MODULE

Applications

PROFESSIONAL EDUCATION

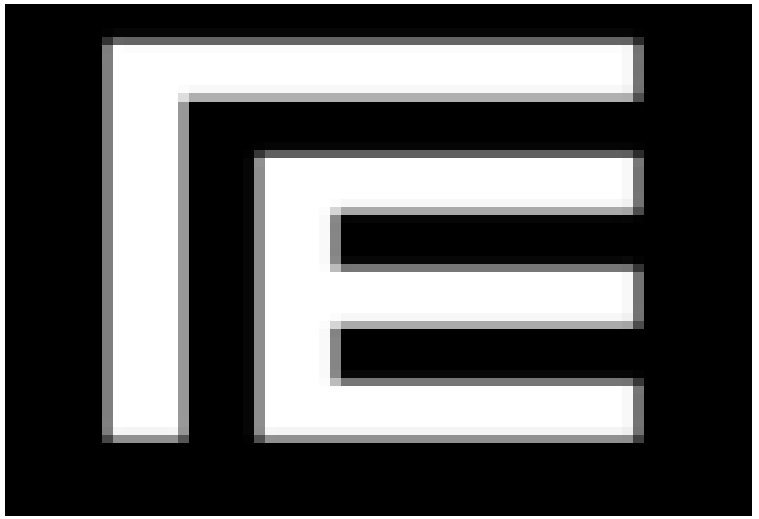
CSAIL
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

Beyond IoT - Ubiquitous Sensing and Human Experience

Joe Paradiso

Responsive Environments Group, MIT Media Lab
Smart Cities

Computer Science and Artificial Intelligence Laboratory (CSAIL)
Massachusetts Institute of Technology



RESENV TEAM (SPRING '15)

