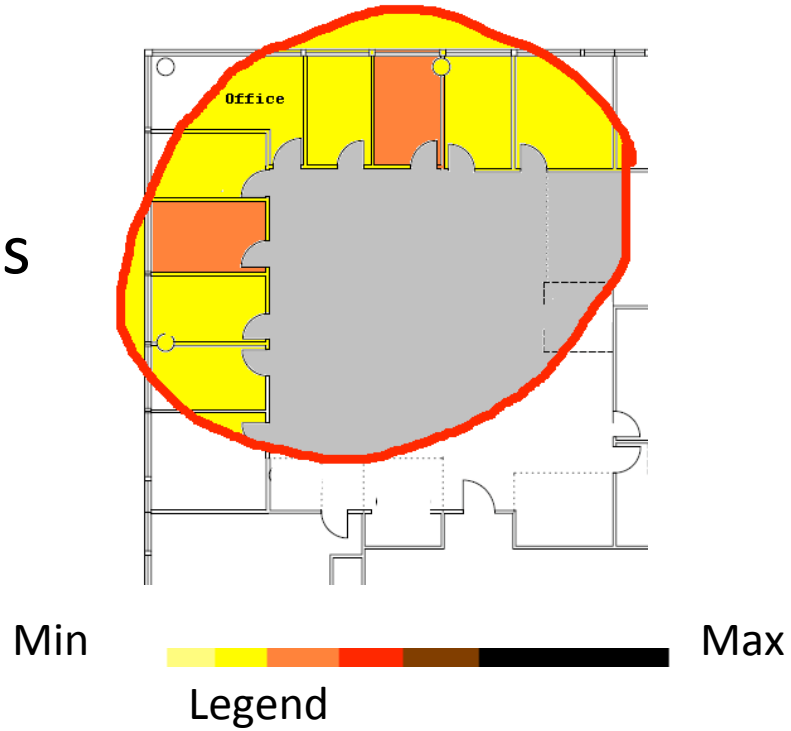


Nokia 770 Sensor Net Tricorder - Mk. I

Selection & Aggregation

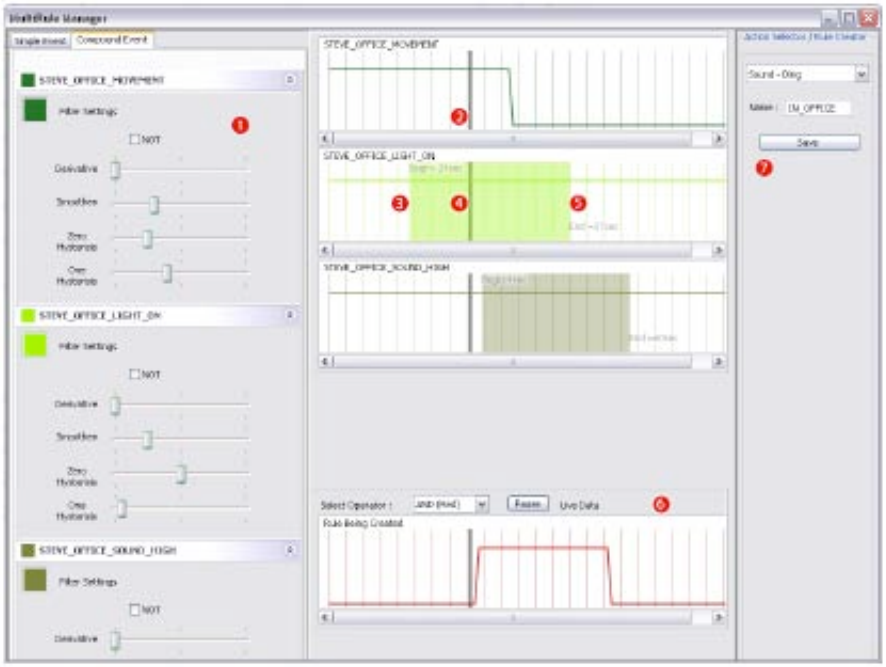
- Selection :
  - Location → Data Values

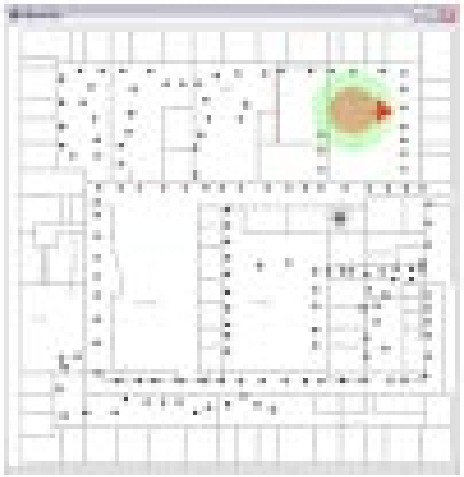




Manas Mittal

The Ubicorder





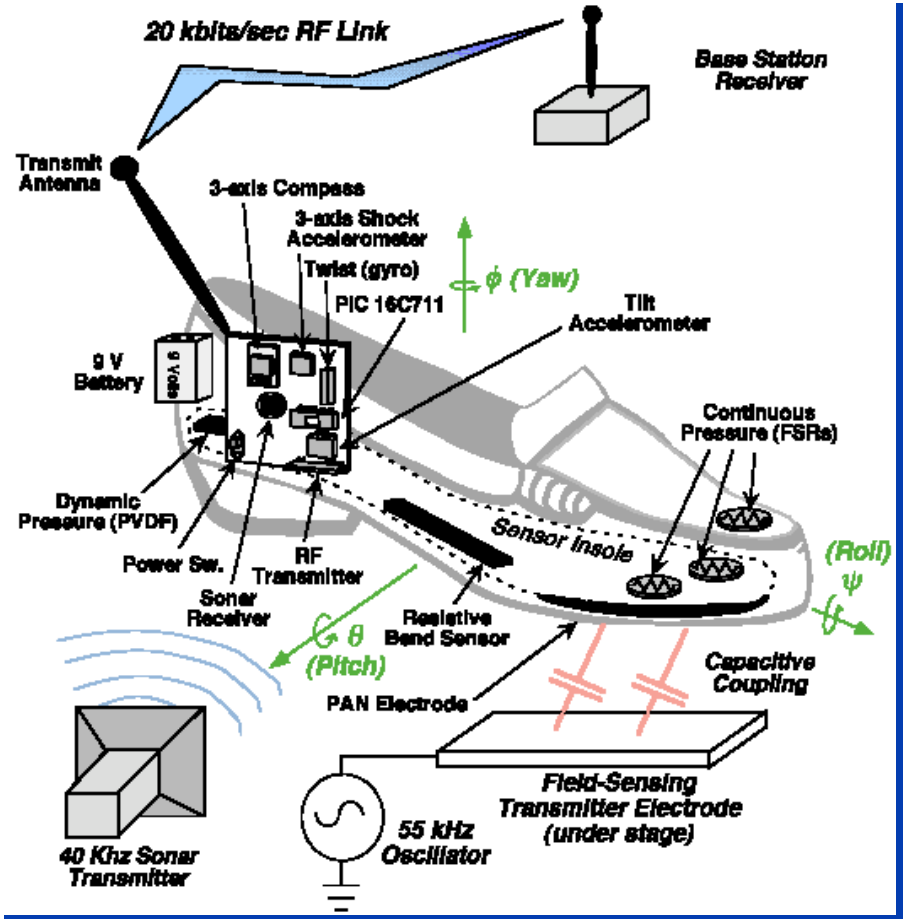
Mobile situated Sensor Net Browsing Script-based rule definition for detection

Manas Mittal's MS

1997 - Expressive Footwear

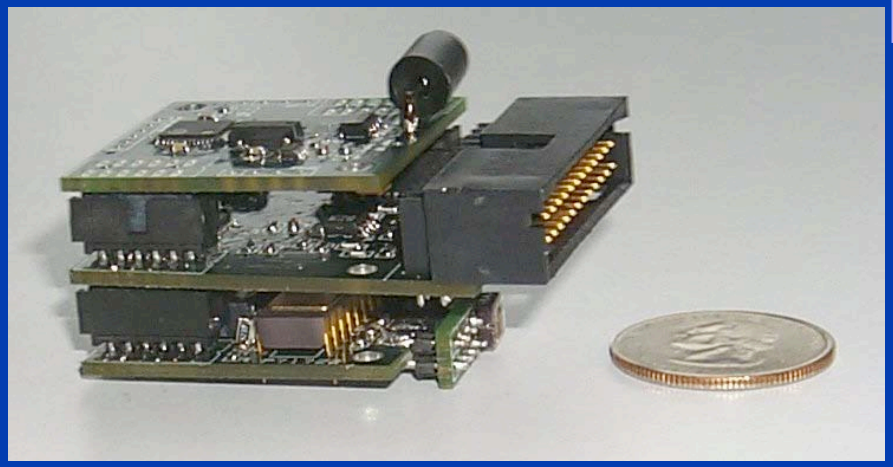
17 Data Channels

Tilt, shock, rotation, height, bend, location, multipoint pressure

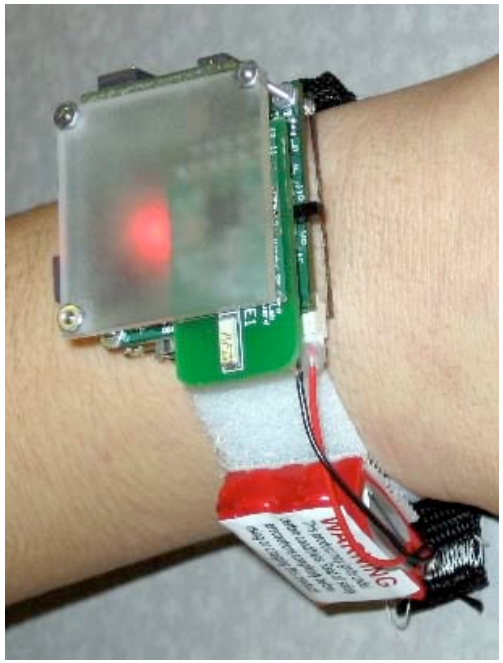


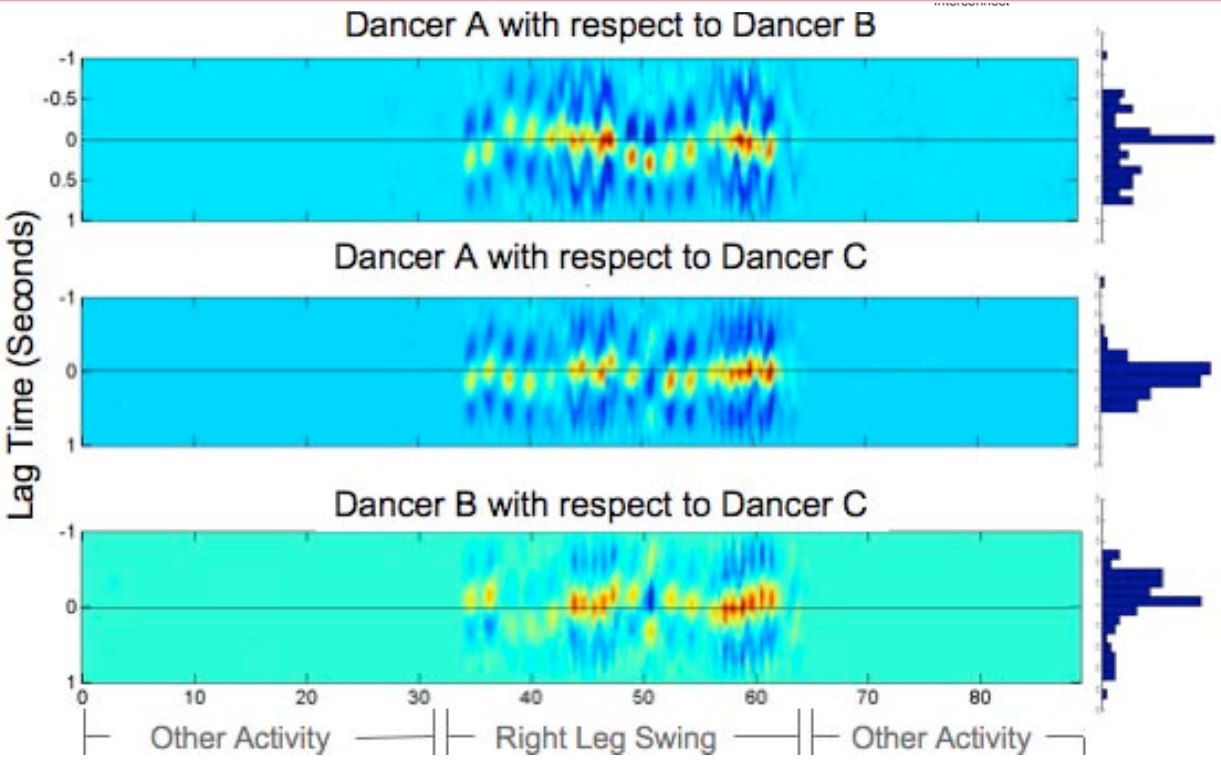
The Wearable Gait Laboratory

Stacy Morris



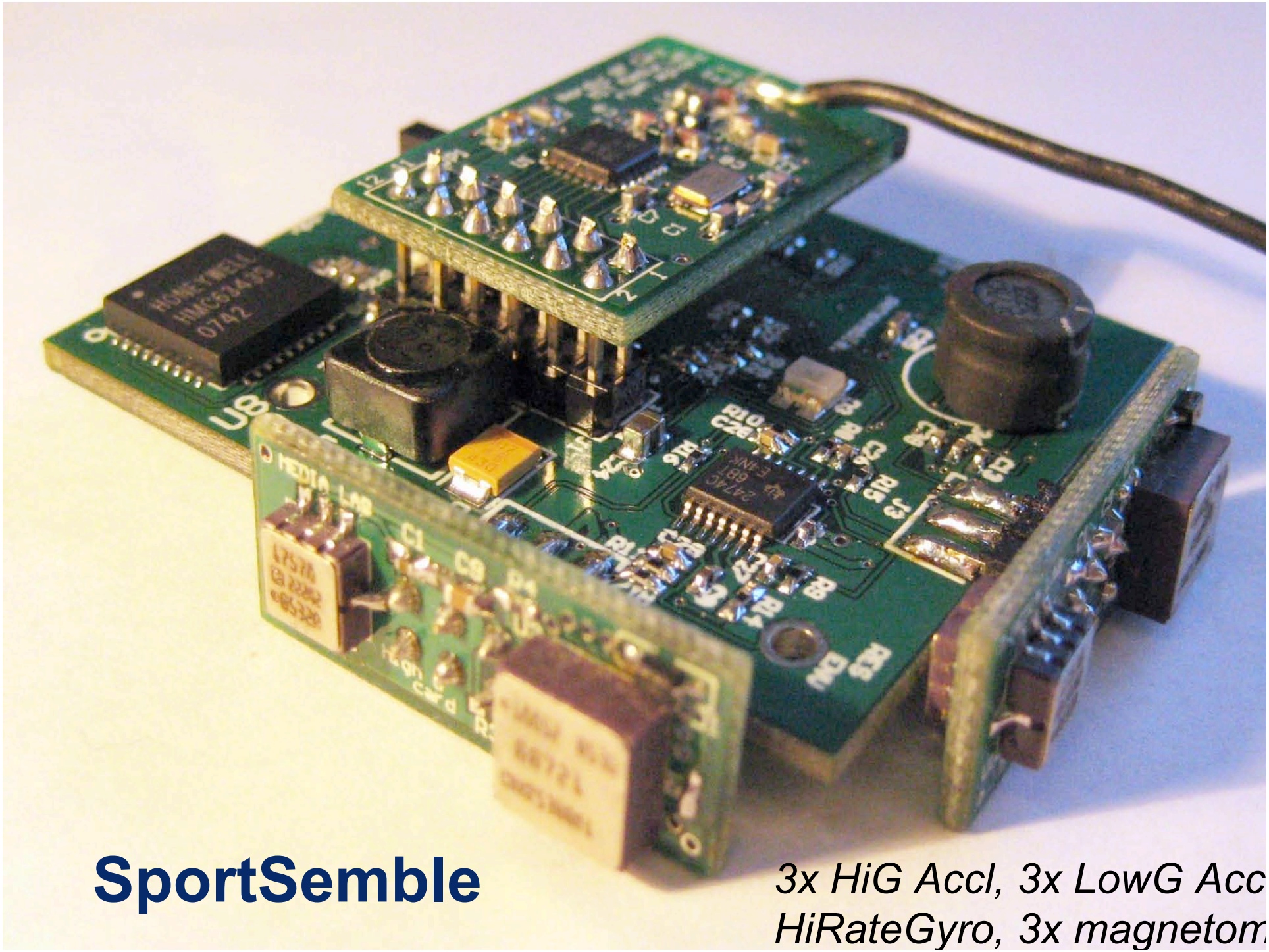
Scaling to several dancers…





Capacitive proximity to 50 cm
6-axis IMU - 1 Mbps TDMA radio
100 Hz Full State Updates from 25 nodes

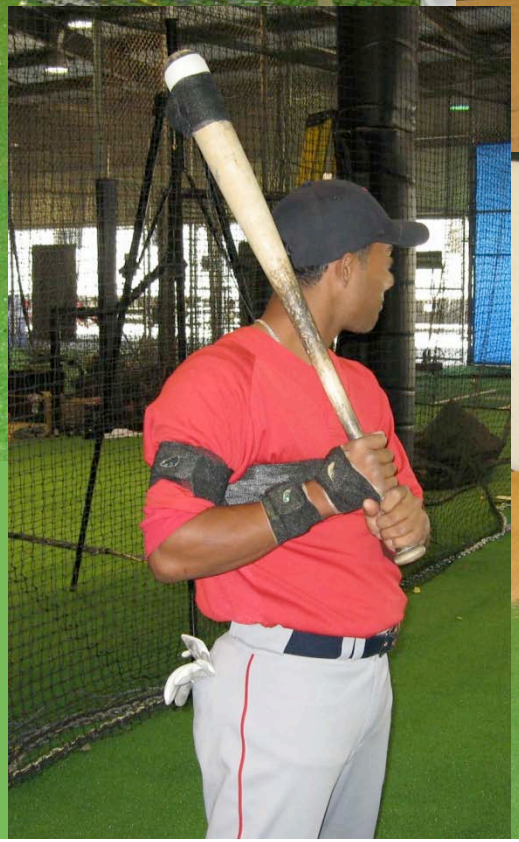
High Speed Sensor Fusion
Vocabulary of features