TOPICS

Ubiquitous Computing

Emerging data standards for IoT & sensors

Immersive visualization of diverse IoT/sensor data

IoT & the Built Environment

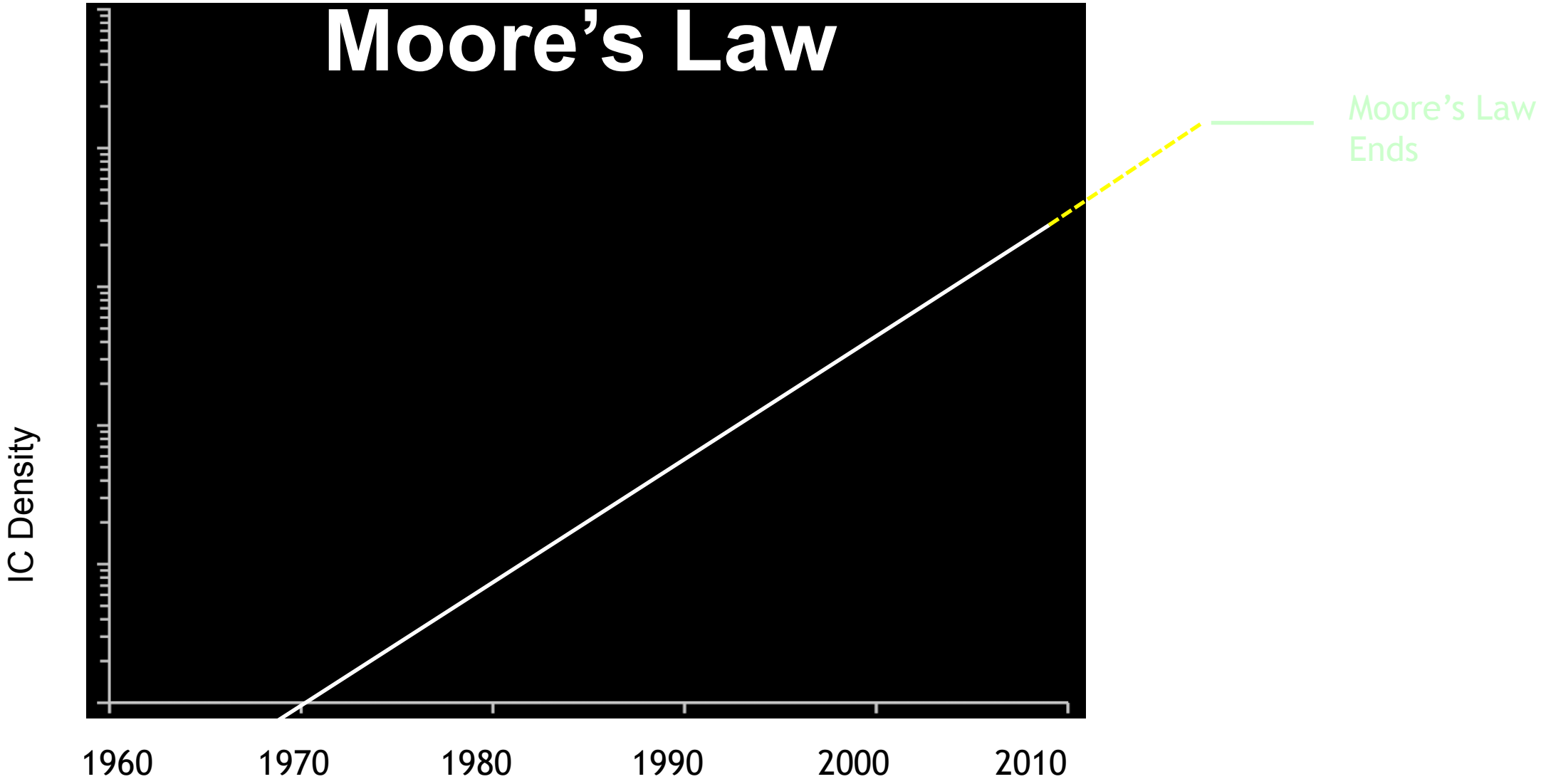
Wearables & IoT on-body

Smart Tools under IoT

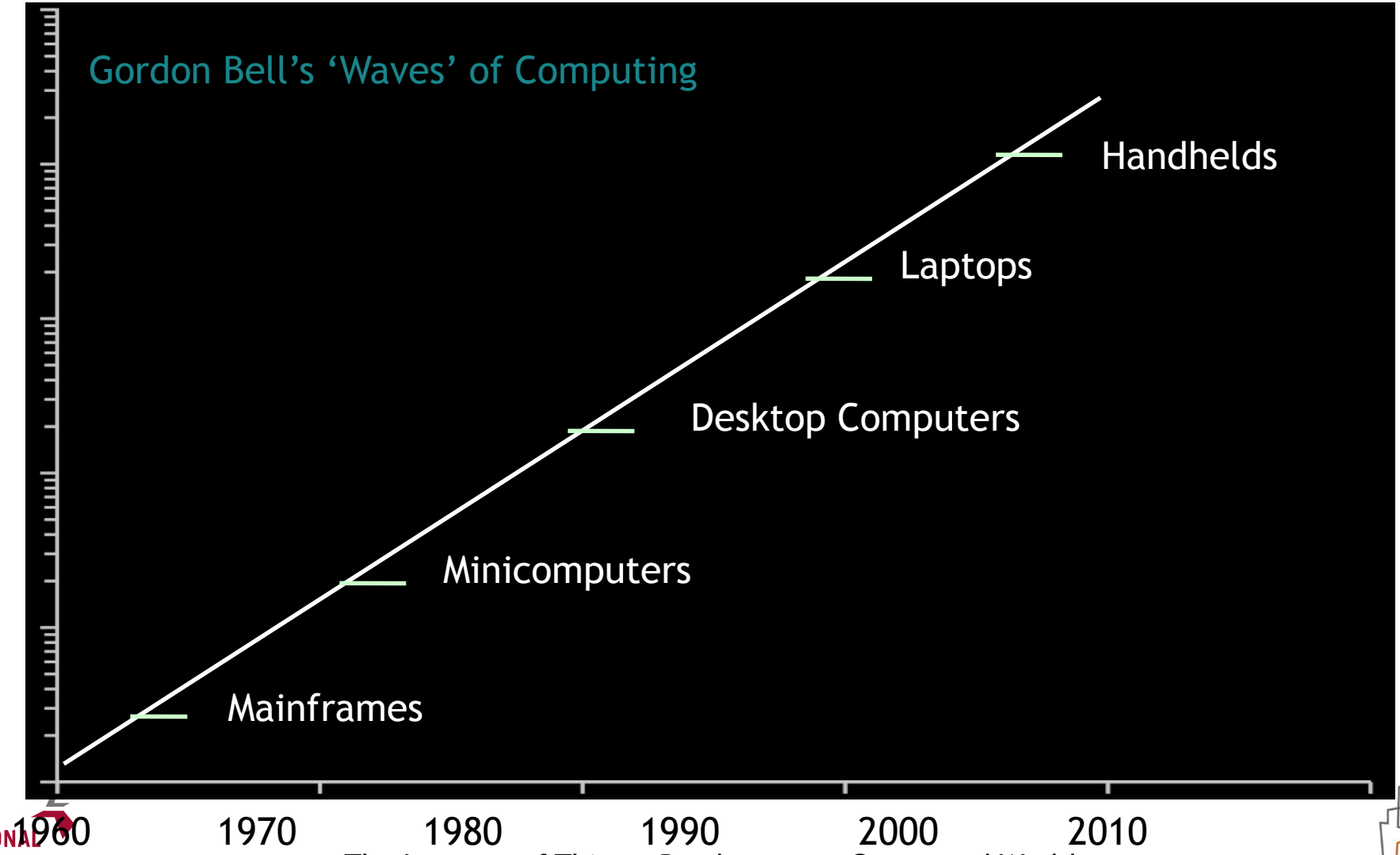
Sensate materials

Pointers to Resources (also citations in listed papers)

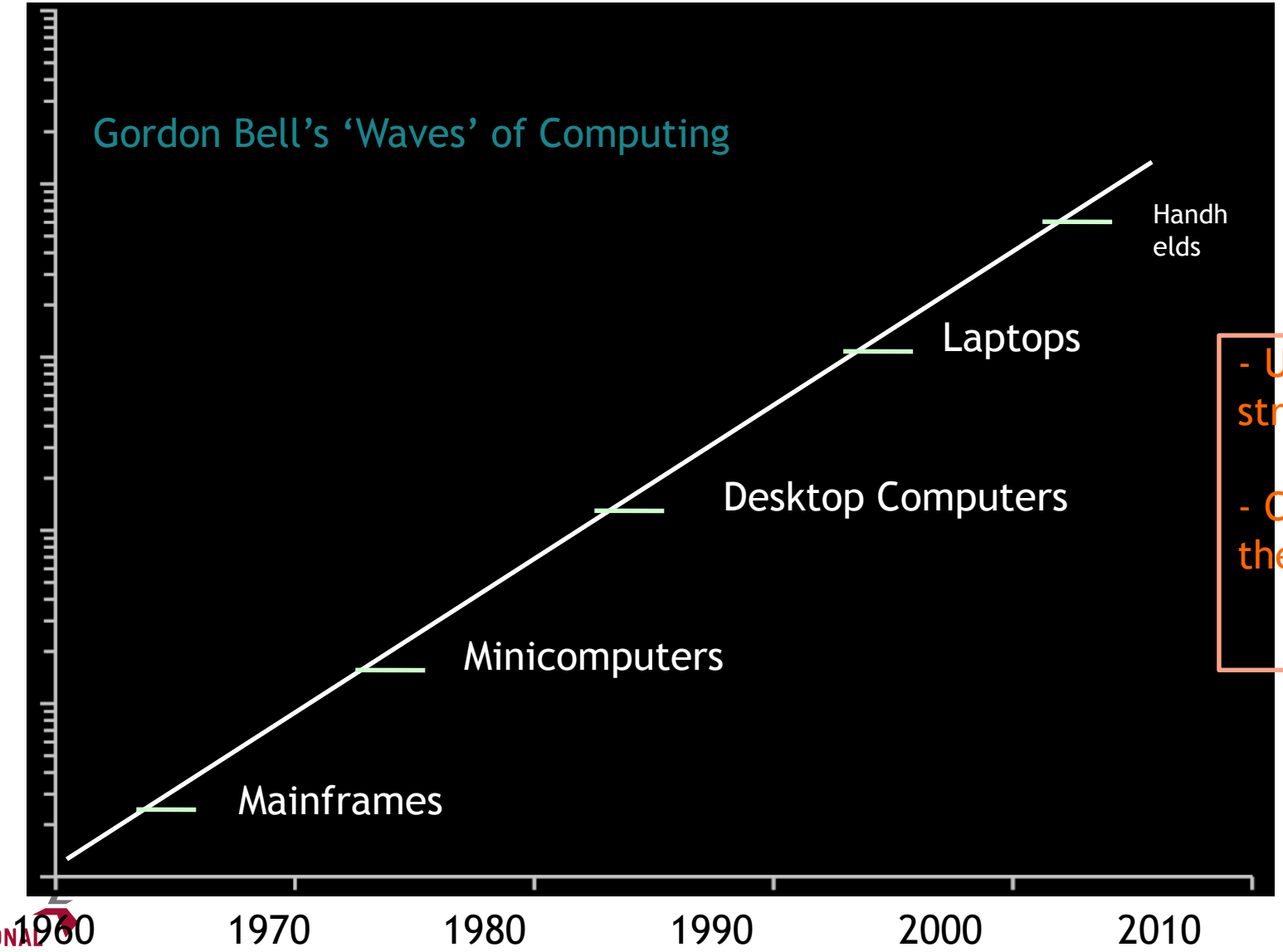
I) Ubiquitous Computing



Thresholds into Epochs Drive Revolutions



The Next Revolution



Everywhere Computing

- Ubiquitous sensor data streams into the cloud

- Context projects down to the user

Interfaces move onto
The body and into
The infrastructure

A VISION WITH MANY FLAVORS & ALIASES

Ubiquitous Computing (Xerox PARC) – 1990

Pervasive Computing (IBM / EU) – ~2000

Disappearing Computer (EU) – Early 2000s

Invisible Computing (UW/Microsoft) – Early 2000s

Ambient Intelligence (EU) – Early 2000s

Things That Think (MIT Media Lab) - 1995

Project Oxygen (MIT LCS) – Late 90s

Amorphous Computing (MIT AI Lab) – Late 90s

Internet of Things (P&G, MIT AutoID) - 1999

MARK WEISER (1952-1999)

Father of 'Ubiquitous Computing'

Pioneering research at Xerox PARC in the late 80s and early 90s envisioned the Internet of Things

Elucidated in his seminal article 'The Computer For the 21st Century', *Scientific American*, September 1991.

Coming more from a CS/HCI perspective than industrial RFID, etc.

II) Emerging data standards for IoT & sensors

The Next Convergence

User

Device-Agnostic
Sensor Description Protocol

Sensors (already) in everything

SOME EMERGING IOT STANDARD PROTOCOLS

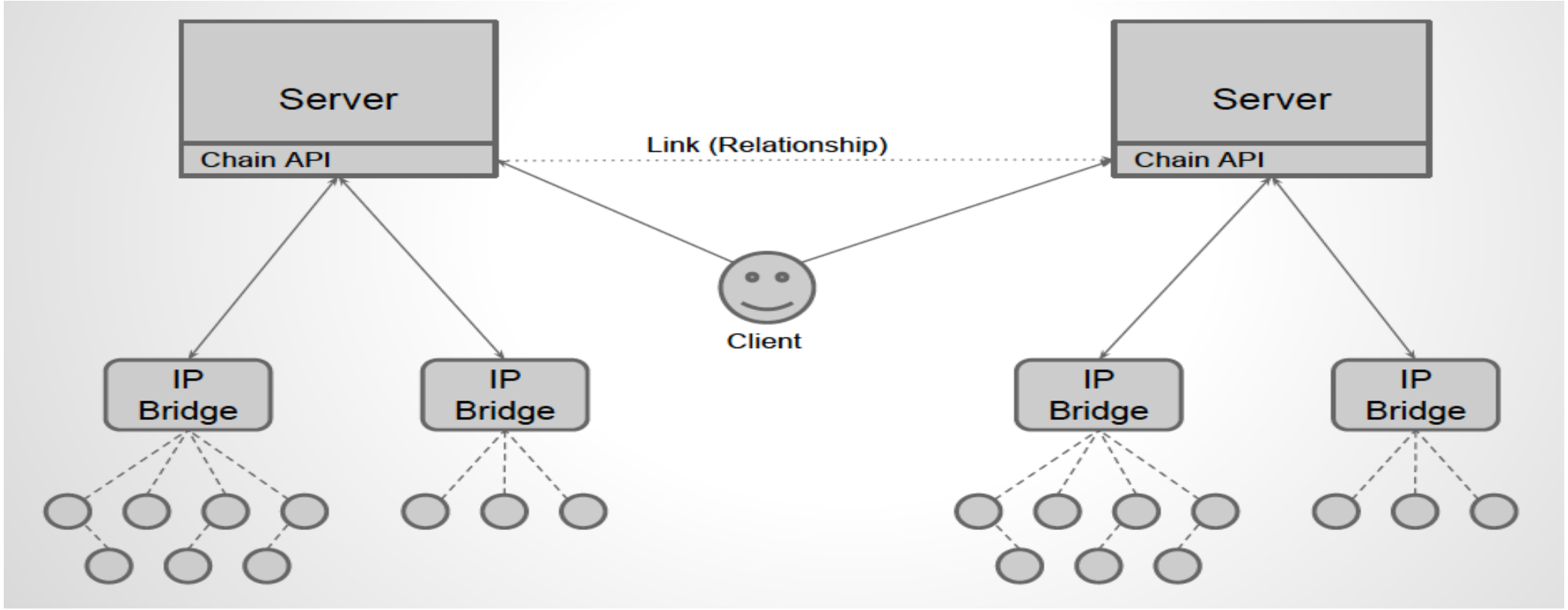
- AllJoyn
  - Protocol from Industrial consortium anchored by Qualcomm (AllSeen Alliance)
  - https://allseenalliance.org/
- IoTivity

-Protocol from Industrial consortium anchored by Intel (The Open Interconnect Alliance)

-http://openinterconnect.org/

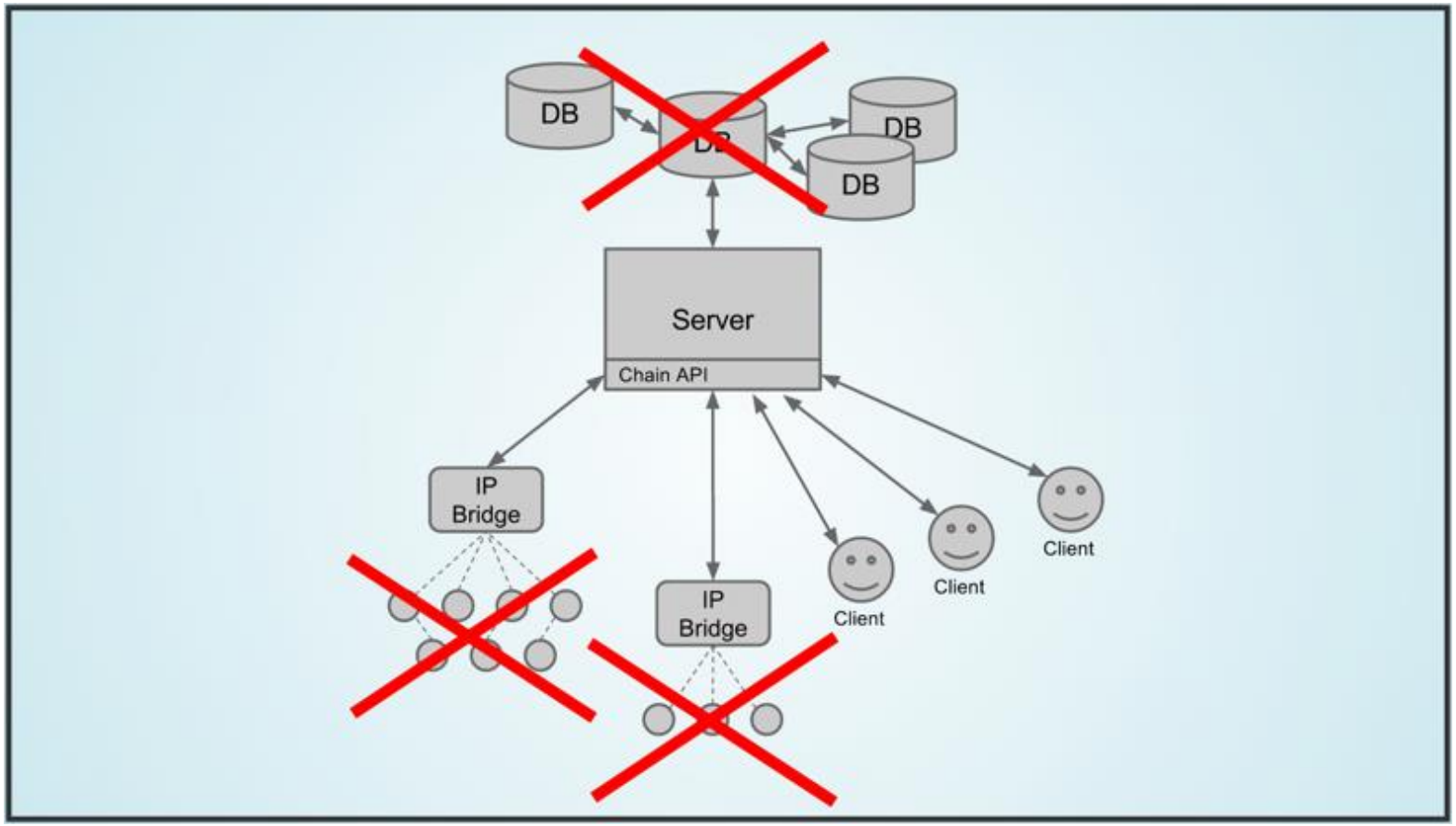
CHAIN-API - General, Decentralized Web-based Sensor Framework

Lightweight, adaptive way to describe sensors (real and virtual) as RESTful resources and specify relations between them with a shared vocabulary