SportSemble

3x HiG Accl, 3x LowG Acc
HiRateGyro, 3x magnetom

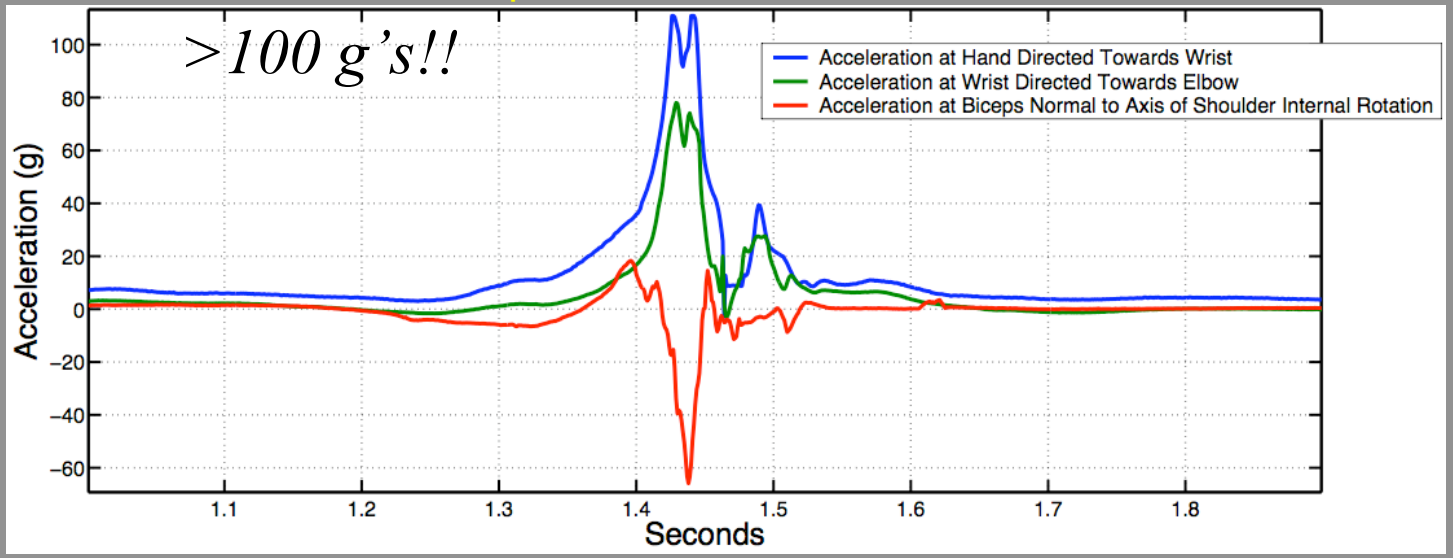
Network In Action



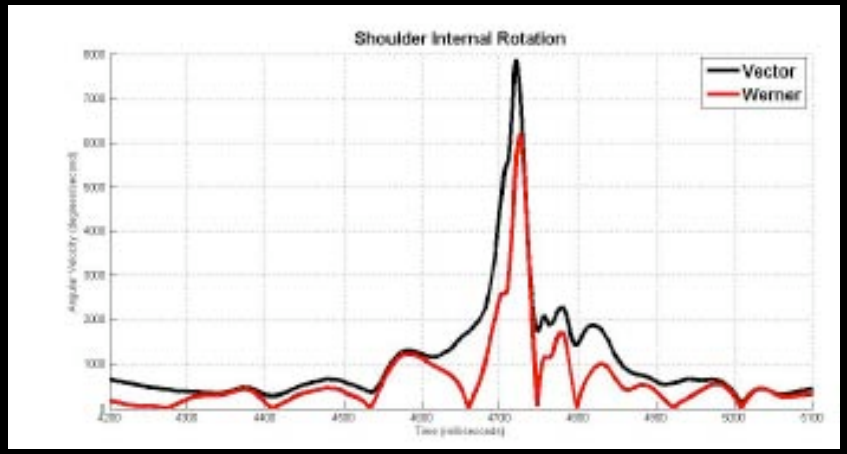
New collaboration, Red Sox Grant - Spring Training in February

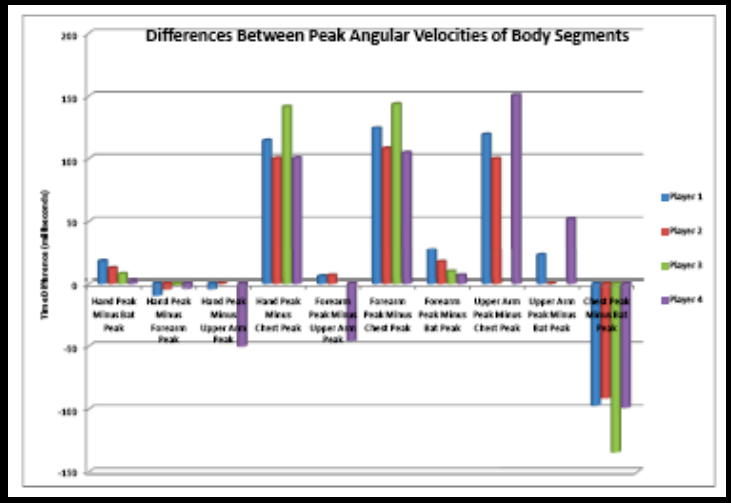
- Acceleration at the wrist peaks well above 100g
- Most of this acceleration occurs in a 30ms window
- Equates to 30 samples for the modified inertial system, but only 5 frames on a 180Hz video capture system

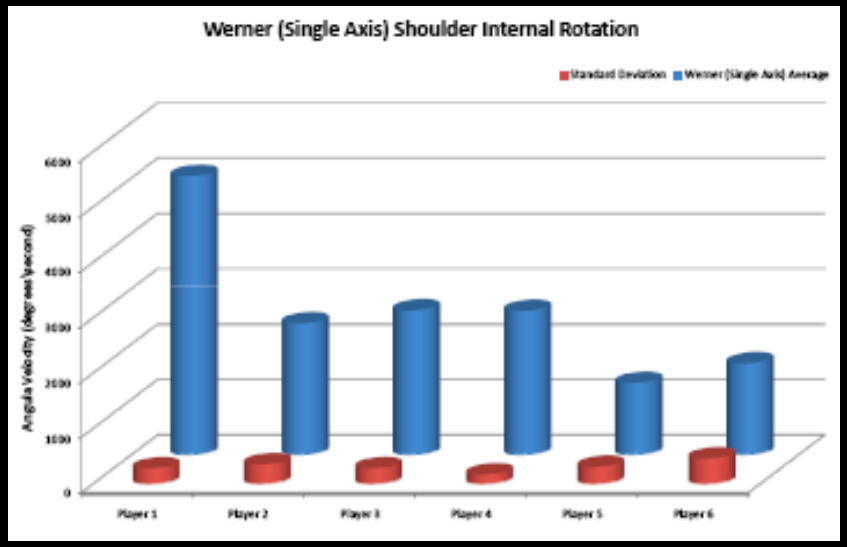
Acceleration of the Pitch Above Captured at Three Critical Locations - Hand, Wrist, & Biceps

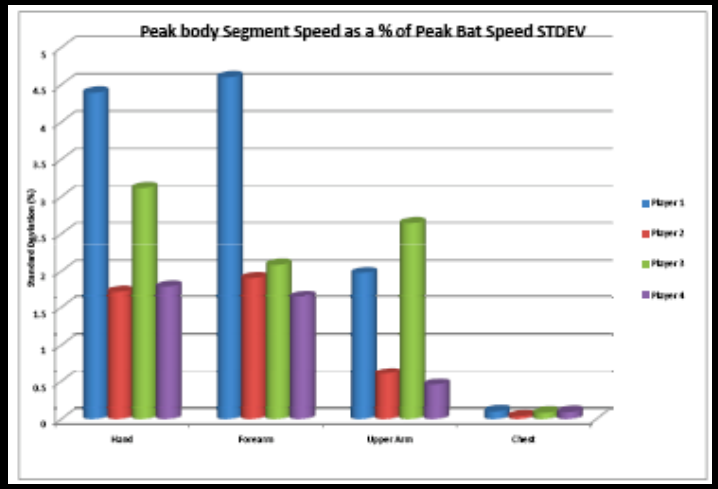


Michael Lapinski's MS



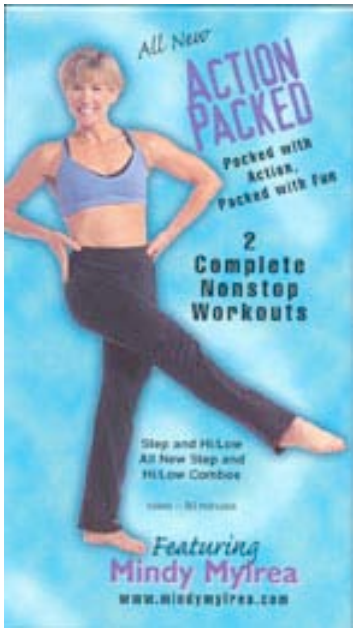






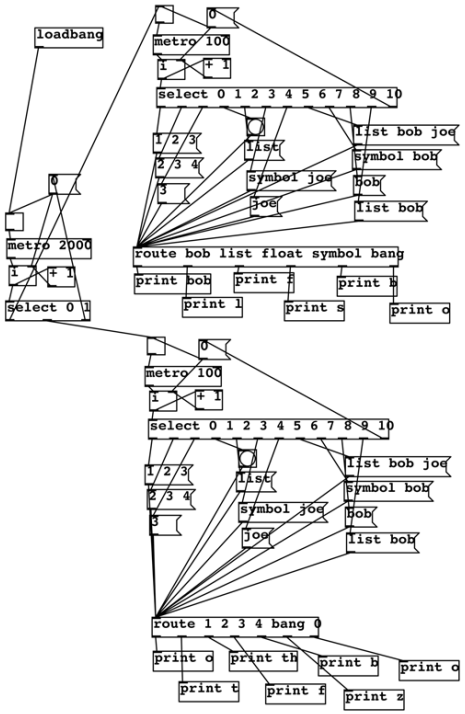
Many results comparing batters, pitchers

Miniaturization & Distribution



- Future of athletic broadcasts
  - Get content directly from point of expression
    - Sensor packs in figure skates, boxing glove, snowboard…
  - Map dynamic content (music, graphics, specs…)
- Therapy with interactive feedback
- Future of exercise
  - Monitor lower, upper limbs, heart rate, etc.
  - Map interactive content
    - Synchs up and nudges participant to stay on track

Interactive Music on N800



- Zigbee interface for N800
  - Easy implementation of wearable sensors (inertial, etc.)
- Pd (PureData) compiler for N800
  - Allows artists to graphically compose music interaction & synthesis
  - Produces C code (not interpreted)
  - Fast, efficient execution

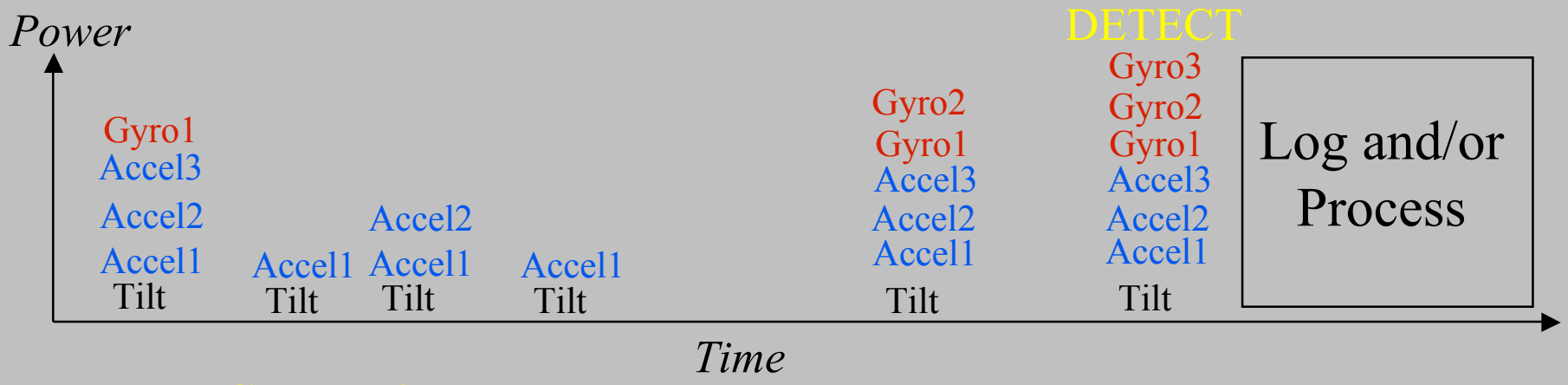
Robert Jacobs' M.Eng. Thesis - demos coming

Groggy Wakeup for Efficient Smart Sensor Systems

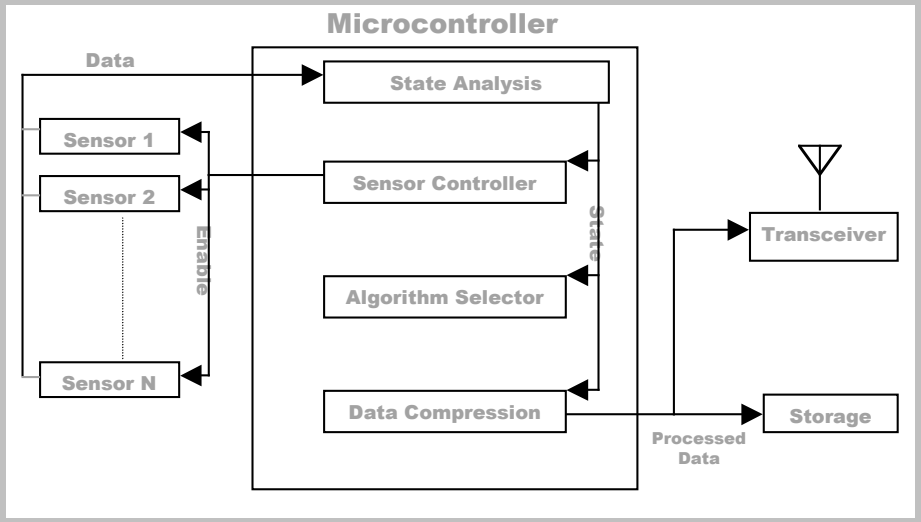
Ari Y. Benbasat

Automated Power-Efficient Sensor Hierarchy

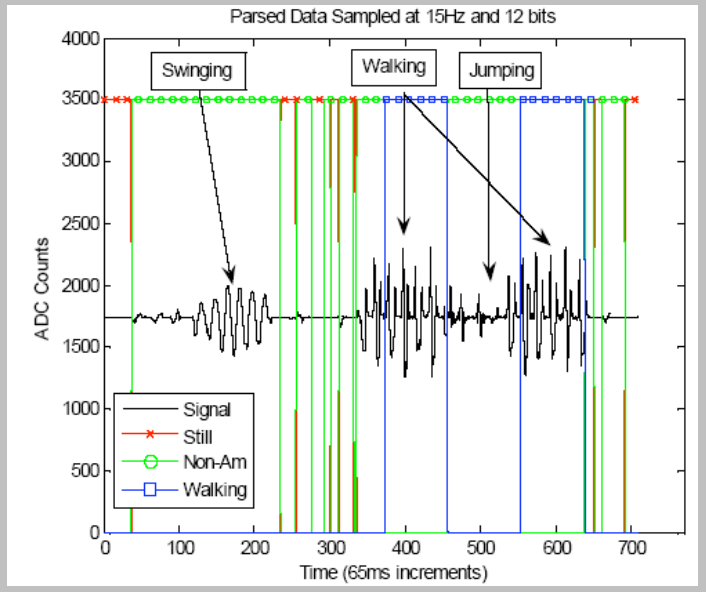
Keep higher-power sensors OFF unless needed for detection decision