Spencer Russell, RESENV Group

CHAIN-API APPLIES WHERE SENSOR DATA TOUCHES THE NET



Not meant to run on low-powered nodes
Doesn't specify database standard

http://resenv.github.io/chain-api/

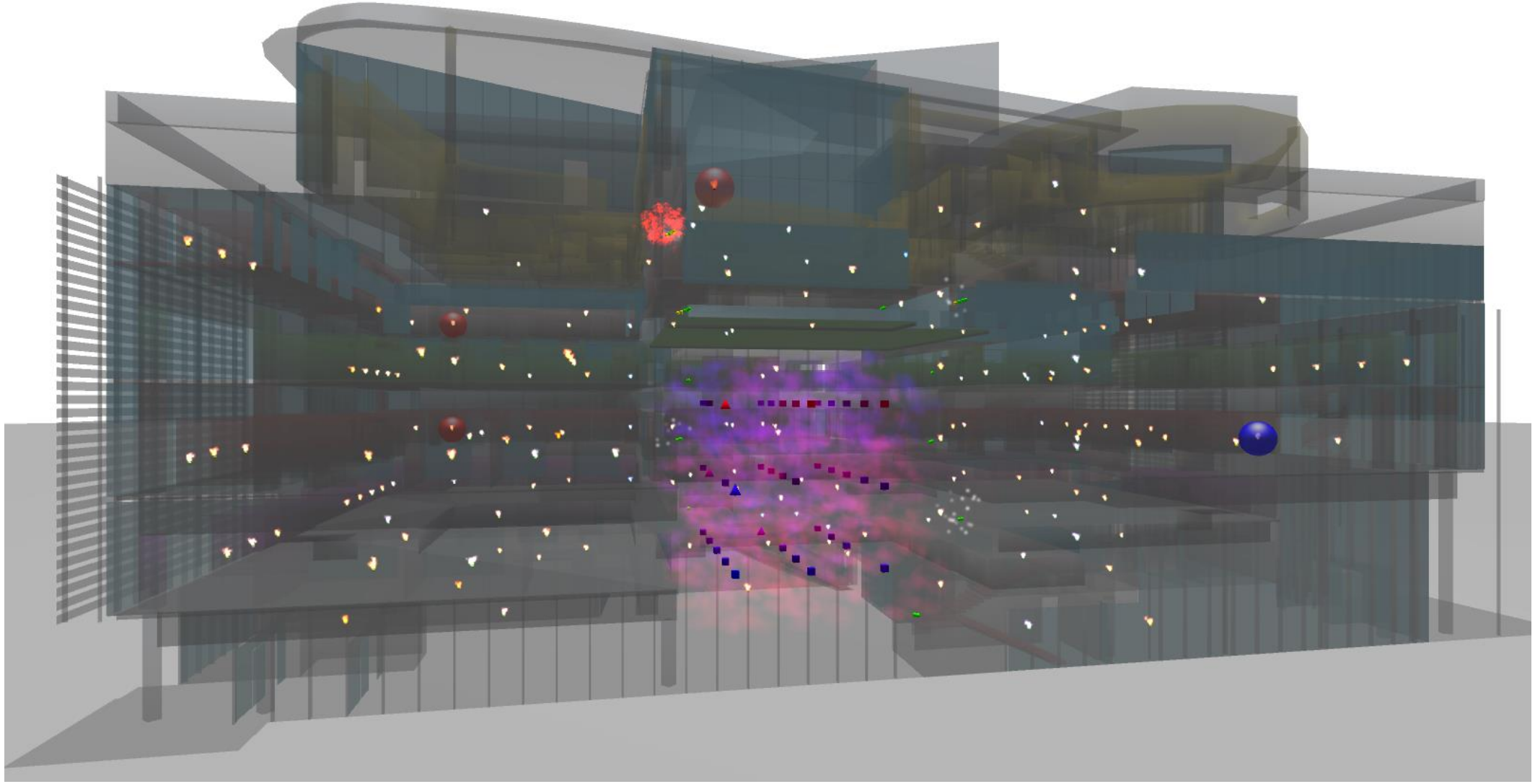
JSON-based


```
{
  "_links": {
    "self": {"href": "http://example.com/sensors/523"},
    "curies": [{
      "name": "rel",
      "href": "http://docs.example.com/relations/{rel}",
      "templated": true
    }],
    "rel:nearby": {"href": "http://example.com/sensors/near/523"},
    "rel:target": {"href": "http://example.com/sensors/837"},
    "rel:stream": {"href": "ws://example.com/sensors/523"}
  },
  "rel:name": "Office Thermometer",
  "rel:metric": "temperature",
  "rel:unit": "celsius",
  "rel:value": 22.8
}
```

Russell, S. and Paradiso J.A., "Hypermedia APIs for sensor data: A pragmatic approach to the Web of Things," presented at *Mobiquitous 2014*

III) Immersive visualization of diverse IoT/sensor data

See: Dublon, G., Paradiso, J. A., “How a Sensor-Filled World Will Change Human Consciousness,” *Scientific American*, July 2014, pp. 36-41.
Cover Article



Gershon Dublon, Nick Joliat, Brian Mayton

http://doppellab.media.mit.edu

PROFESSIONAL EDUCATION

The Internet of Things: Roadmap to a Connected World

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REDEFINING PRESENCE

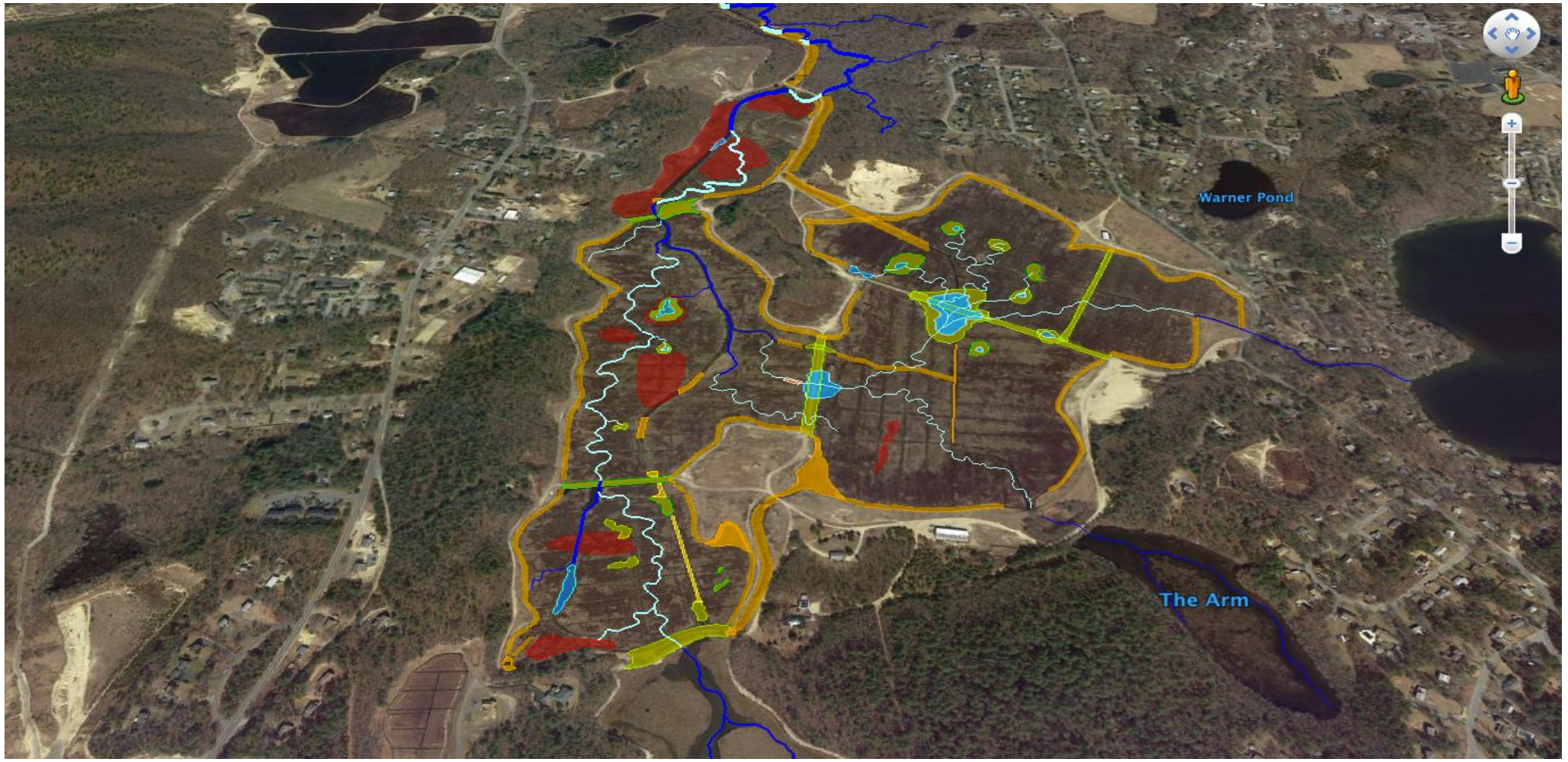
Living Observatory (~600 Acres, 1% Ocean Spray's Cranberries)

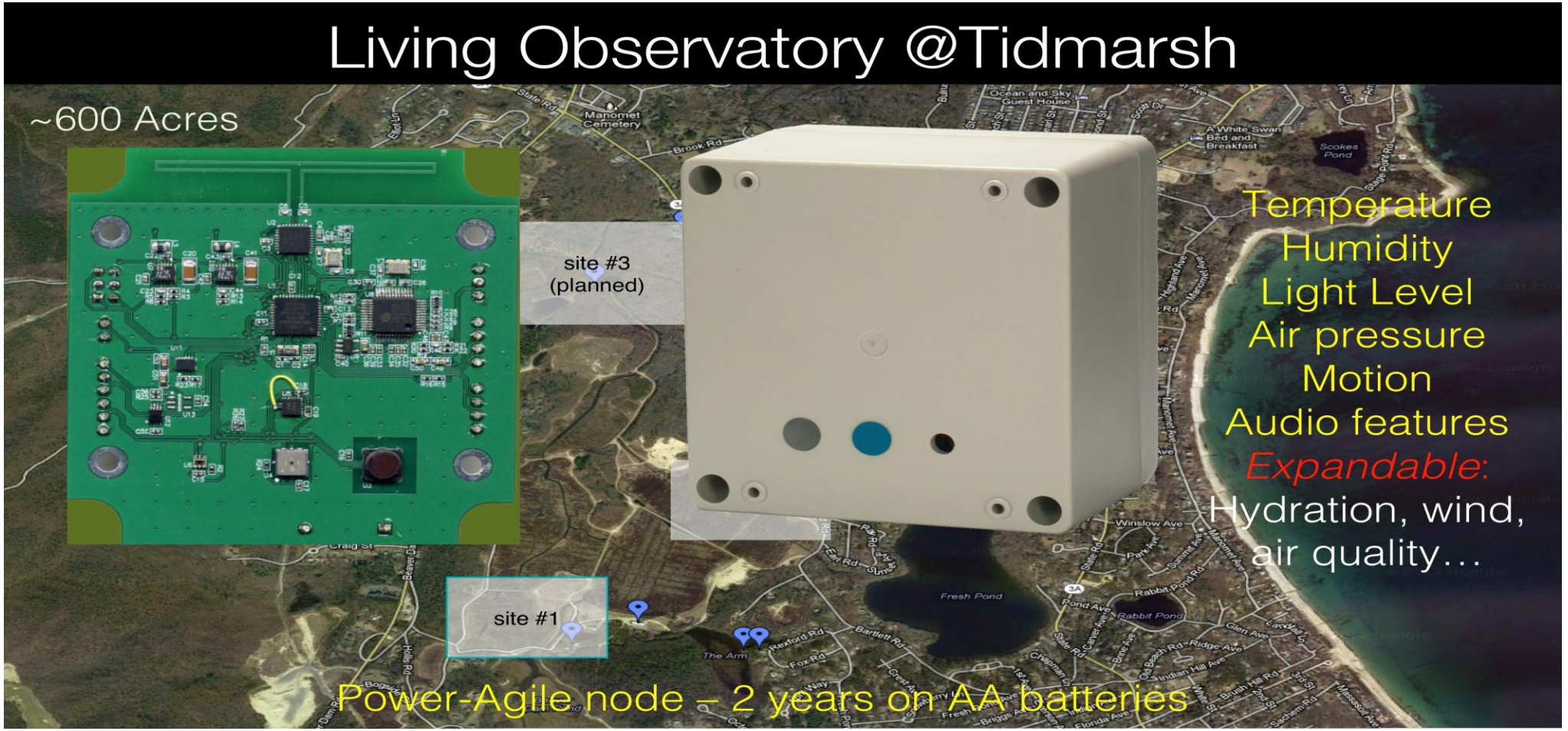
Tidmarsh Farms

Glorianna Davenport & Evan Schulman

The Internet of Things: Roadmap to a Connected World

Now Massachusetts' Largest Ecological Restoration Project





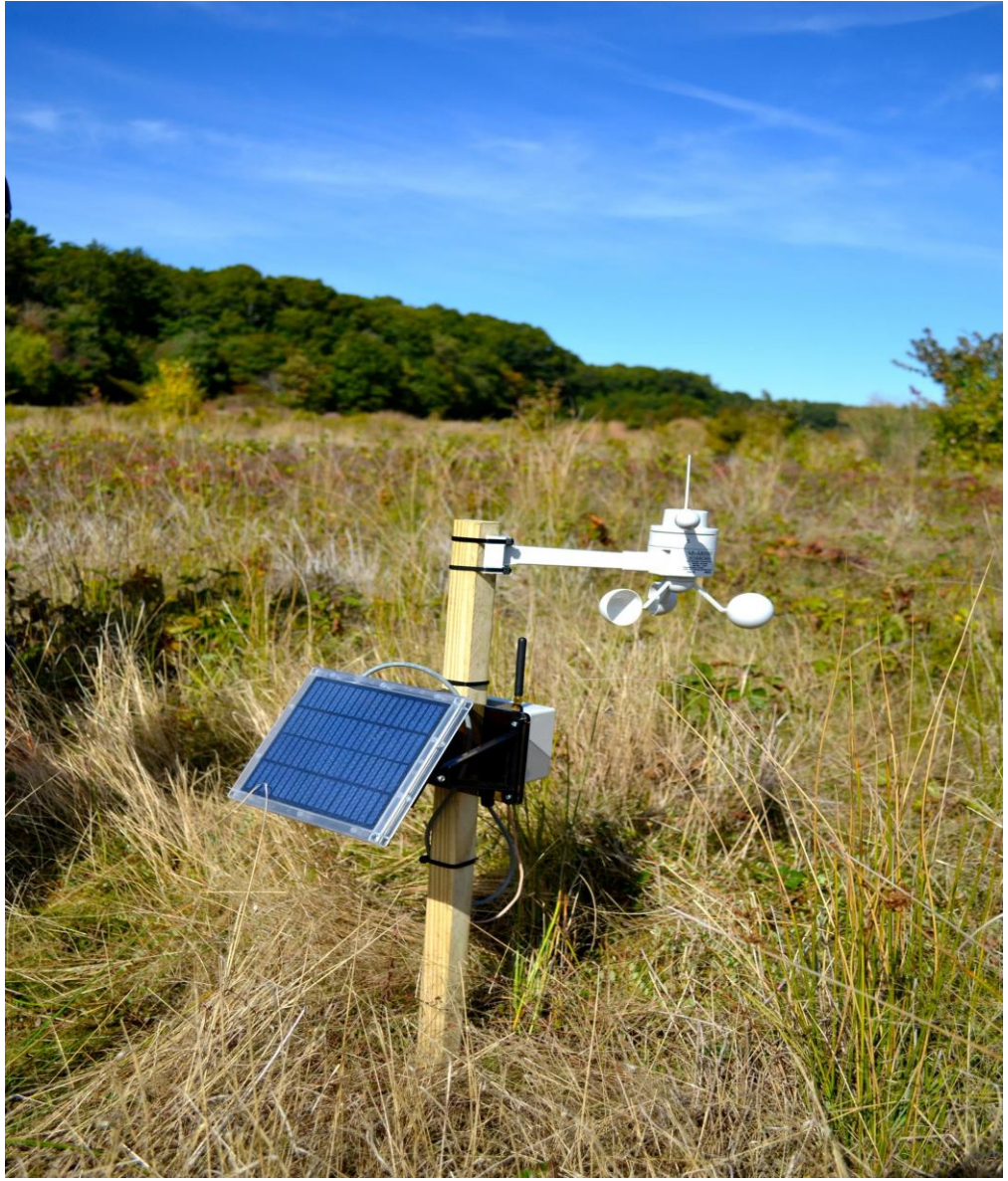
Micropower sensor nodes form the 'leaves' of IoT