In Sensys 07



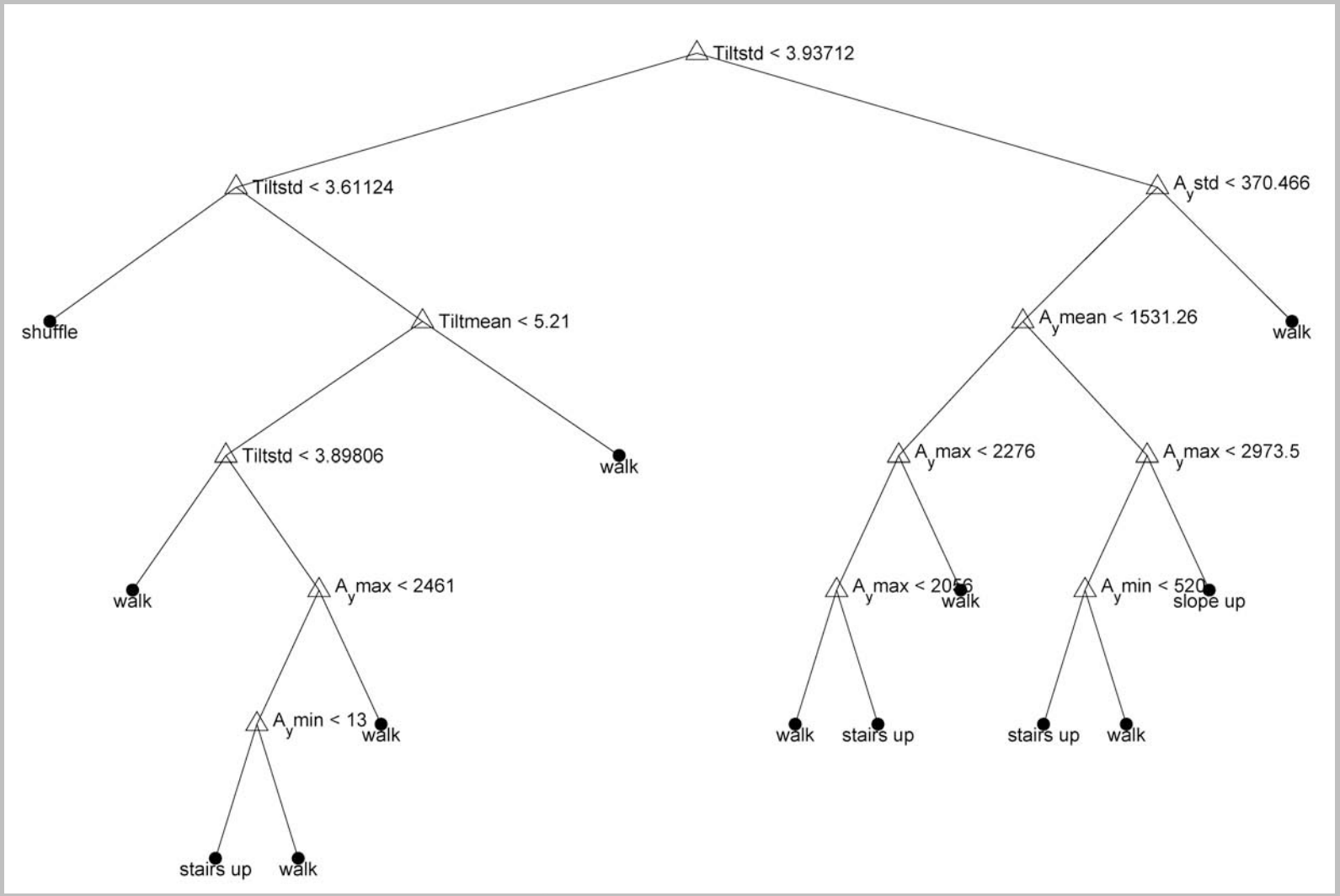
General on-node implementation



Power-efficient detection of gait phase

Automated Power-Efficient Sensor Hierarchy

Trade Power Consumption with Detection Efficiency



Power-efficient detection of walking up stairs

Automated Power-Efficient Sensor Hierarchy

Trade Power Consumption with Detection Efficiency

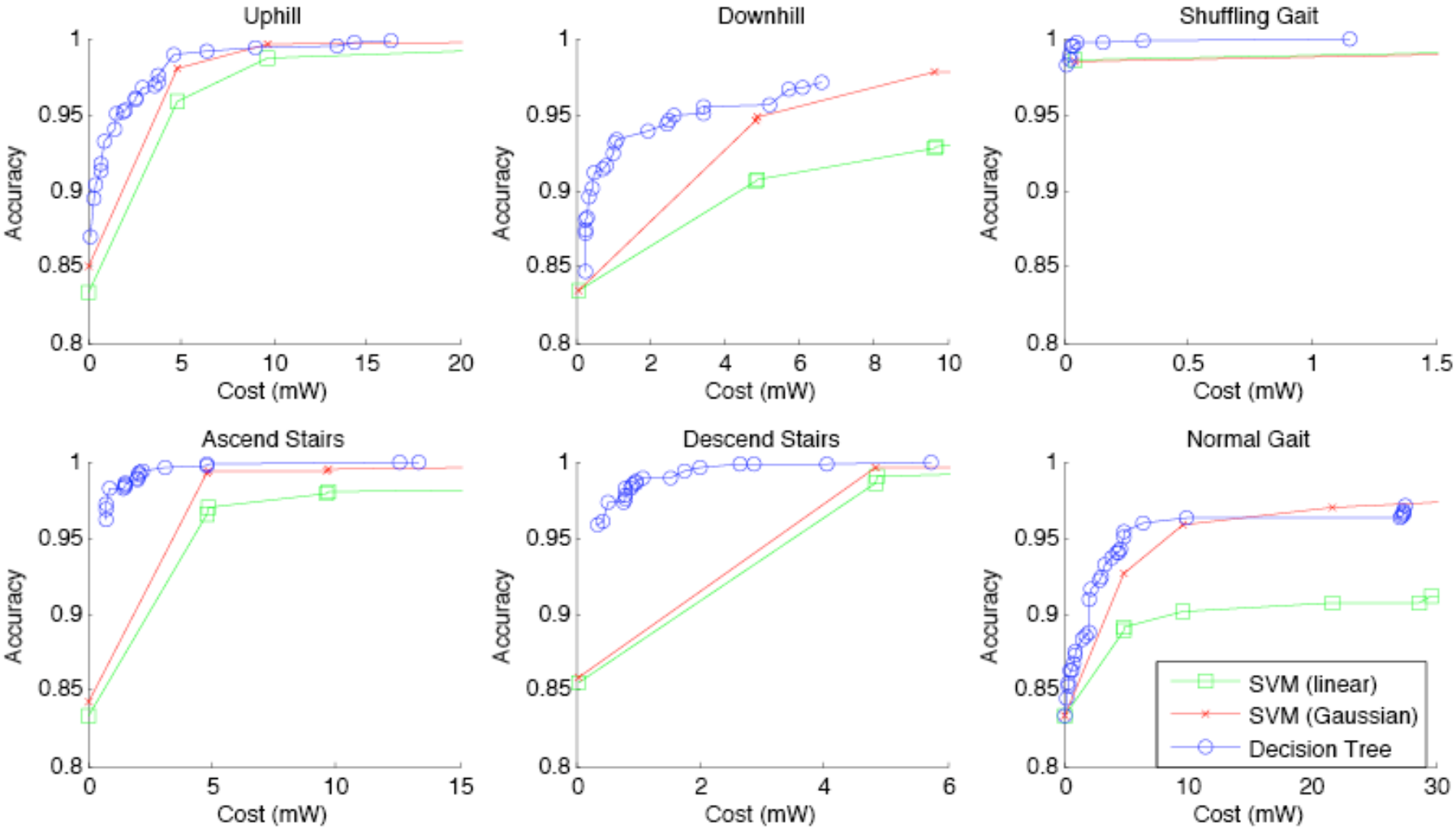
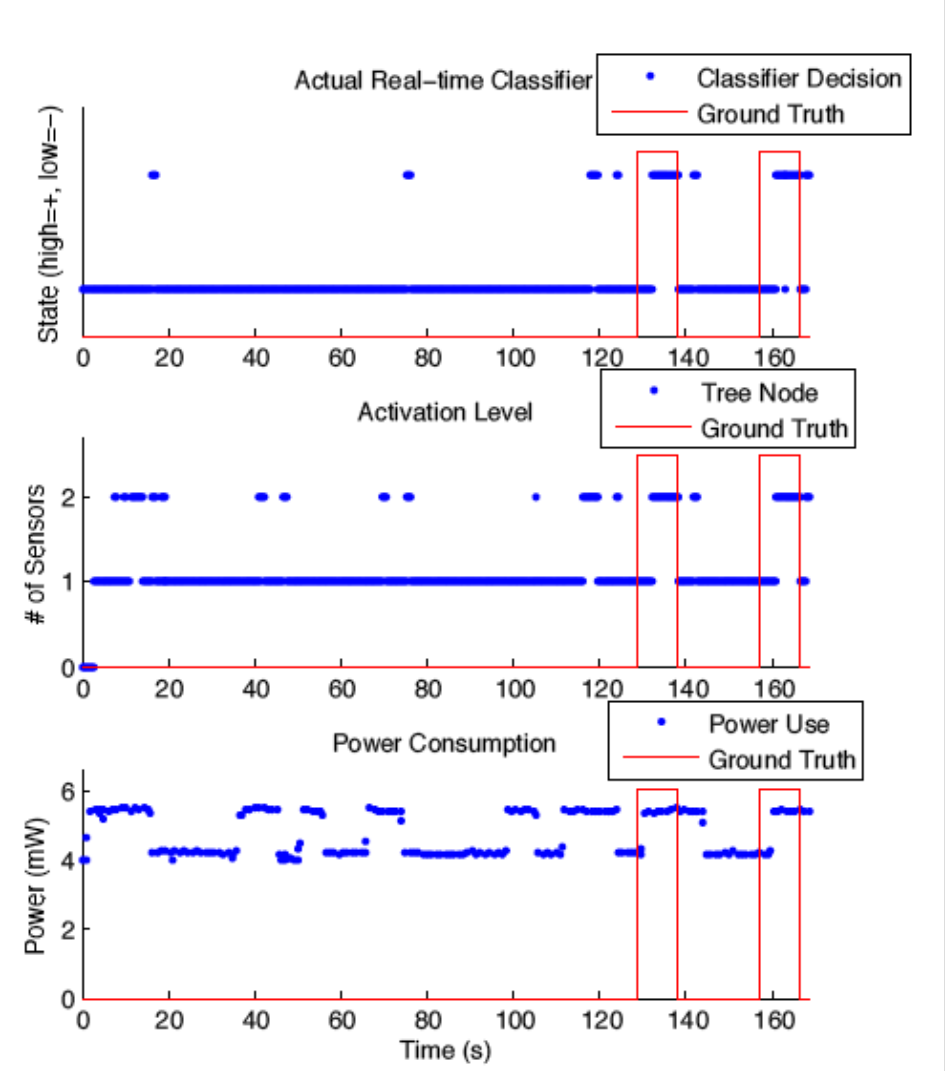


Figure 3. Power/accuracy tradeoff for decision trees and SVM

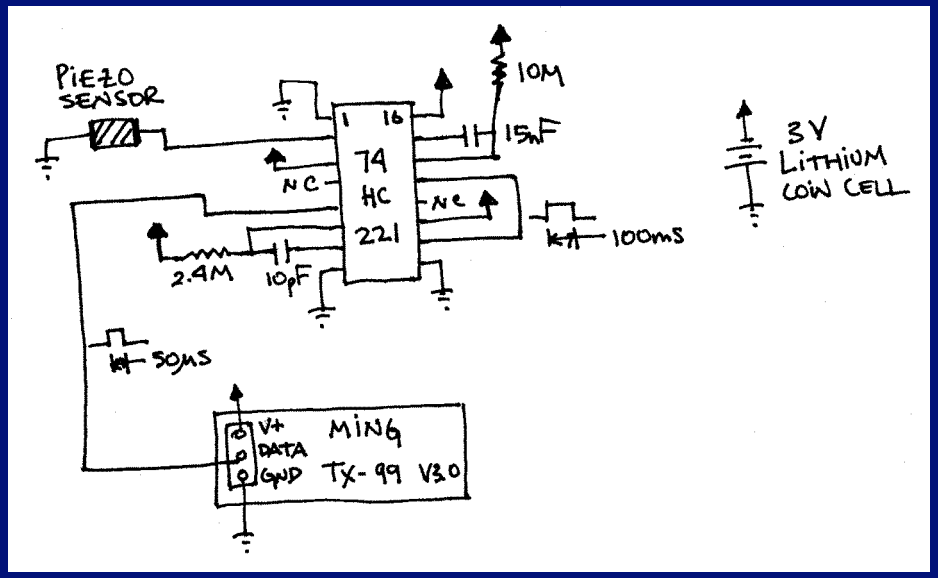
Power-efficient detection of gait phase

Tree Execution Running on the Stack in Real Time



2-level gait classifier tree during actual walking

The Disposable Wireless Sensors

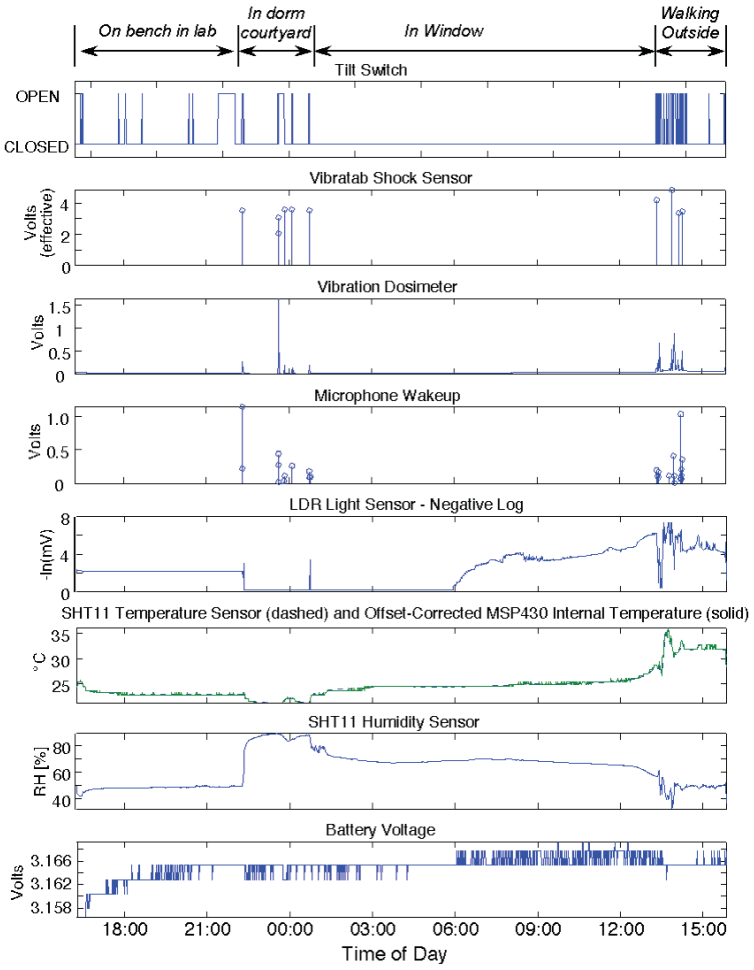


- Very simple "featherweight" motion sensor
  - Cantilevered PVDF piezo strip with proof mass
  - Activates CMOS dual monostable when jerked
  - Sends brief (50 μs) pulse of 300 MHz RF
  - 100 ms dead timer prevents multipulsing
  - Can zone to within ~10 meters via amplitude
  - **Ultra low power – battery lasts up to shelf life**
  - **Extremely cheap – e.g., under $1.00 in large quantity**

CargoNet: A Low-Cost MicroPower Sensor Node Exploiting Quasi-Passive Wakeup for Adaptive Asynchronous Monitoring of Exceptional Events

Malinowski, Moskwa, Feldmeier, Laibowitz, and Paradiso - Presented at ACM Sensys 2007

- Dynamically adaptable thresholds
  - Adapts to environments with persistent stimuli
- Small and inexpensive
- Microampere current draw
  - 5 years on a single coin cell battery



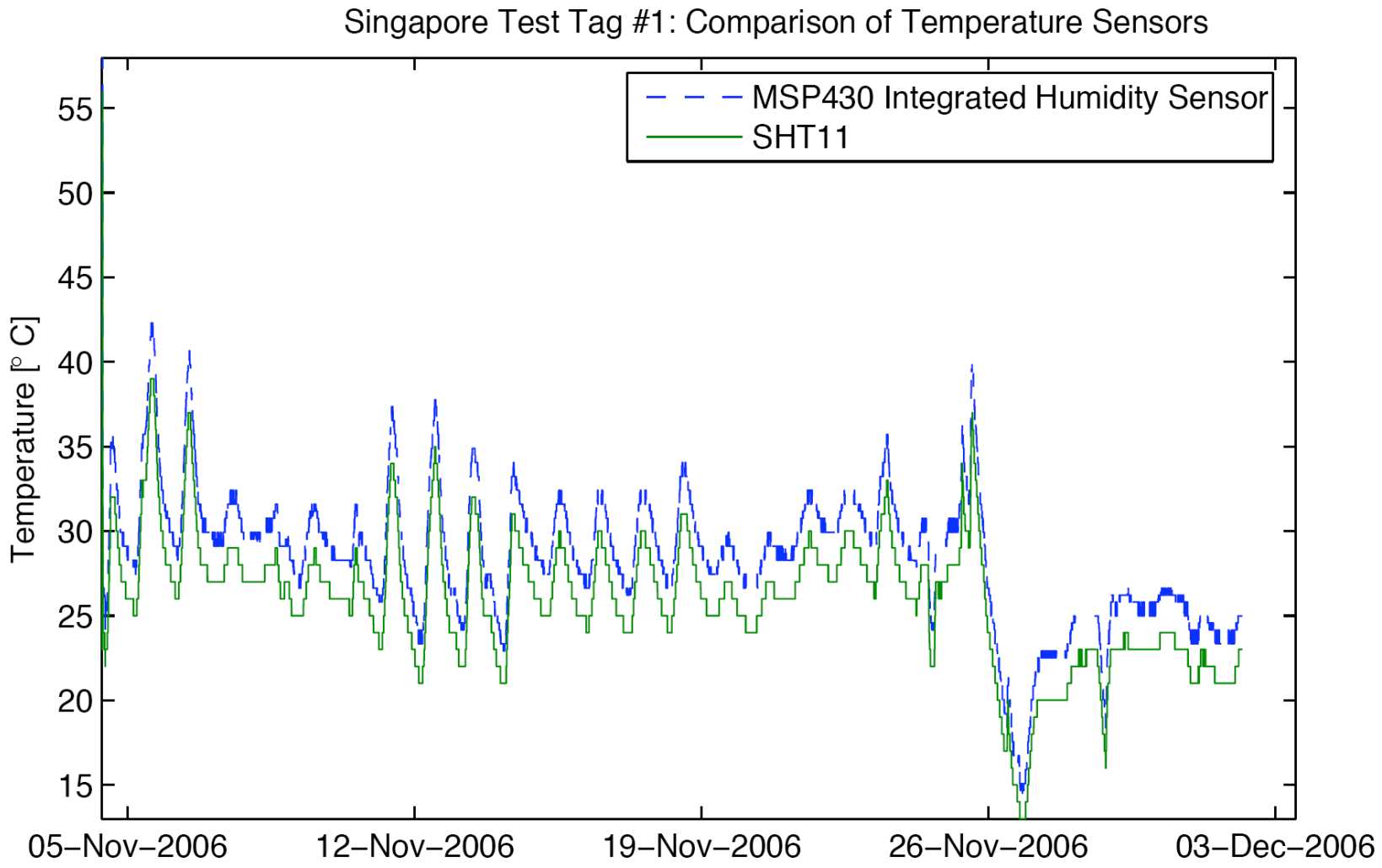
Sensor Type	Measurement or Application
Shock Sensor	Potential impact damage
Vibration Dosimeter	Average low-level vibrations
Tilt Switch	Package orientation and shaking
Piezo Microphone	Events causing loud nearby sounds
Light Sensor	Container breach or box opening
Magnetic Switch	Package removed or box opened
Temperature Sensor	Overheating or potential spoilage
Humidity Sensor	Potential moisture damage
RF Wakeup	Query from reader or another tag

Table 1. List of sensors present on the CargoNet tag.

MIT Media Lab

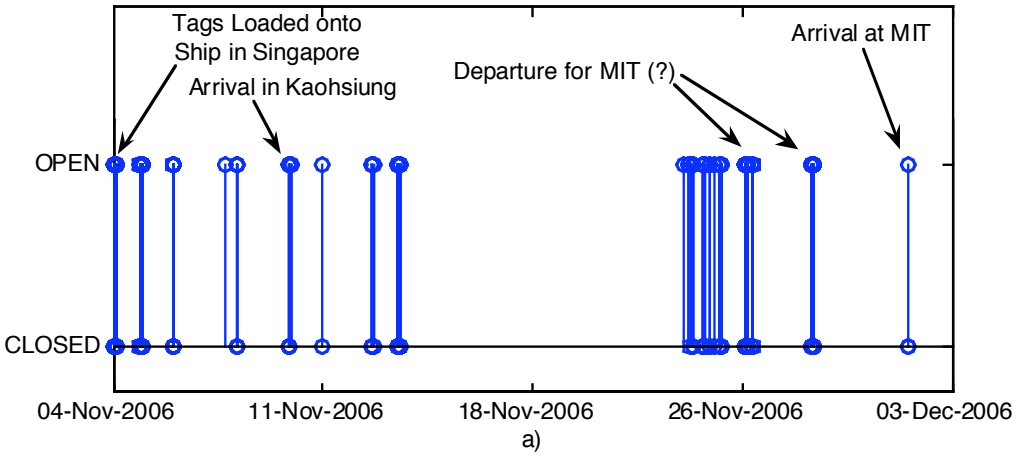
CargoNet Singapore—Taiwan Test

Internal vs. External Sensors

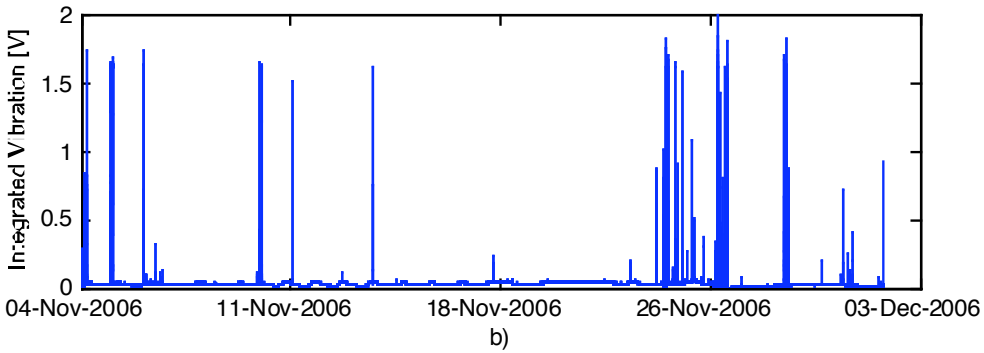


CargoNet Tag - Singapore to Taiwan - Malinowski M.Eng.

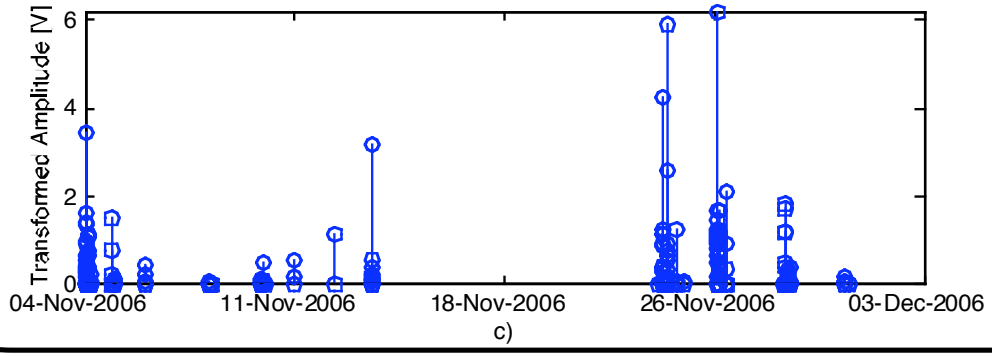
Tilt, Vibration, Sound Enroute



Passive Tilt

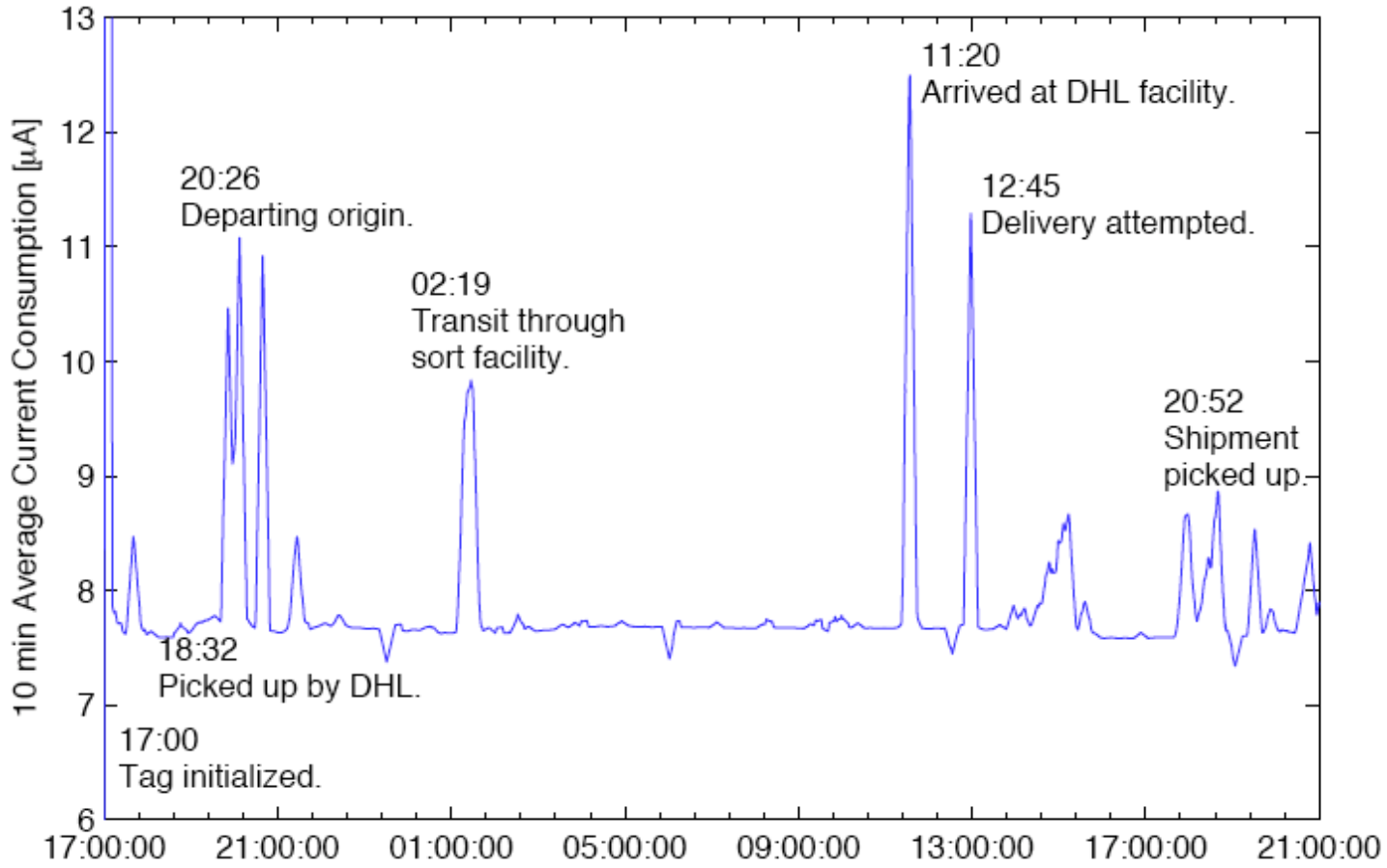


Micropower Vibration Dosimeter



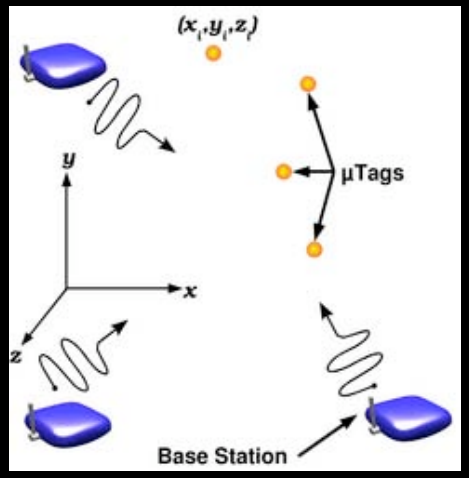
Sonic Events

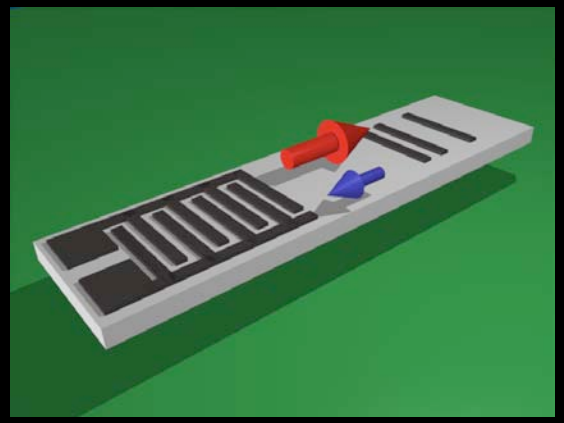
Power - DHL Cambridge to CA

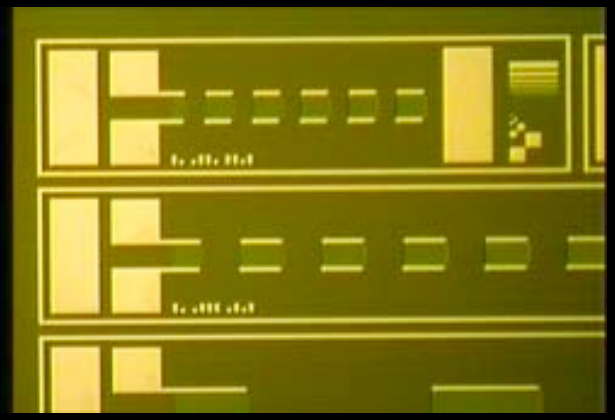


- Quiescent (alive) current of under 8 uA
- Average power under 25 µW
  - 5 years on a lithium coin cell!

Utags : Passive Real-Time 3-d Localization & Remote Sensing





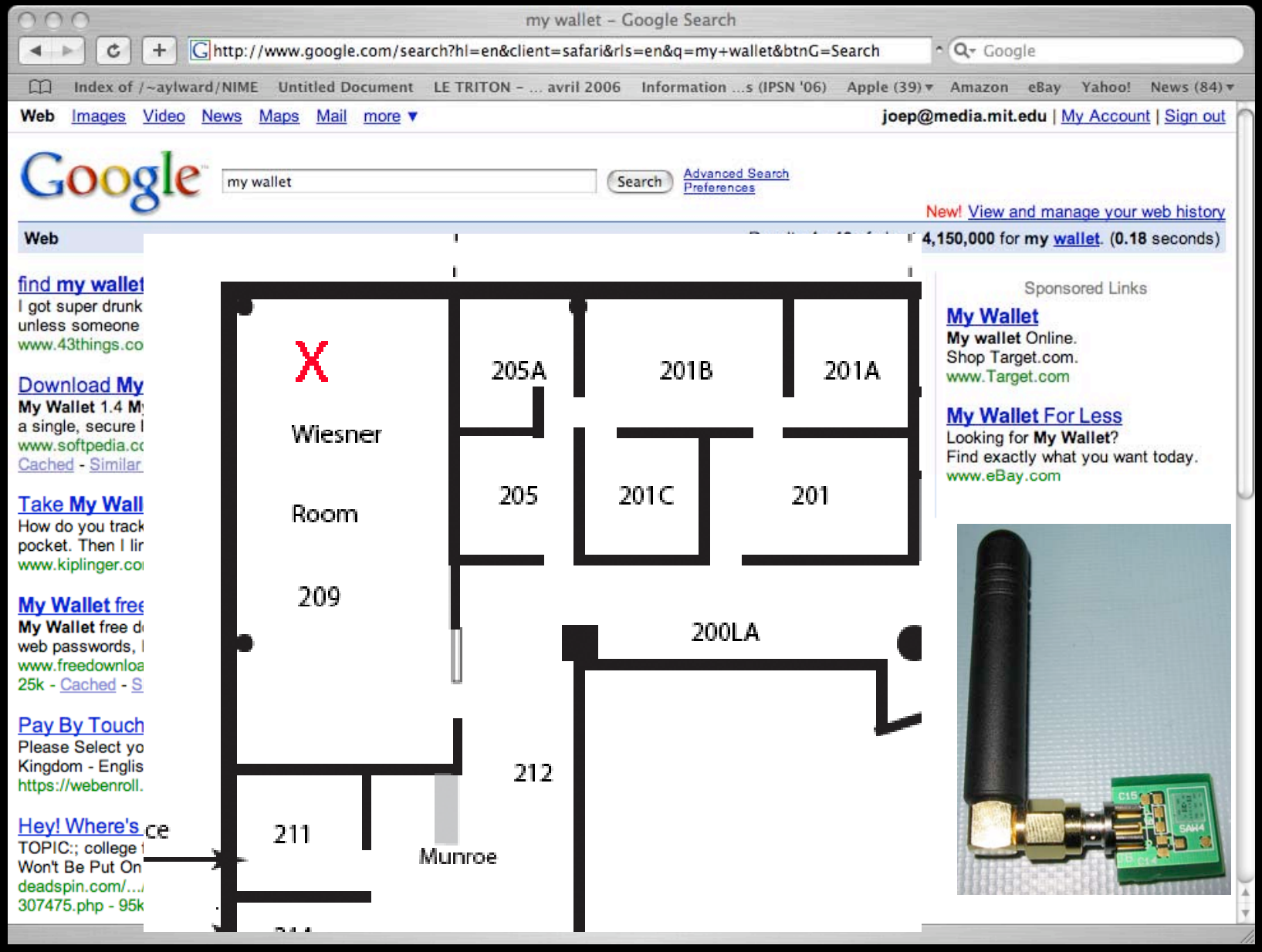


Precise, ultra low cost wide-area tracking of small passive tags for indoor localization
Will revolutionize asset tracking and supply chain operation, search & rescue, etc.

- Utilizing passive RFID surface acoustic wave (SAW) and low-cost radar technology.
- Target short-range (3-100m) applications
  - Expect single-measurement resolution of under 10 cm
- Multipath from reader dies out before tag responds
- 900 MHZ devices coming out of MIT MTL and nano labs
  - Now being characterized and tested

Jason LaPenta

Google for Reality



Power Harvesting Shoes

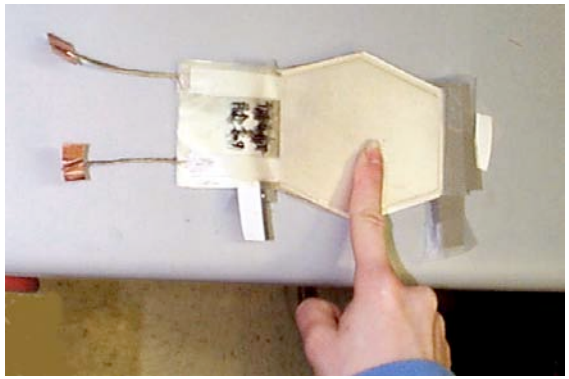
PVDF Stave

Molded into sole

Energy from bend

$P_{peak} \cong 10$ mW

$\langle P \rangle \cong 1$ mW



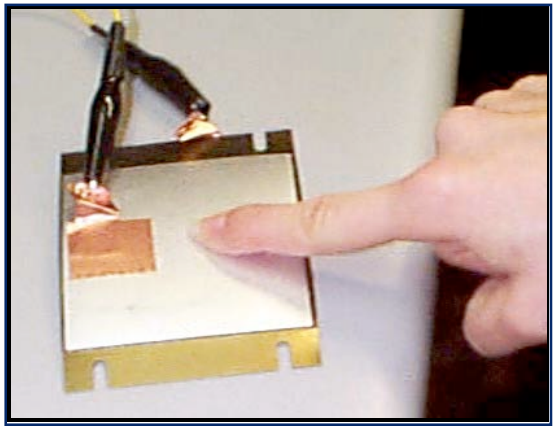
Flex PZT Unimorph

Under insole

Pressed by heel

$P_{peak} \cong 50$ mW

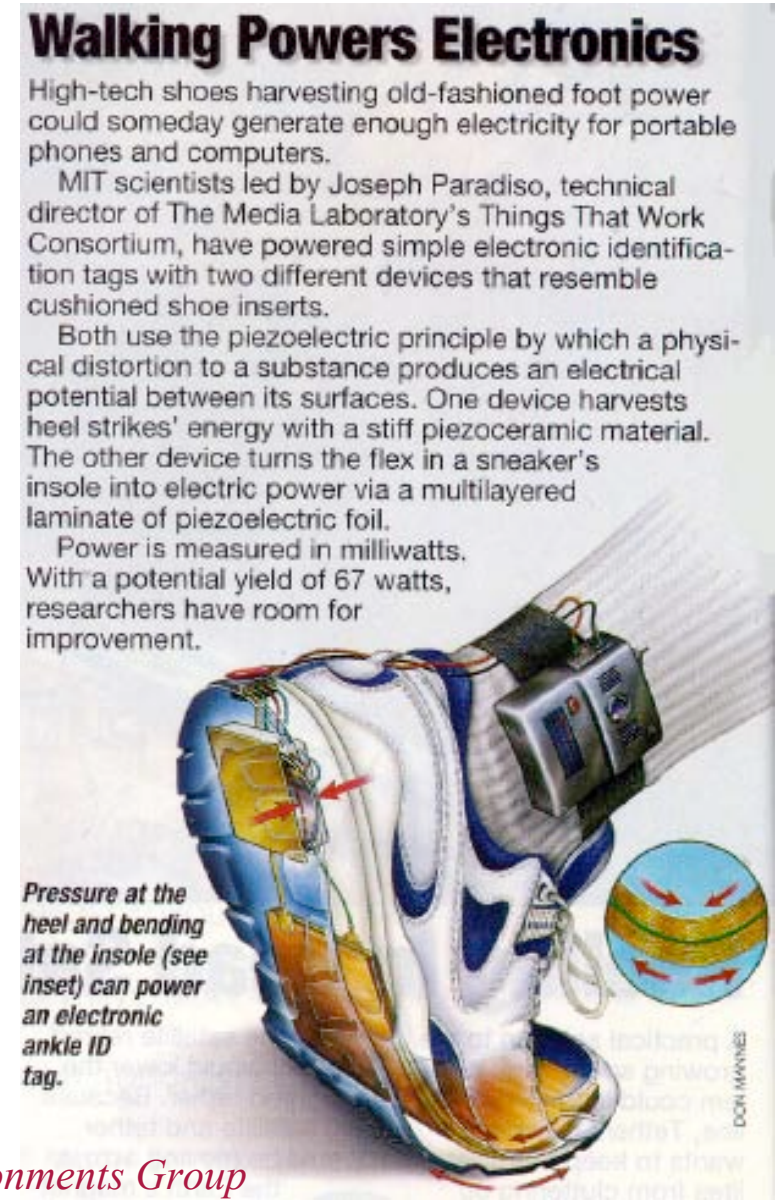
$\langle P \rangle \cong 10$ mW



Raw Power

circa 1% efficient

unnoticable



Walking Powers Electronics

High-tech shoes harvesting old-fashioned foot power could someday generate enough electricity for portable phones and computers.

MIT scientists led by Joseph Paradiso, technical director of The Media Laboratory's Things That Work Consortium, have powered simple electronic identification tags with two different devices that resemble cushioned shoe inserts.

Both use the piezoelectric principle by which a physical distortion to a substance produces an electrical potential between its surfaces. One device harvests heel strikes' energy with a stiff piezoceramic material. The other device turns the flex in a sneaker's insole into electric power via a multilayered laminate of piezoelectric foil.

Power is measured in milliwatts. With a potential yield of 67 watts, researchers have room for improvement.