WE HAVE DEPLOYED!

Modified 802.15.4 ‘Zigbee’ Network

Brian Mayton

http://tidmarsh.media.mit.edu/sensor_node.html



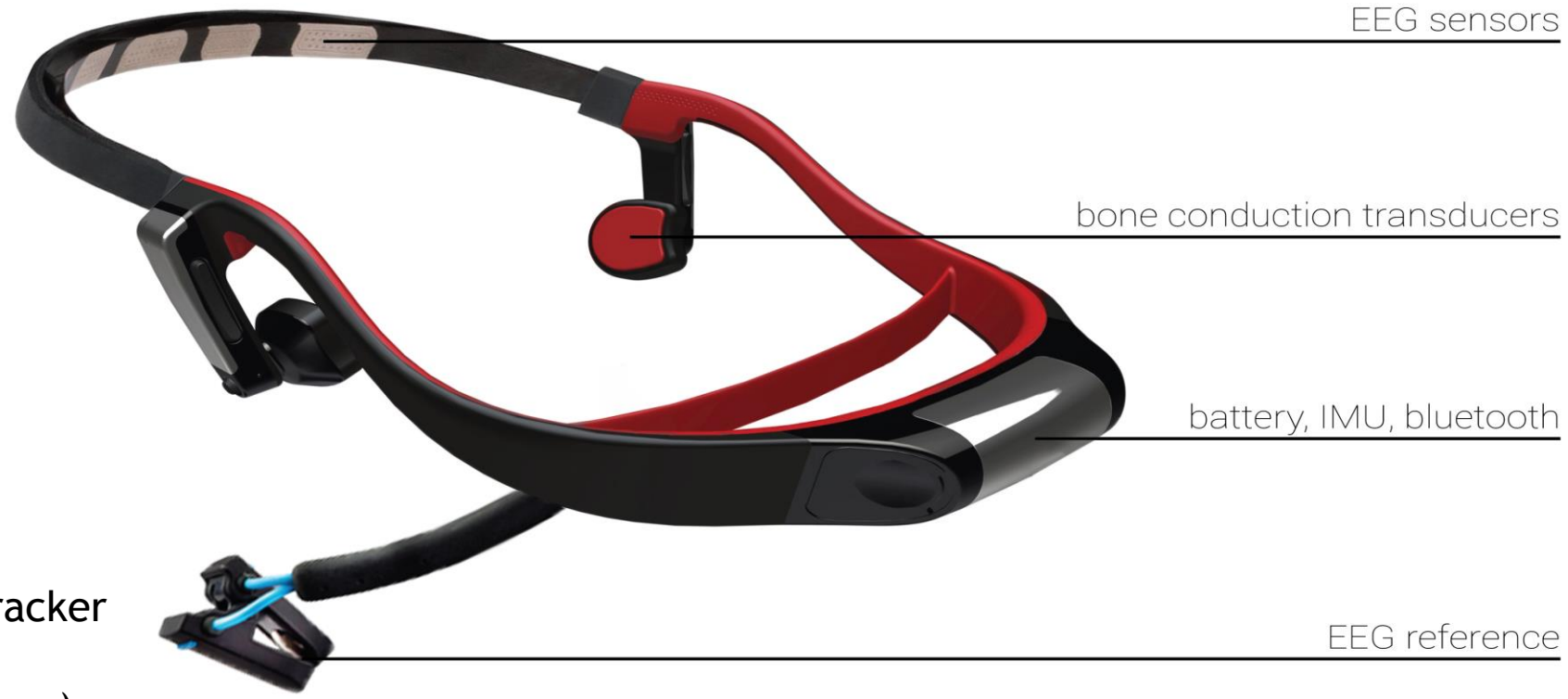
QuadraSense – control drone within Unity

Work in Progress - *Vasant Ramasubramanian, Donald Derek Haddad*

CONCEPTUAL RENDERING

HearThere

Immersive spatialized audio everywhere



Infrastructureless head tracker
Integrated EEG
Bone Conduction (extra ears)
Position sensing
(continuous tradeoff from GPS to UWB)

Spencer Russell, Gershon Dublon

IV) IoT & the Built Environment

PERSONAL COMFORT CONTROL

Hot OK Cold

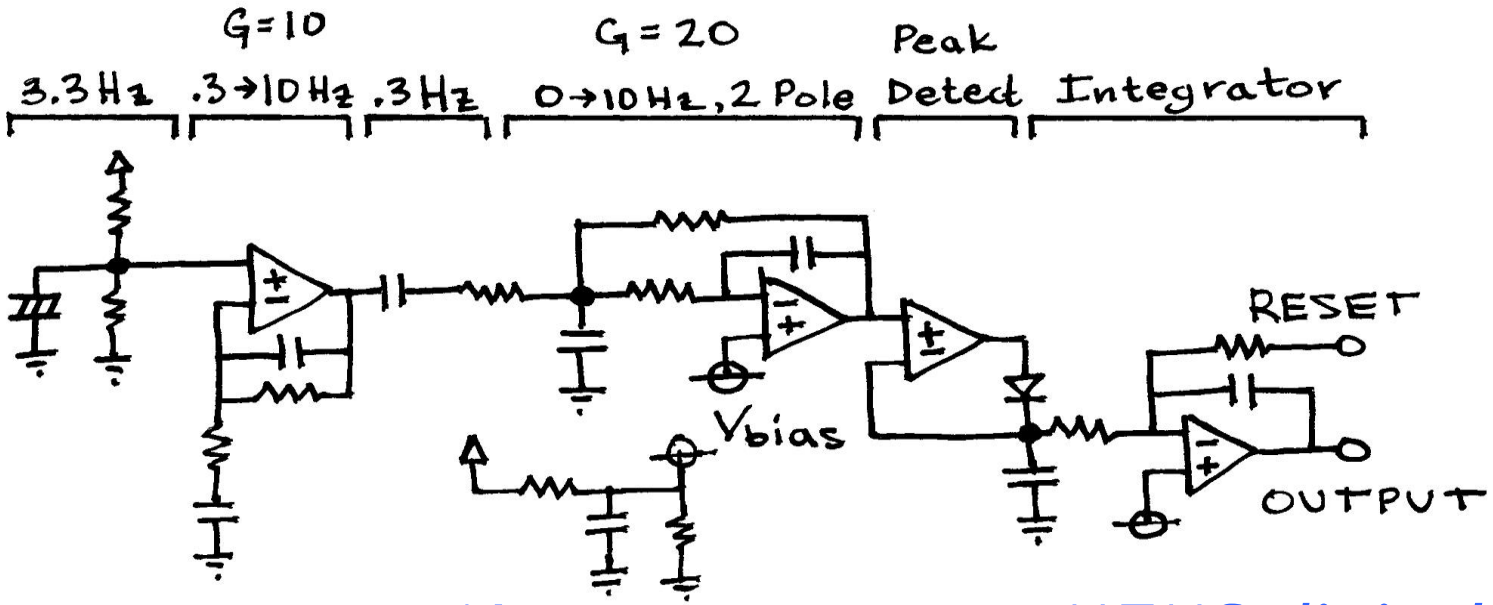
Feldmeier, Paradiso, "Personalized HVAC Control System," IOT Tokyo Nov. 30, 2010

Wearable Sensor

Integrated vibration, T & H, Light @ μW

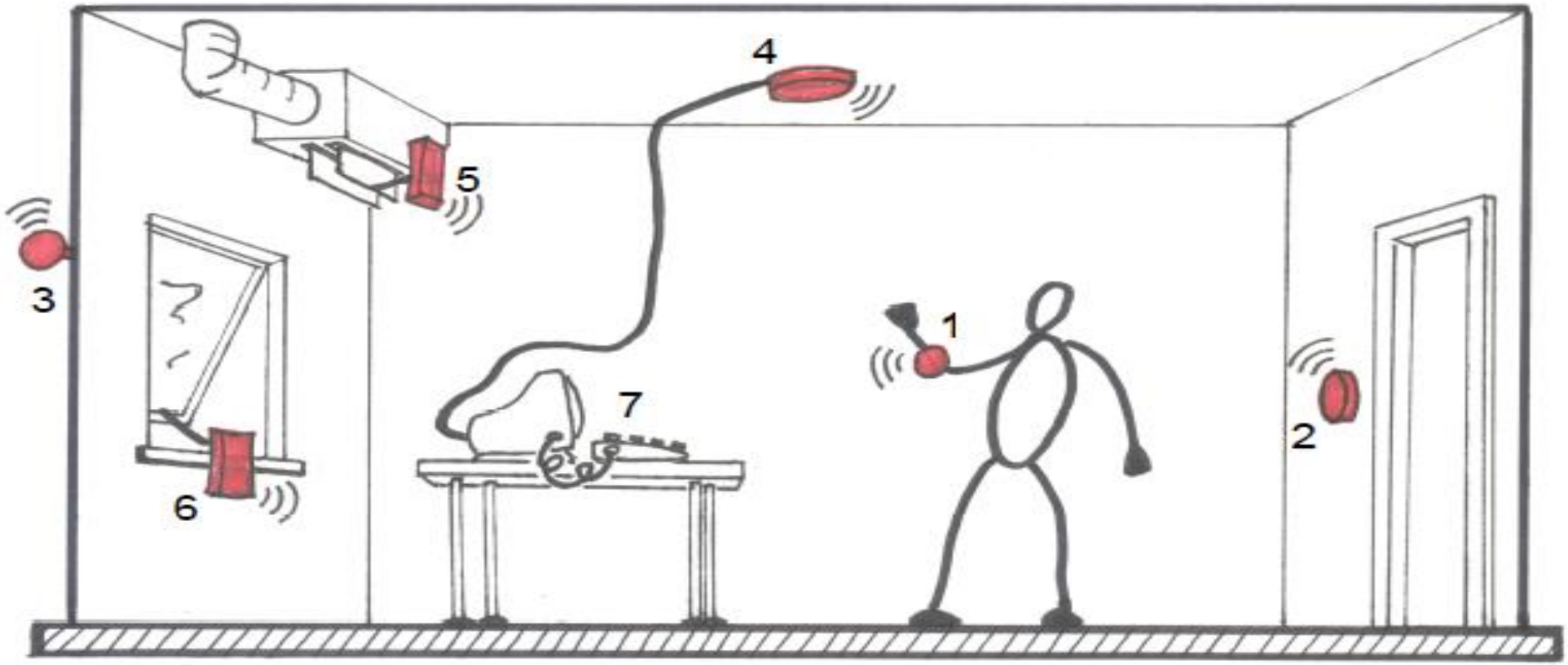
LOW POWER ACTIVITY SENSOR

Passive, surface mount, piezo element (1:2:4 - x:y:z sensitivity)
.1Hz to 10Hz frequency range
Micro-power op-amps with low cross-over distortion
1 minute integration time with reset