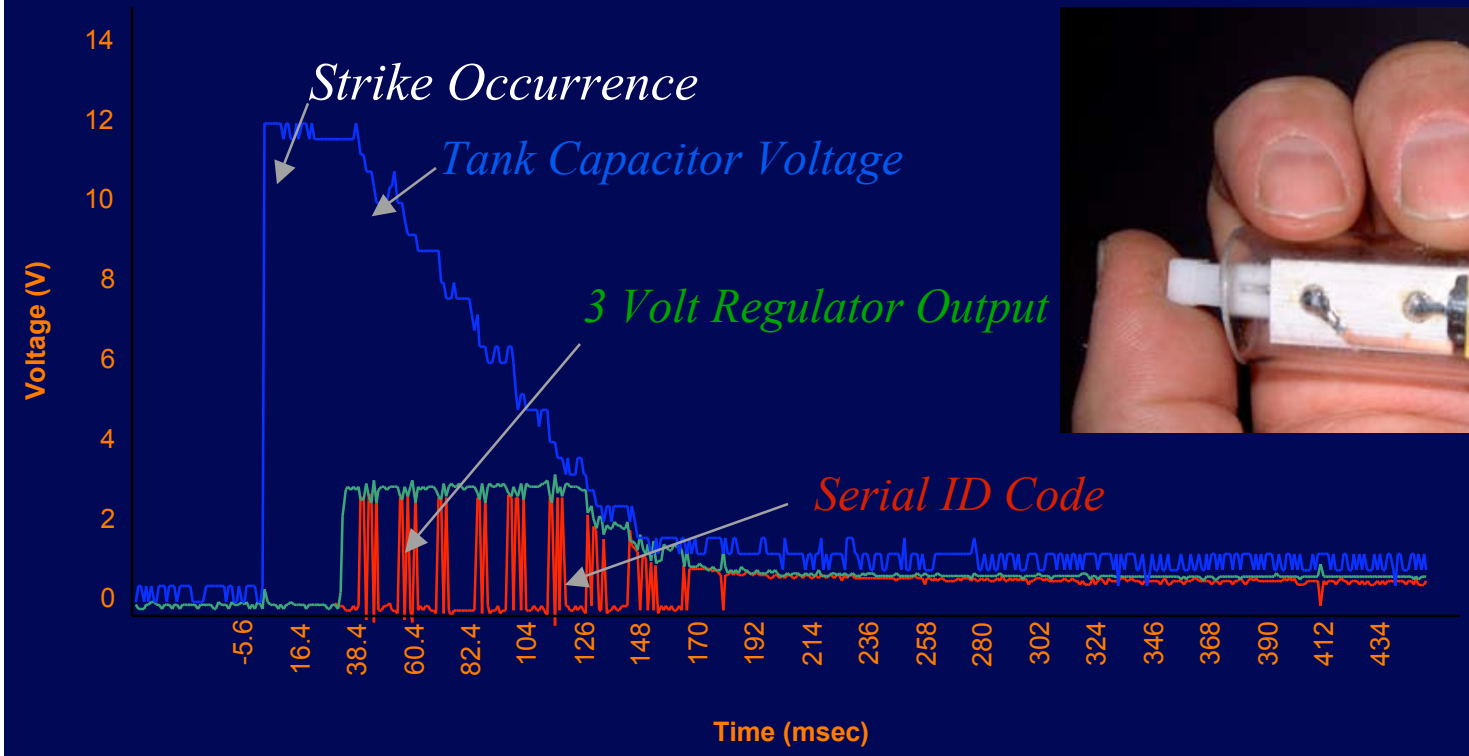
Pressure at the heel and bending at the insole (see inset) can power an electronic ankle ID tag.

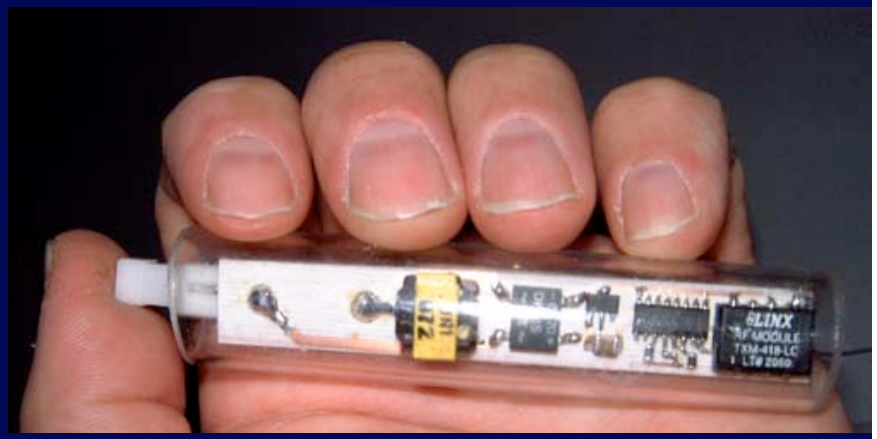
Responsive Environments Group

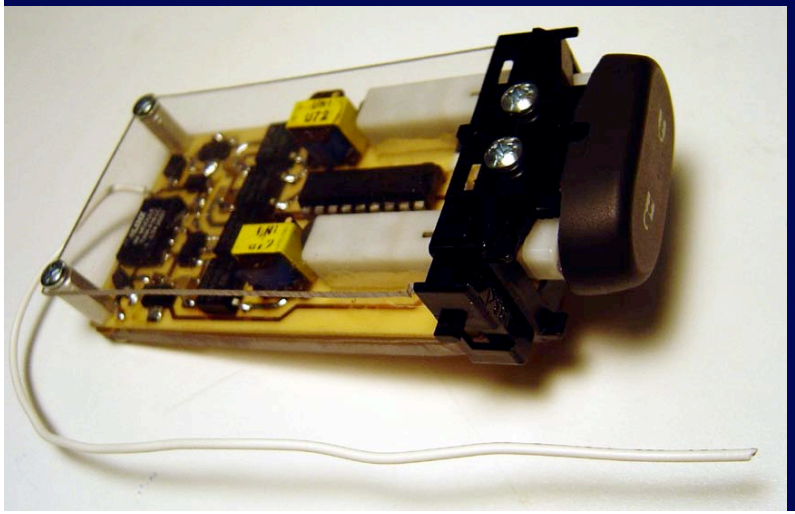
MIT Media Lab

1998 IEEE Wearable Computing Conference

The Self-Powered Wireless Switch







The Self-Powered Switch

Feldmeier & Paradiso

Ubicomp 2001

~1 mJ @ 3V per push

Public Misinformation…

Japan: Producing Electricity from Train Station Ticket Gates

by Michael Graham Richard, Gatineau, Canada on 08. 4.06

SCIENCE & TECHNOLOGY (alternative energy)

EMAIL THIS 2141 diggs digg it -2 poin

MIT duo sees people-powered "Crowd Farm"

Plan would harvest energy of human movement

July 25, 2007

Two graduate students at MIT's School of Architecture and Planning want to harvest the energy of human movement in urban settings, like commuters in a train station or fans at a concert.

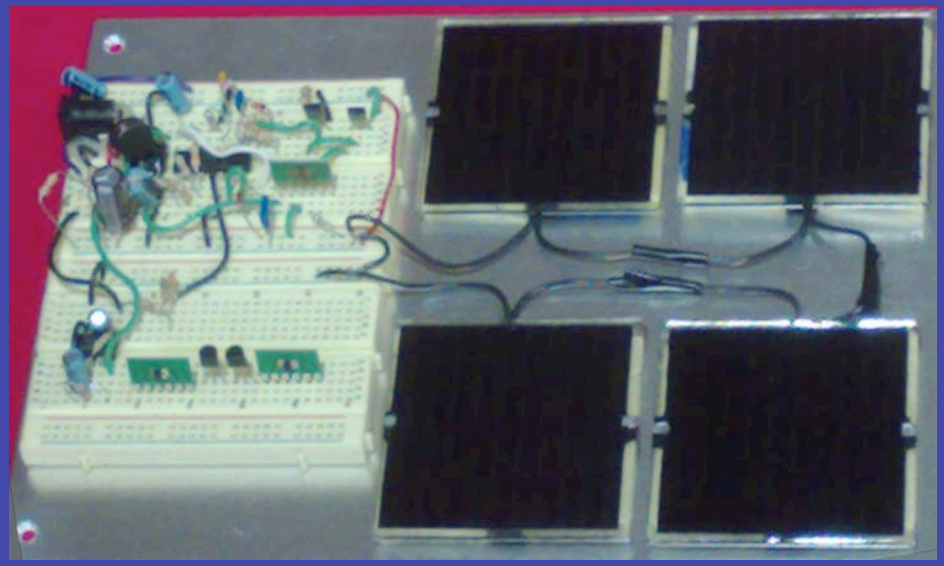
Little treadmills everywhere: Floors that harvest the energy in every step

By Jennifer Cutraro The Boston Globe Published: July 31, 2007

"Human" Energy harvesting will do little for sustainability

It will only be valuable in extending/eliminating batteries in portable devices, wearable sensors, etc.

Sensor networks for energy conservation



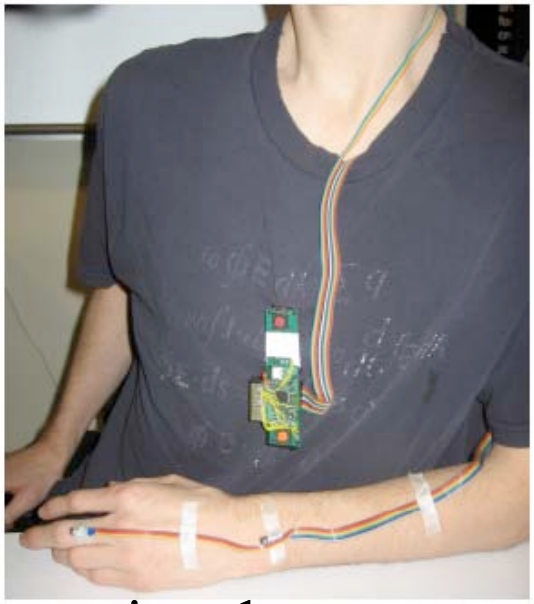
Optimal Solar Cell Charger

- Dynamically loads solar array at its optimal impedance for maximum power transfer
  - Essential for varying light
- Circuit requires under 10 μA
- Regulator is 87% efficient

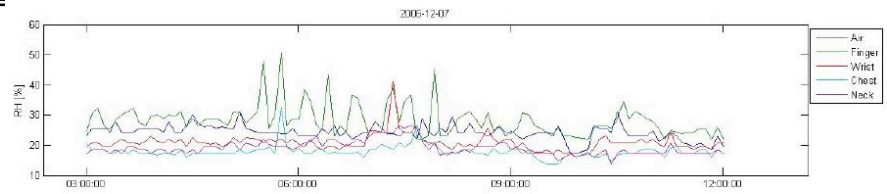
- Leveraging dense sensor networks for optimal urban energy management
  - 40% of US energy is spent in buildings
  - Pervasive sensor/actuator network seeks to minimize this
    - Wearable sensors to ascertain personal comfort
    - Dense in-situ sensor net for determining heat, airflow
  - Sensors must be long-lived
    - Use micropower techniques, harvest energy where possible

Mark Feldmeier

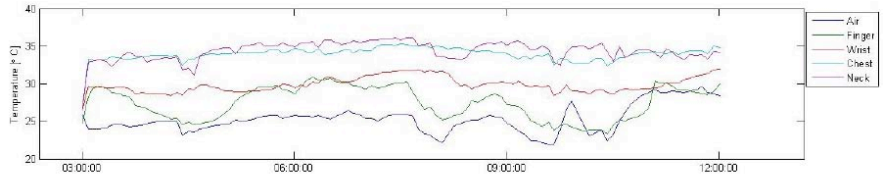
Sensor networks for energy conservation



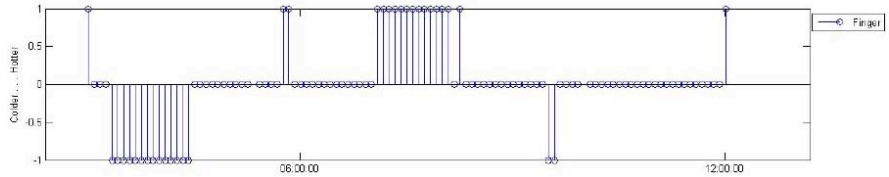
Humidity



Temp.

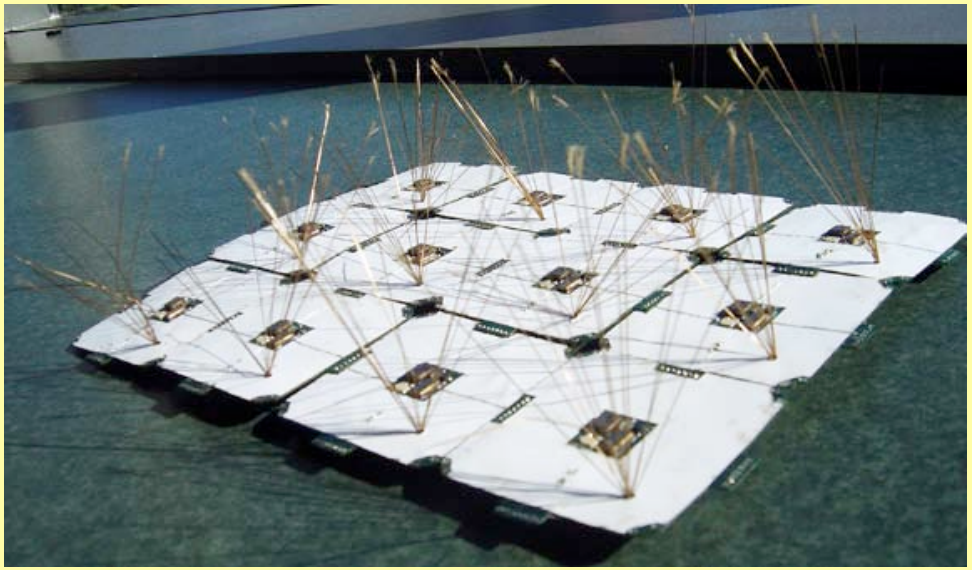


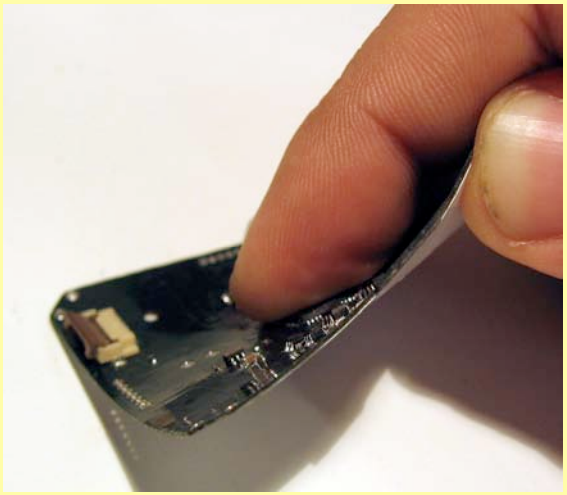
Comfort

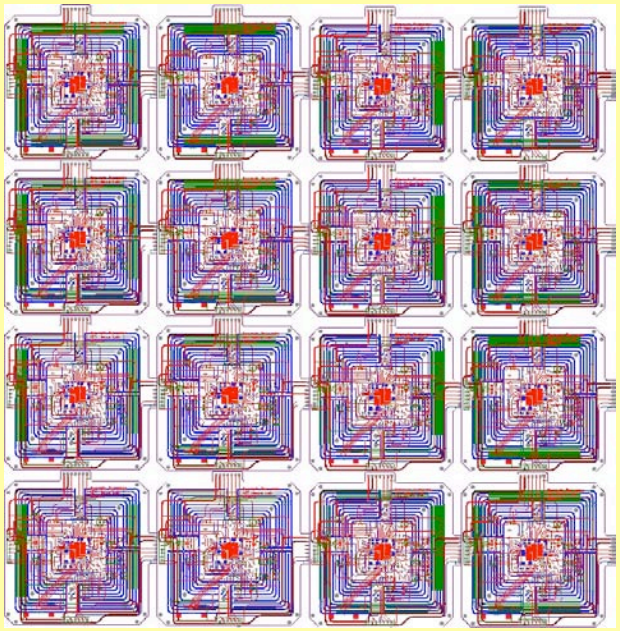


- Leveraging dense sensor networks for optimal energy management
  - 40% of US energy is spent in buildings
  - Pervasive sensor/actuator network can work to minimize this
    - Optimize heating, AC, lighting for *Person* not room
    - Anticipating behavior & build usage models over time
  - My RA, Mark Feldmeier is now a MIT Martin Energy Fellow
    - Exploring ways to sense "comfort" to optimize distributed utility control

Sensor Net Array, Kapton Embedded (SNAKE) Skin





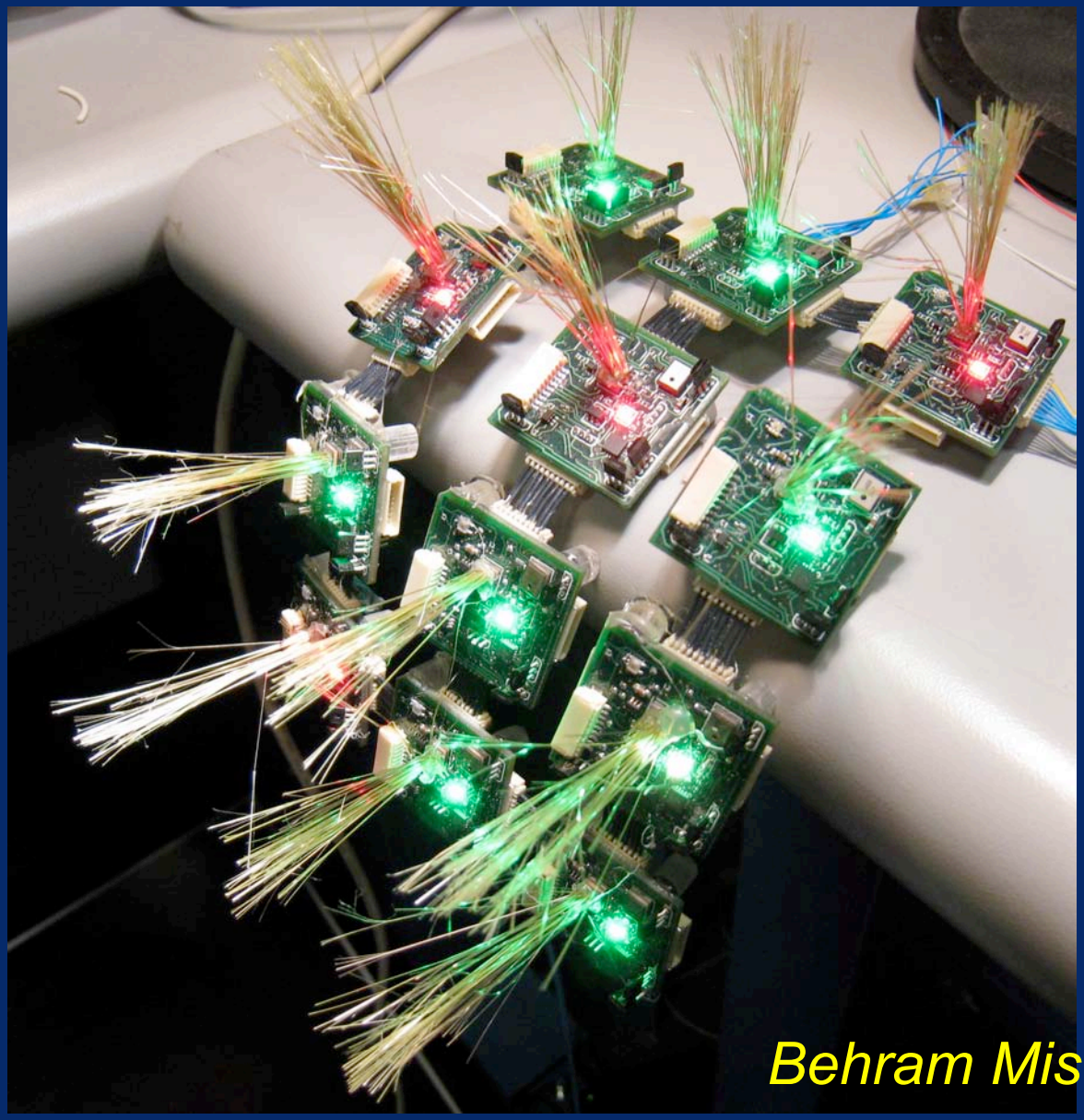


- **All on flex**
- Embedded strain gauges
- Covered by a layer of QTC pressure-measuring material
- Piezo whiskers
- Optical sensors, microphones, temperature
- Peer-Peer network
- High-Speed I^2C backbone
- ***Scalable!***

Behram Mistree develops new "Chainmail" system

ChainMail - Scalable Sensate Surface

- Rigid nodes, flex connects
- Multimodal:
  - Light
  - Sound
  - Whiskers
  - Pressure
  - Temperature
  - Bend
- Videos on YouTube



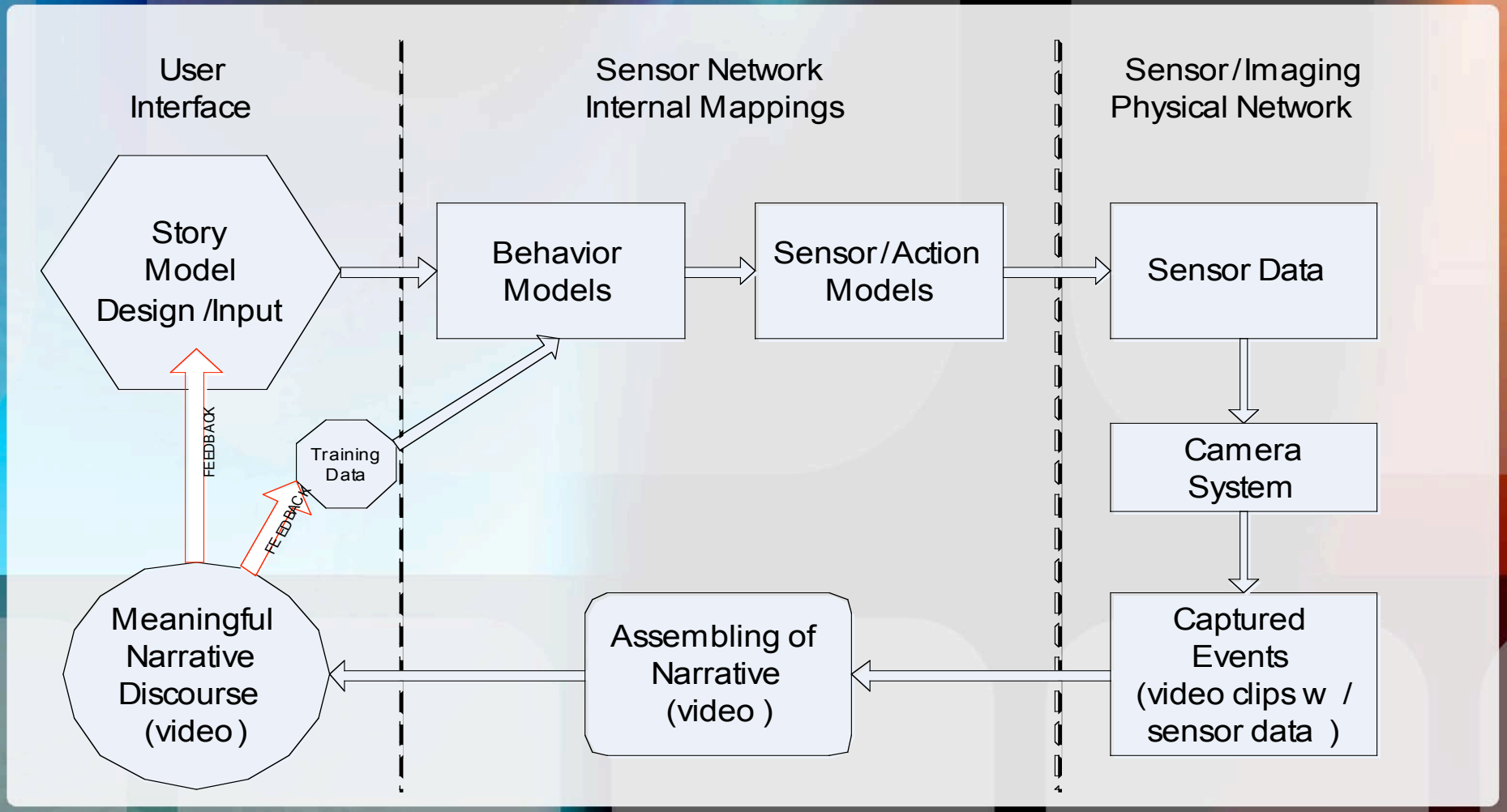
SPINNER

Sensate Pervasive Imaging Network for Narrative Extraction from Reality

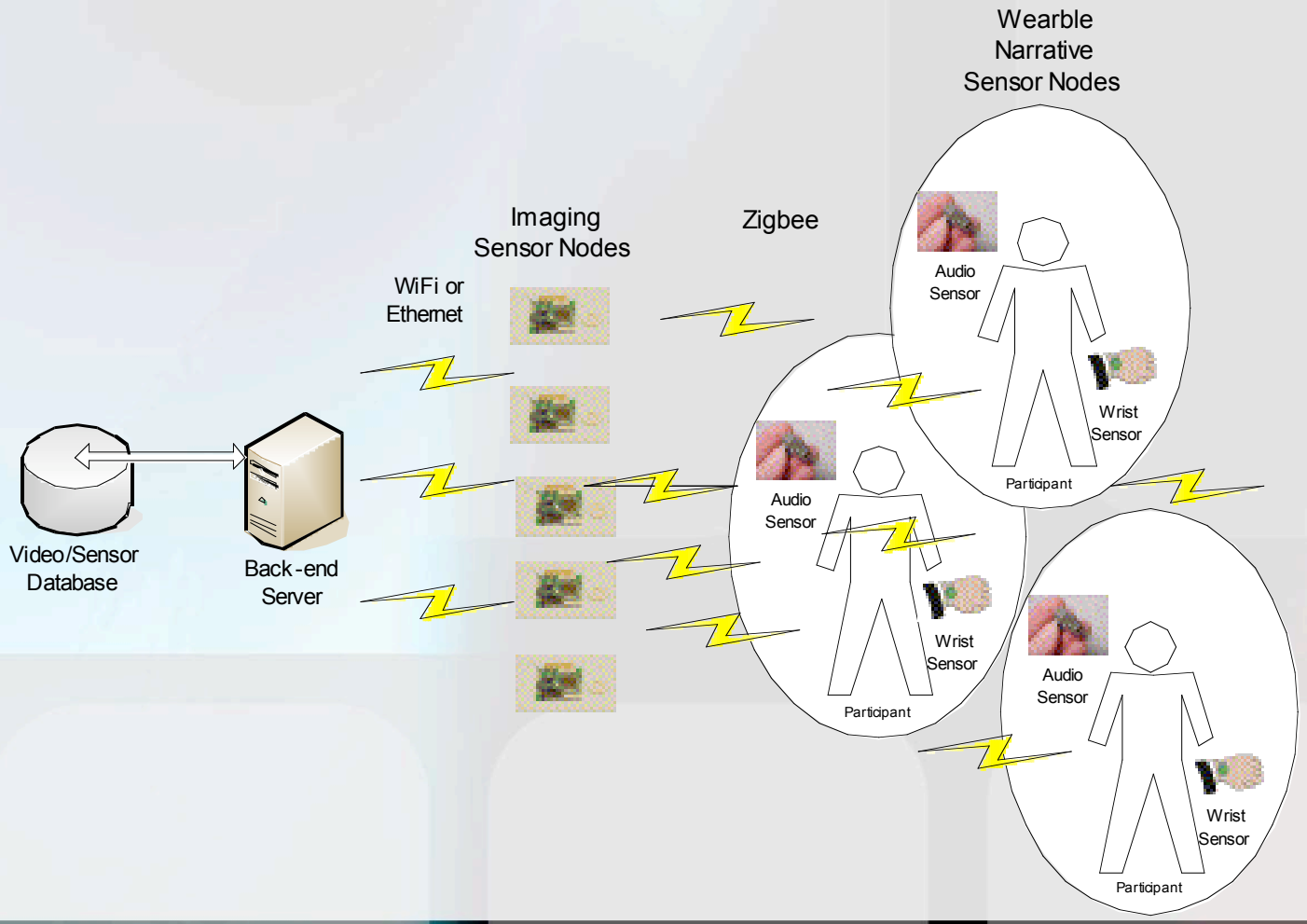
- **Unites wearable human sensing with video capture**
- **Maps sensor data to high-level concepts for creation of meaningful video**
  - **Investigates how humans perform this mapping (i.e., how they create stories and narrative)**
- **Use of wearable sensing allows access to subject/data channels far beyond what can be achieved with standard image pixel processing**

Mat Laibowitz - PhD in Progress

Overall System Diagram



Sensor Network Devices



Device Overview

Spinner devices include

- **Wrist mounted sensor → gesture- and bio- sensing**
- **Collar mounted sensor → social signaling and audio analysis/recording**
- **Camera system**

Wearable devices functions and capabilities

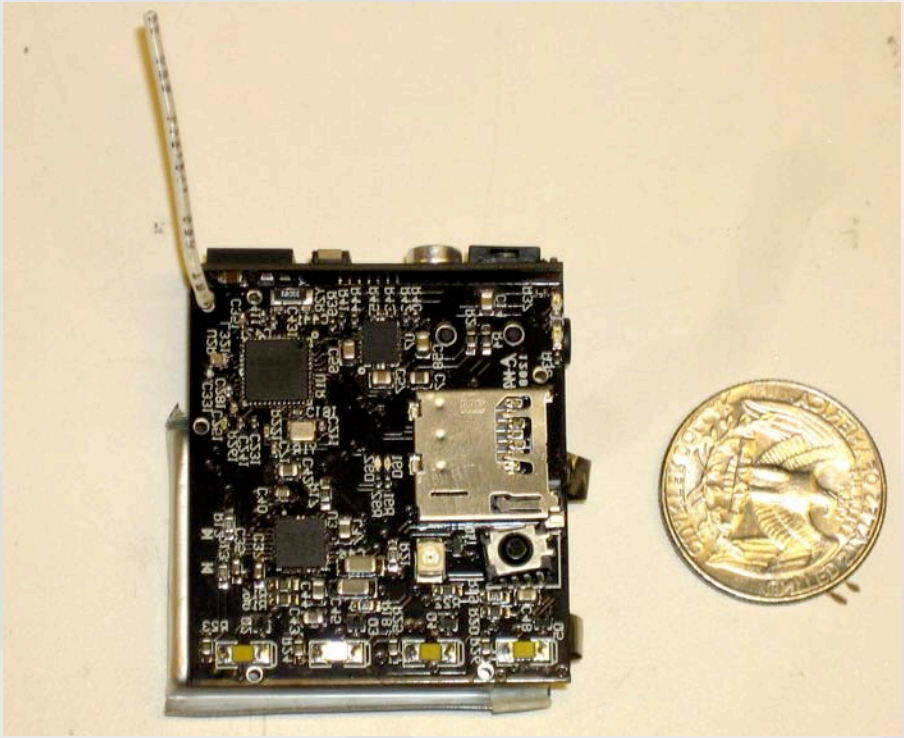
- **Camera system control**
- **Sensor data capture for video footage cataloguing**
- **Multimedia browsing**

All devices

- **support mesh networking**
- **Are equipped with a location/orientation system**
- **Have dedicated DSP processing for real-time classification of event data**

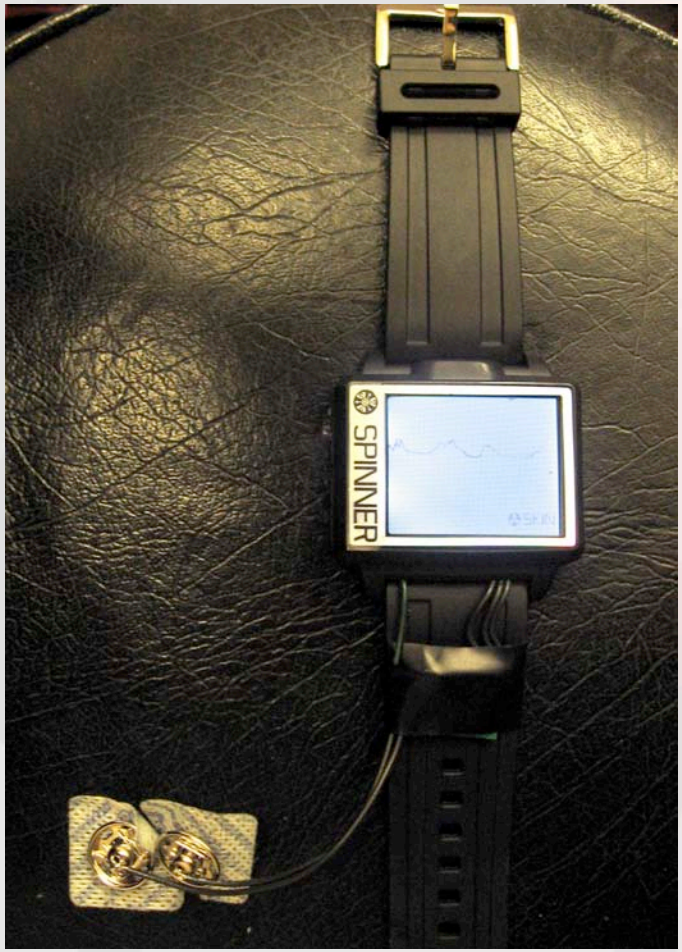
Device Details – Spinner Social Sensor

- Wearable on collar or as pin/badge
- Audio system with DSP for analytics and CD quality recording
- Compass for orientation
- 3-axis Accelerometer
- IR communication and line of sight detection/proximity
- Location engine
- Captures social signal and group dynamics



Device Details – Spinner Wrist Sensor

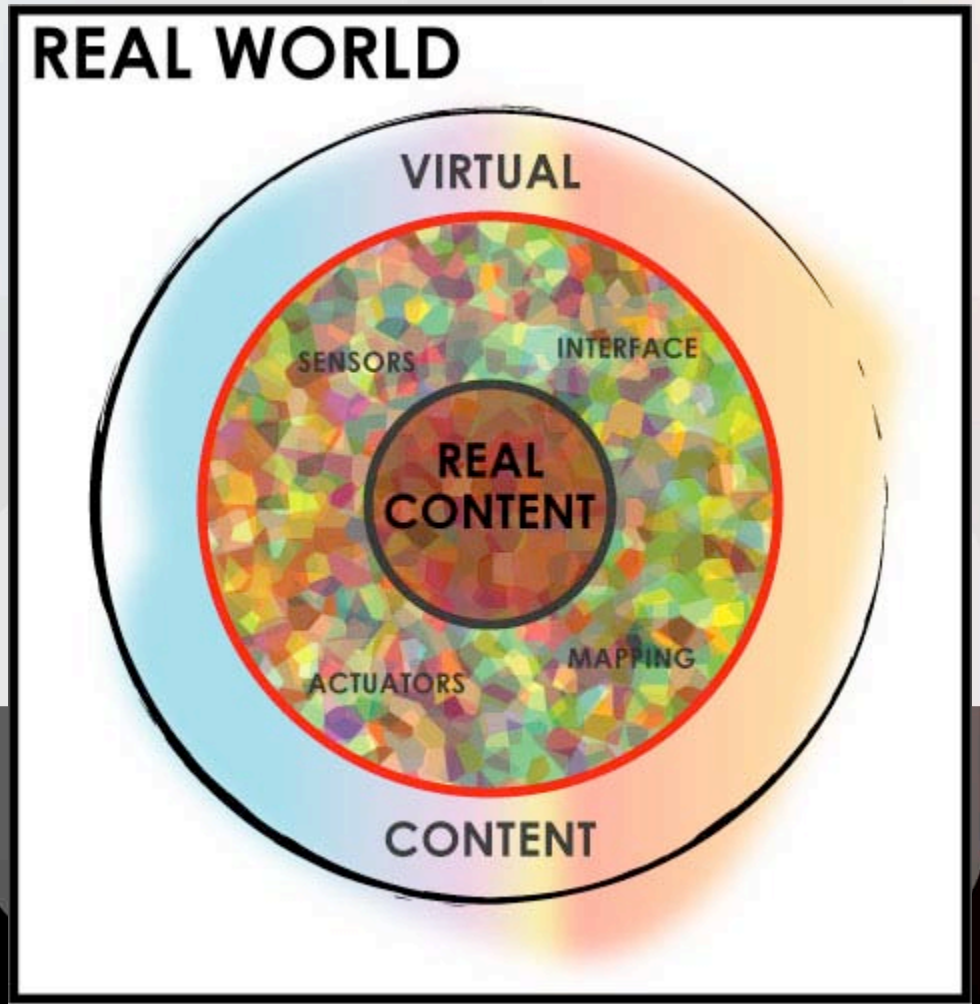
- Wrist worn device
- 3-axis Accelerometer
- Galvanic Skin Response (GSR) Sensor
- Location engine
- UI for interacting with network
- Stores and plays videos, providing ownership of video to end user
- Captures gesture and indications of affective state



Expanded Reality

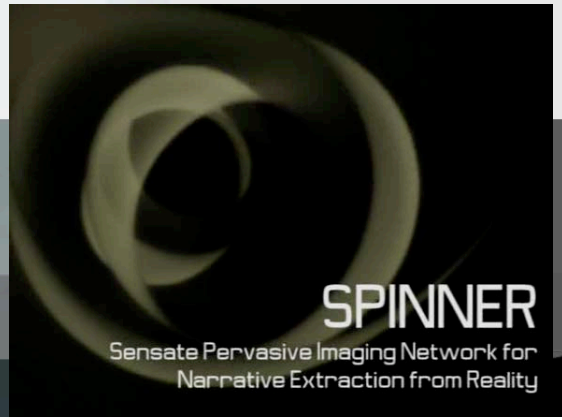
Not just a pipe

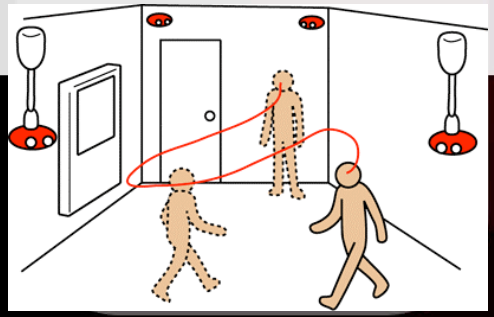
Technology removes boundaries from Real World to allow new content



Contributions

- A novel methodology for humans and machines to filter, organize, and understand large streams of video data
- A new form of entertainment and communication that allows you to create media with your social and personal behavior
- Toolkit for documentation of daily life that may lead to new and unexpected insights about random events
- These capabilities could lead to a new form of online community





The UberBadge

Mediate Group Interaction & Behavior Modeling

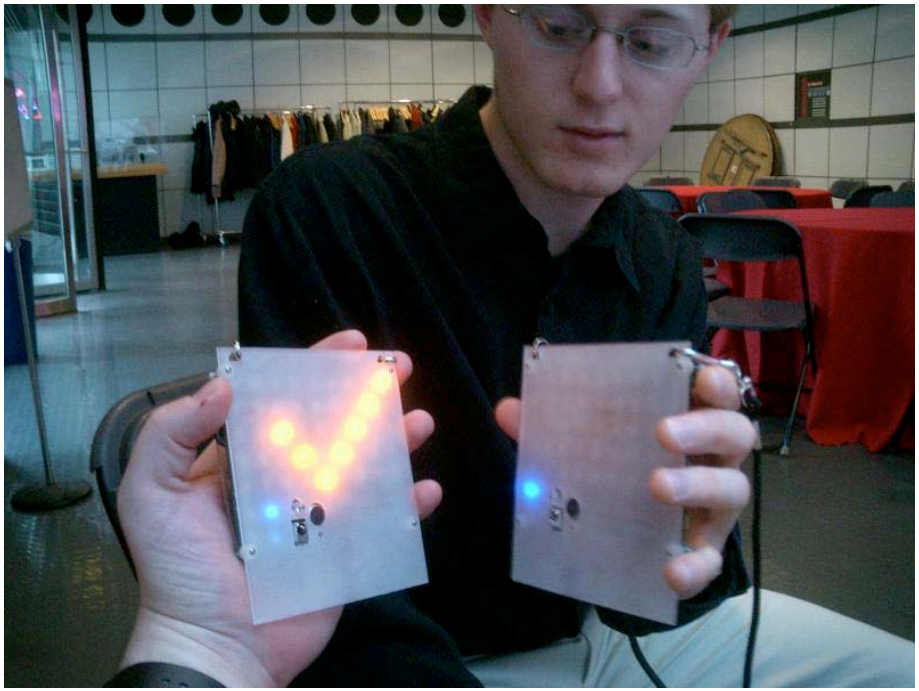
Mat Laibowitz
Responsive Environments Group

- 16-bit MCU w/ 64kb flash, 2k RAM, and GCC support
- 45-LED Display intended to be read at distance
- IR communications
- RF communications with second processor to handle MAC
- Up to 256MB of data memory
- Audio input and output with onboard microphone
- Onboard accelerometer
- Pager motor for vibratory feedback
- Multiple ports for expansion
  - Accepts Sensor Stack Modules
- Optional LCD display

Broadcast Messages

Information on your badge is mainly for other people, not you!

Exchange Business Card, Bookmark Demos



Parasitic Mobility

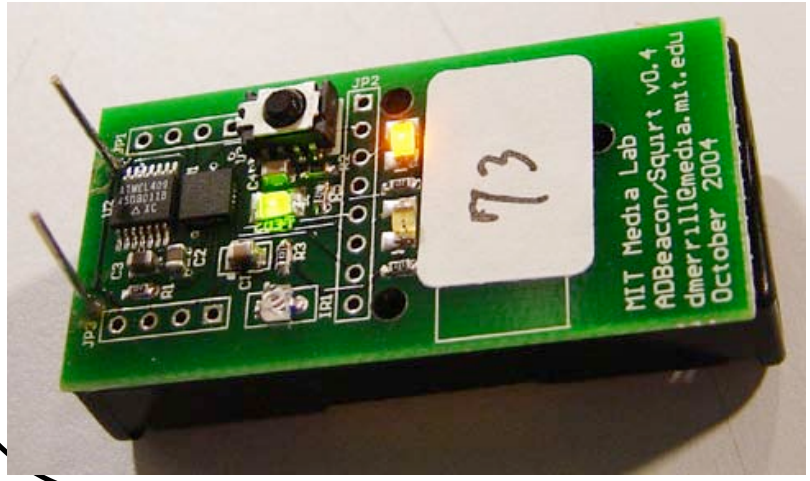
Responsive Environments Group

To request more info on this demo:

Aim badge at the hot-spot
Do you see a green Light?

Press either button on the badge.

Orange and Red Light?
The request is noted.



The UbER-Badge Demo Hot-Spot

Bookmark data posted on website

Insite *Sponsors Collaboration and Feedback*

JosephBranc

Edit Attach Printable More

Joseph Branc

Sponsors you interacted with:

- Michael Caine
- Frank Graziano
- Kiyoshi Kunii
- Jay Lee
- Akinori Matsuo
- Paul Moody
- Joel Stanfield
- Makoto Takashima
- Saeko Tezuka
- Funio Ueno
- Steve Whittaker
- Muneharu Yoshida
- Peter Wakim

Projects you have expressed interest in tracking:

- **Treehouse Studio**
- **Moving Portraits**
- **Attentive Devices**
- **Object Awareness**
- **Plunge n' Play**
- **SandScape**
- **The FindIT Flashlight**
- **Audiopad**

Note: You can make private or company-specific annotations to the projects by editing this page. If you'd like to make public annotations to the projects, please enter the discussion on the project page in pedia.media.

Bookmark data posted on website

Insite *Sponsors Collaboration and Feedback*

StephanGuttowski

Edit Attach Printable More

Stephan Guttowski

Sponsors you interacted with:

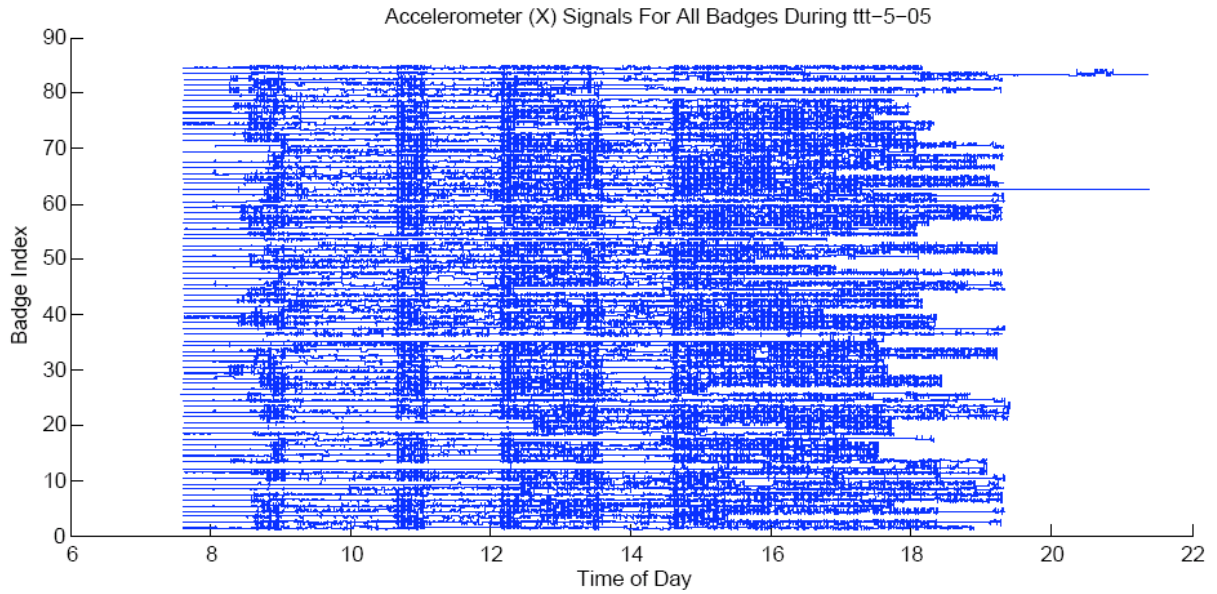
- Christine Kallmayer (Fraunhofer IZM)
- Torsten Linz (Fraunhofer IZM)

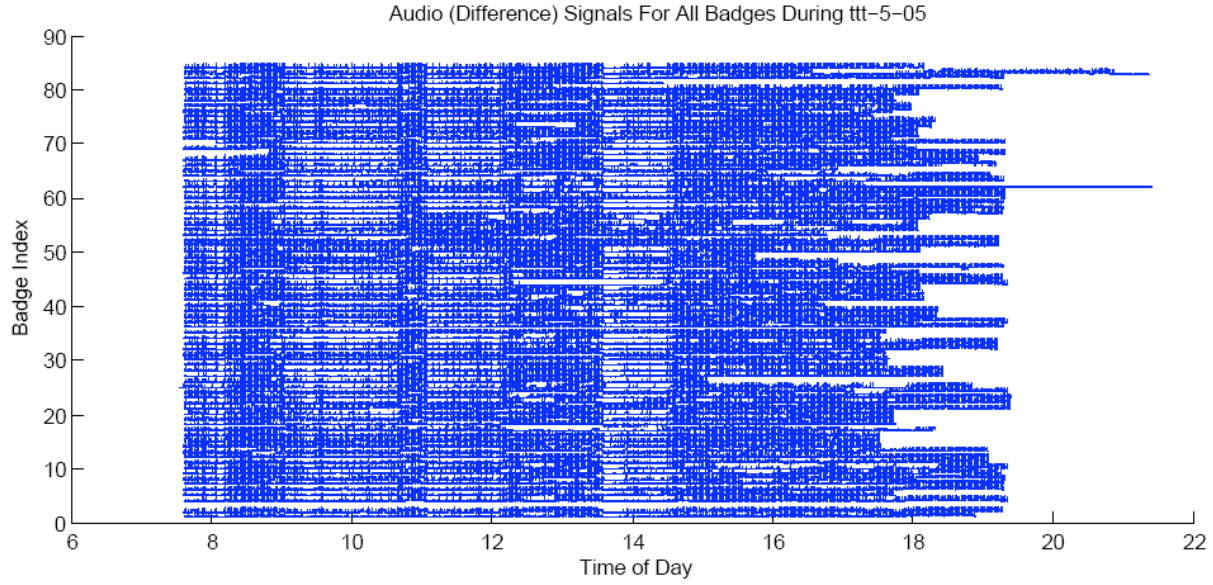
Projects you have expressed interest in tracking:

- **Affective-Cognitive Learning and Decision-Making** Affective Computing (**http://www.media.mit.edu/~hiahn**)
- **Conversation Table, Stealing Table** Computing Culture (lira\@mit.edu)
- **Negotiation Dynamics** Human Dynamics (**http://groupmedia.mit.edu**)
- **How to Make Almost Anything, Almost Anywhere** Physics and Media Group (**http://fab.cba.mit.edu**)
- **Tangible BPA** Tangible Media (**http://tangible.media.mit.edu/projects/tbpa/**)

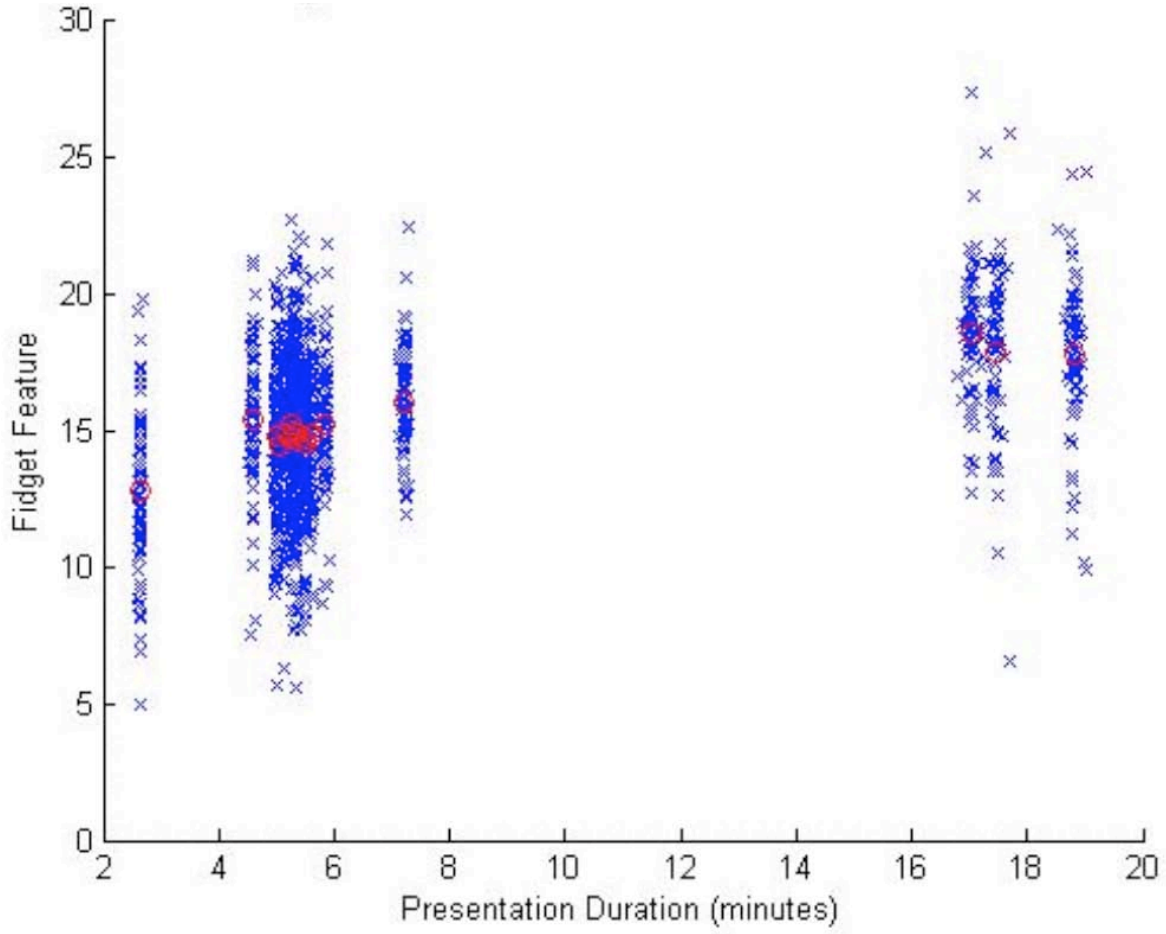
Note: You can make private or company-specific annotations to the projects by editing this page. If you'd like to make public annotations to the projects, please enter the discussion on the project page in pedia.media. Badge data you may previously have had on this page can be viewed in the page history below.

Badge Accelerometer Data





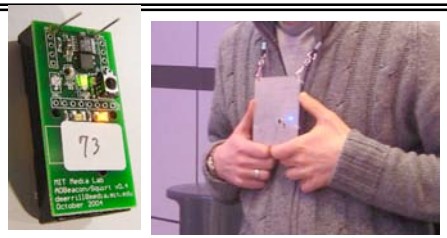
Auditorium Fidgeting



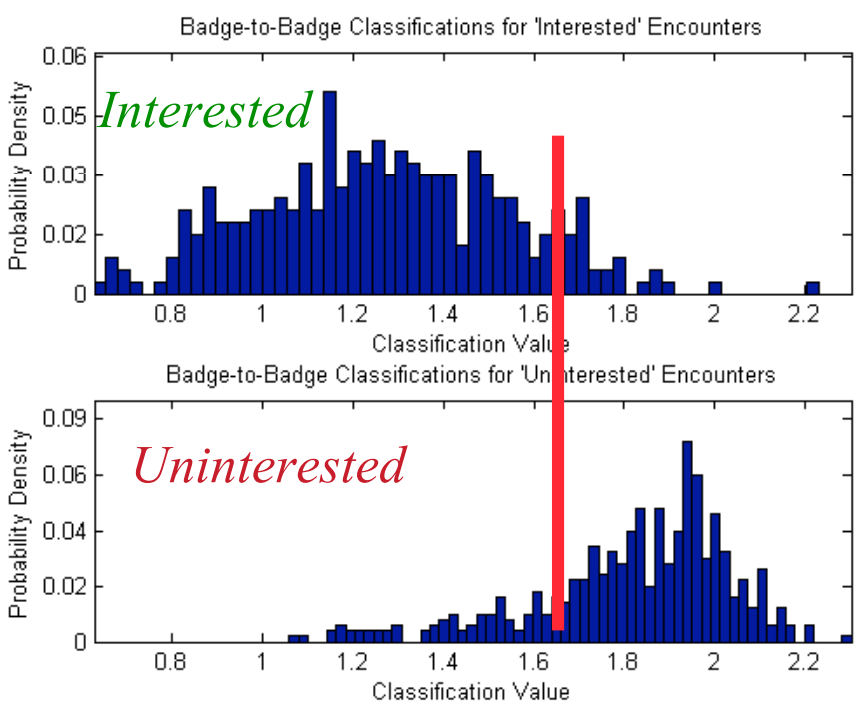
- Medium-good correlation with length of talk
- "Resets" with every presentation

Interest Meter & Group Dynamics

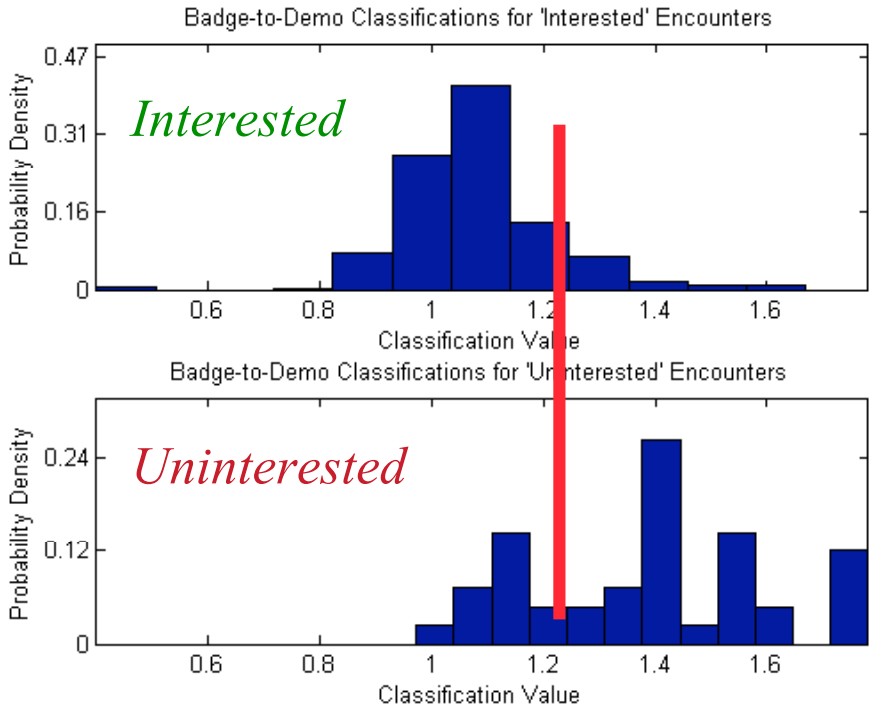
80% Accuracy



Badge-Badge



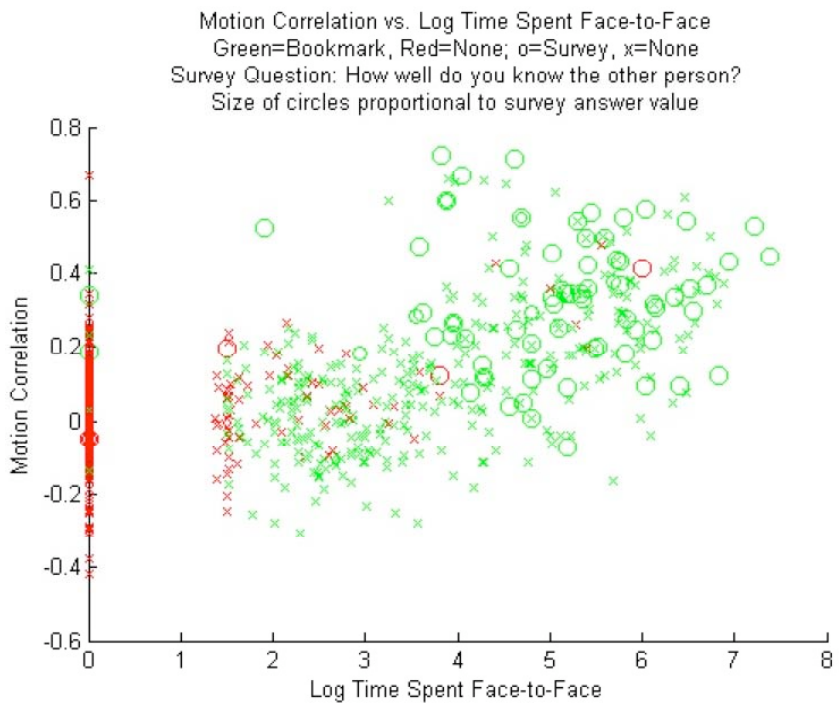
Badge-Demo

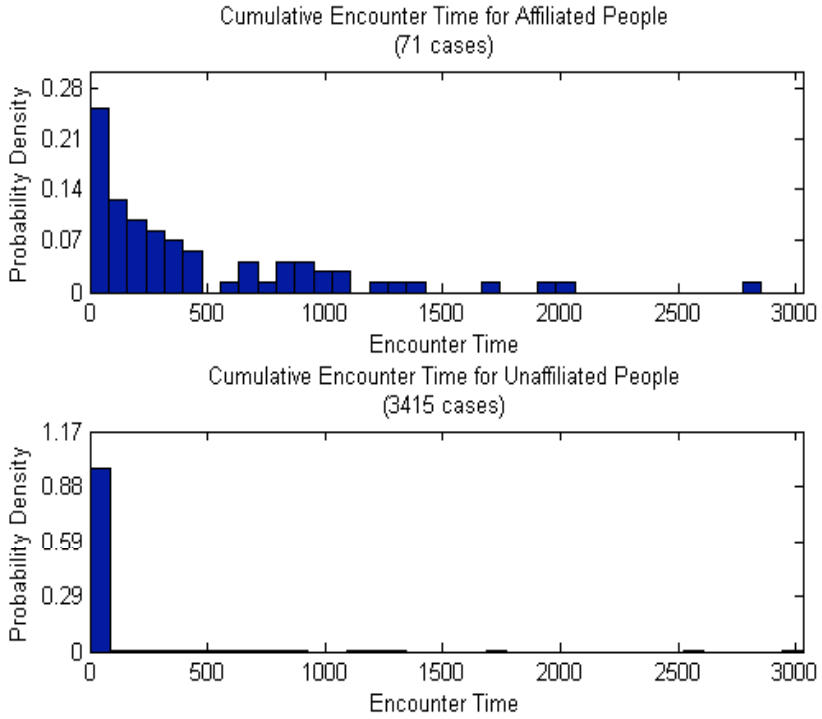


Classification Value = f (voice, motion, face-face time…)

Collaboration with Human Dynamics Group

Affiliated Wearers





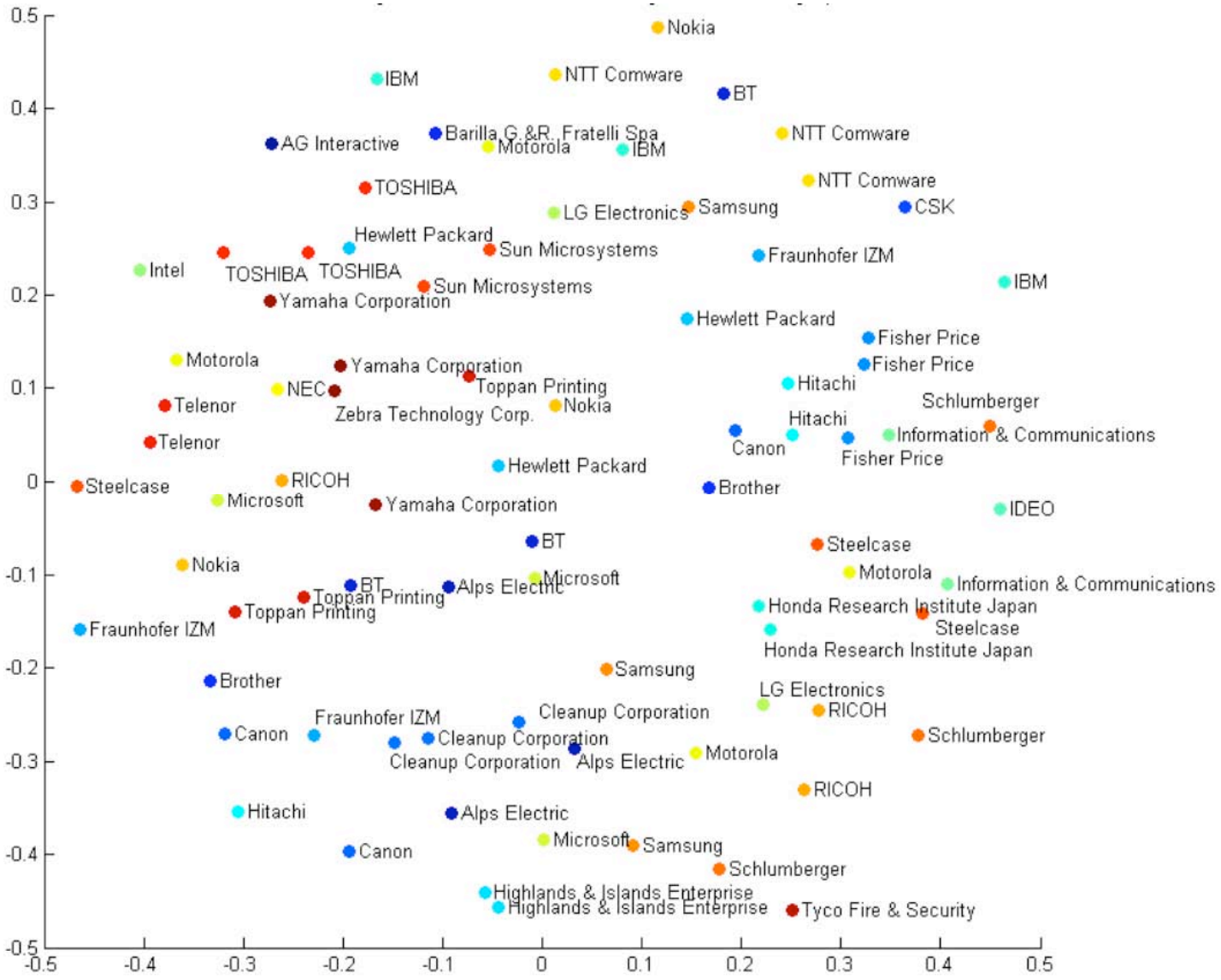
Correlated Motion (accels)

Face-Face Time (IR)

Affiliated people tend to spend more time face-face and *move together!*

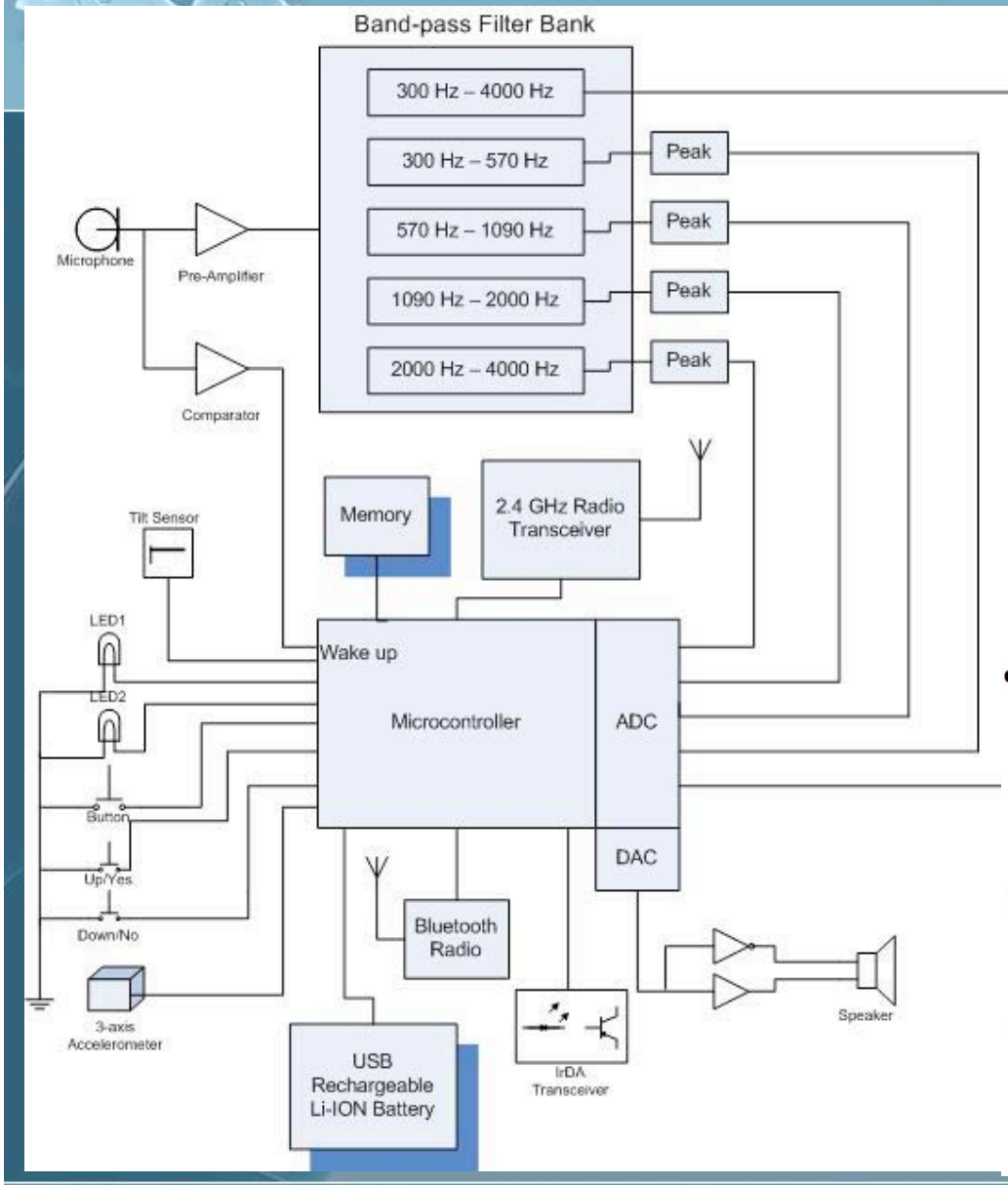
Accuracy of inferred affiliation: 93%

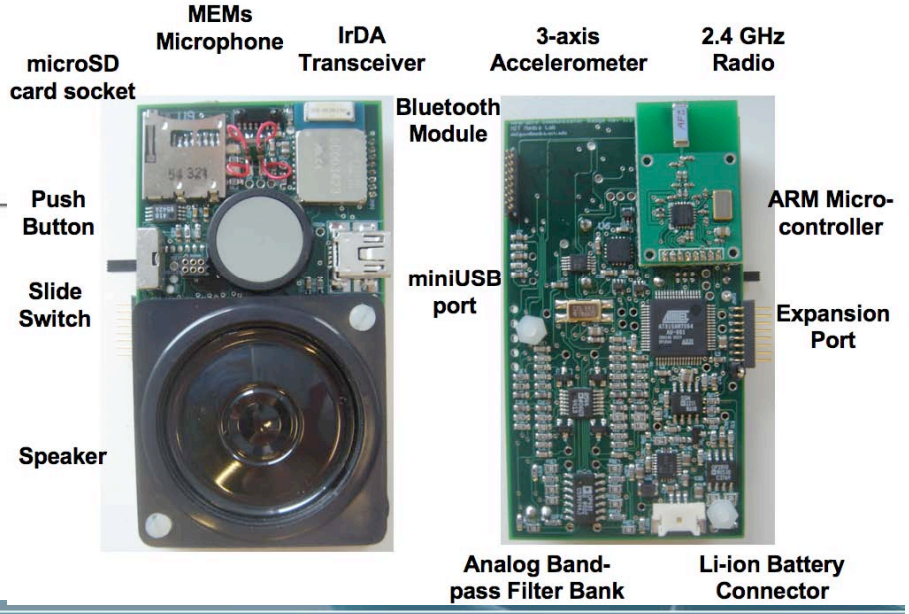
Affiliated Wearers from Energy Only



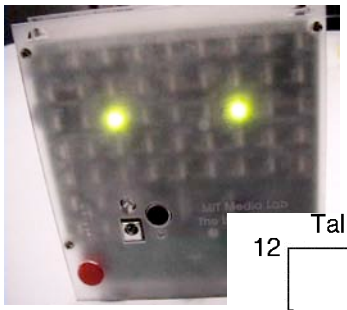
Smart pendants to Amulets

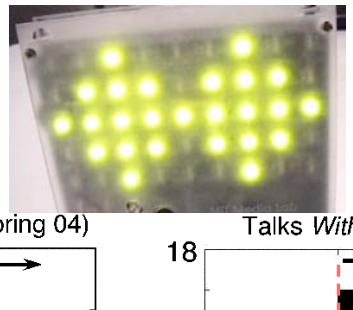
Collaboration with Hitachi CRL

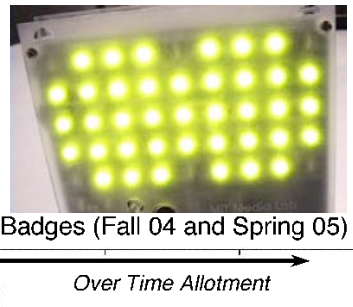




Timekeeping for Talks

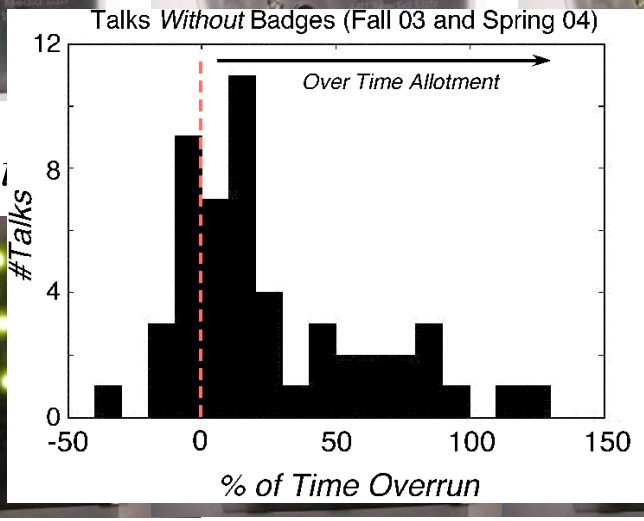


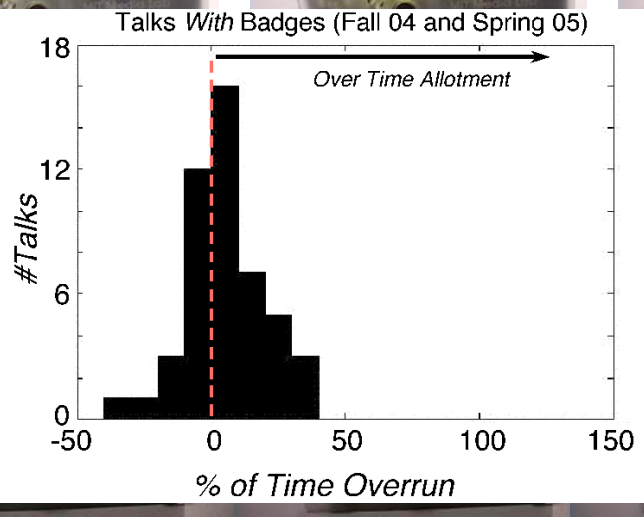




T – 3 mi

T – 30 sec





Out of time!!

- 24 talks in the morning (research updates)
- 5 Minute time limit on each!
- Audience badges flashed time queues
- We didn't run over (first time ever…)!!

Conclusions

- Sensing, computation, and communication become tightly integrated and commonly embedded
- Low power and energy scavenging enable active nodes to be embedded and "forgotten"
- The Ubicomp infrastructure permiates our cities, our dwellings, our objects, our clothing, and eventually our bodies
  - Pervasive-Wearable-Implantable
- The 5 human senses locked into our body are augmented by interfaces into ubiquitous sensor network data
  - Marshall McLuhan for real
  - Interface devices now - implantables some day
  - Omniscience…
- This infrastructure mediates everything
  - Collaboration, business, social interaction, resource use…
  - Context engines filter, represent, and manifest information
    - Google for reality
- Brave New World
  - Privacy, security, promises vs. perils…