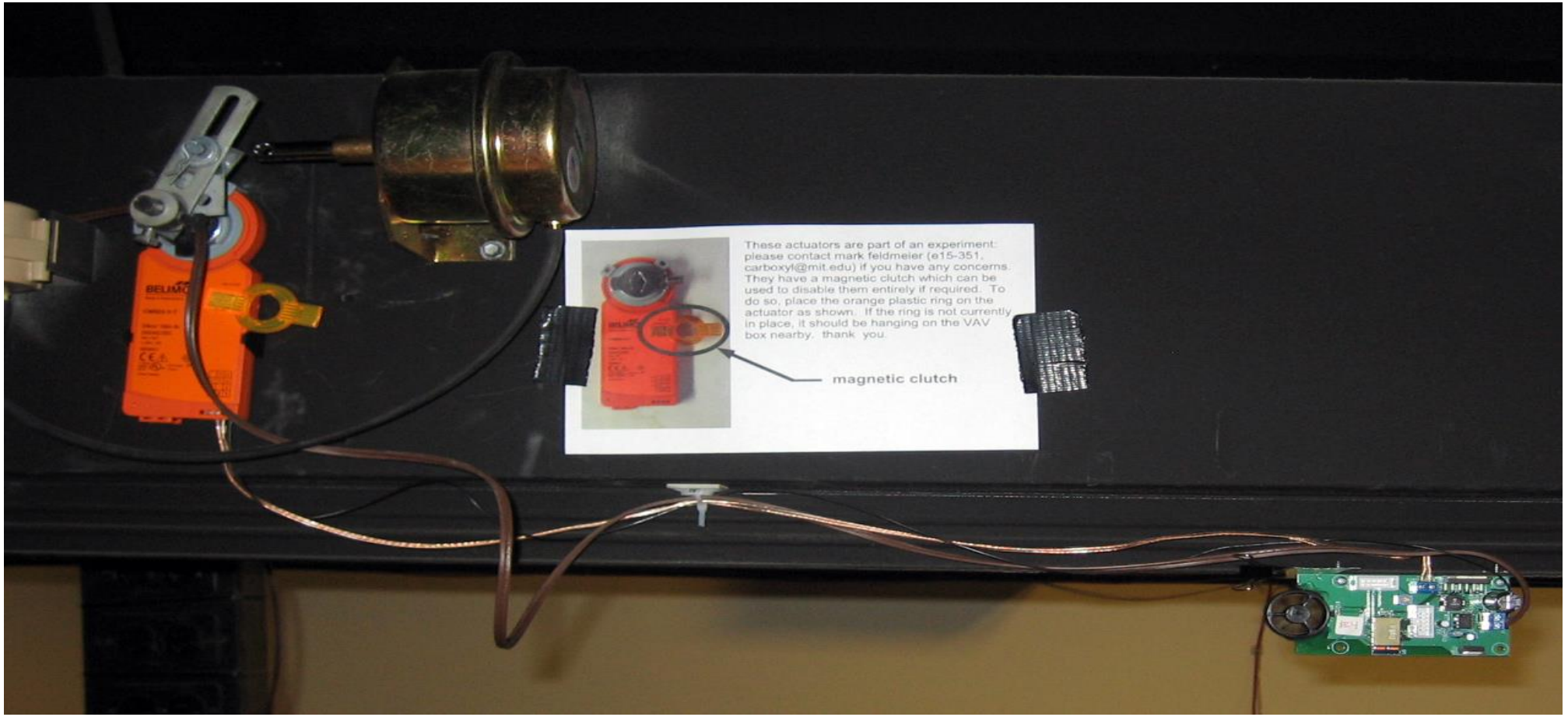


Now use µ-power MEMS digital accelerometer

MELDING WEARABLE WITH INFRASTRUCTURE SENSING

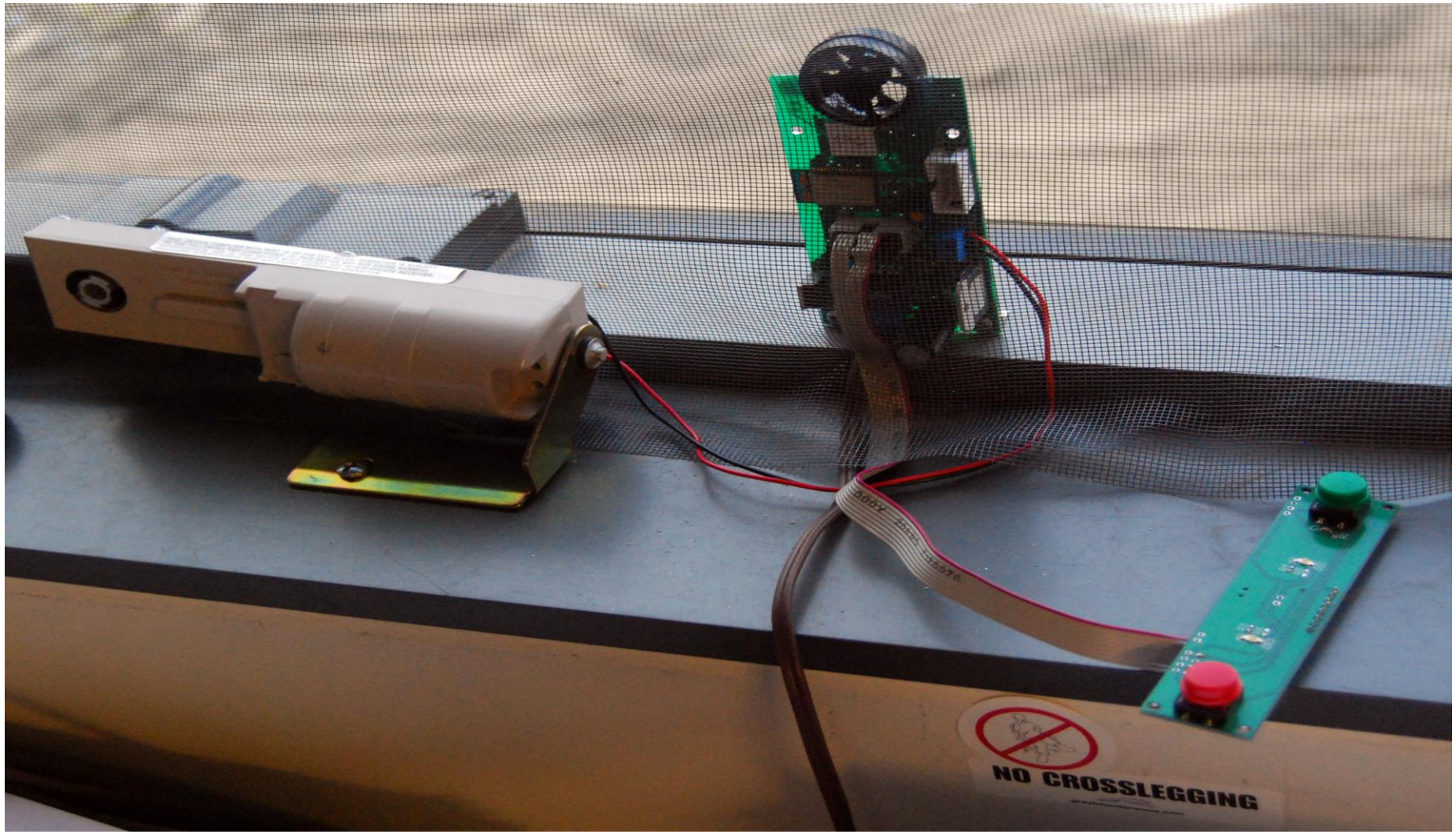


CEILING HVAC DAMPER CONTROL

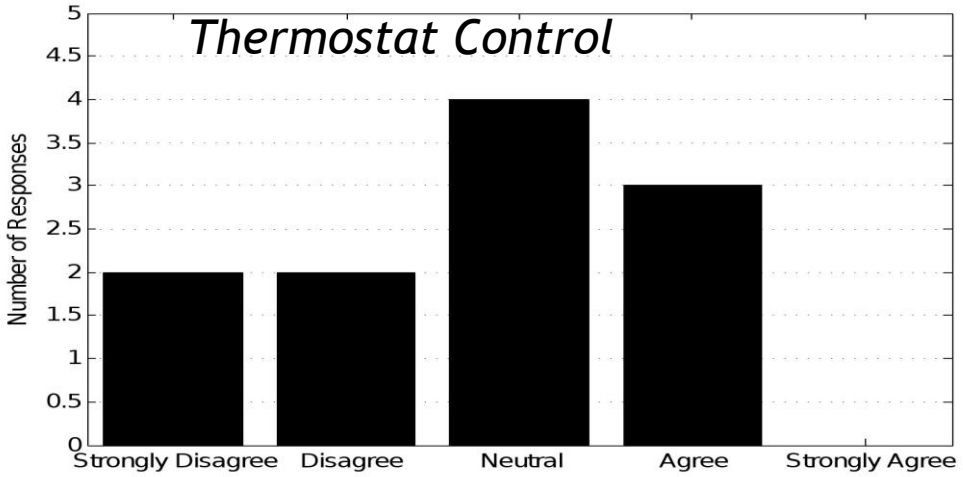


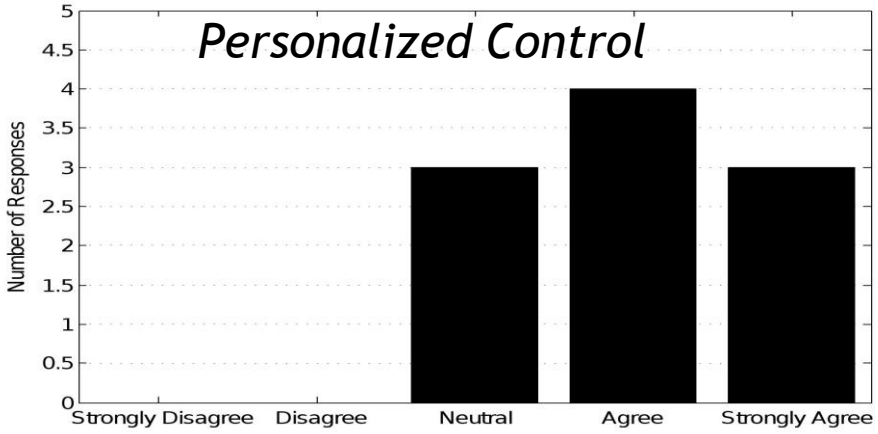
Measure temperature, humidity, airflow, PIR motion
Continuous Control of Damper

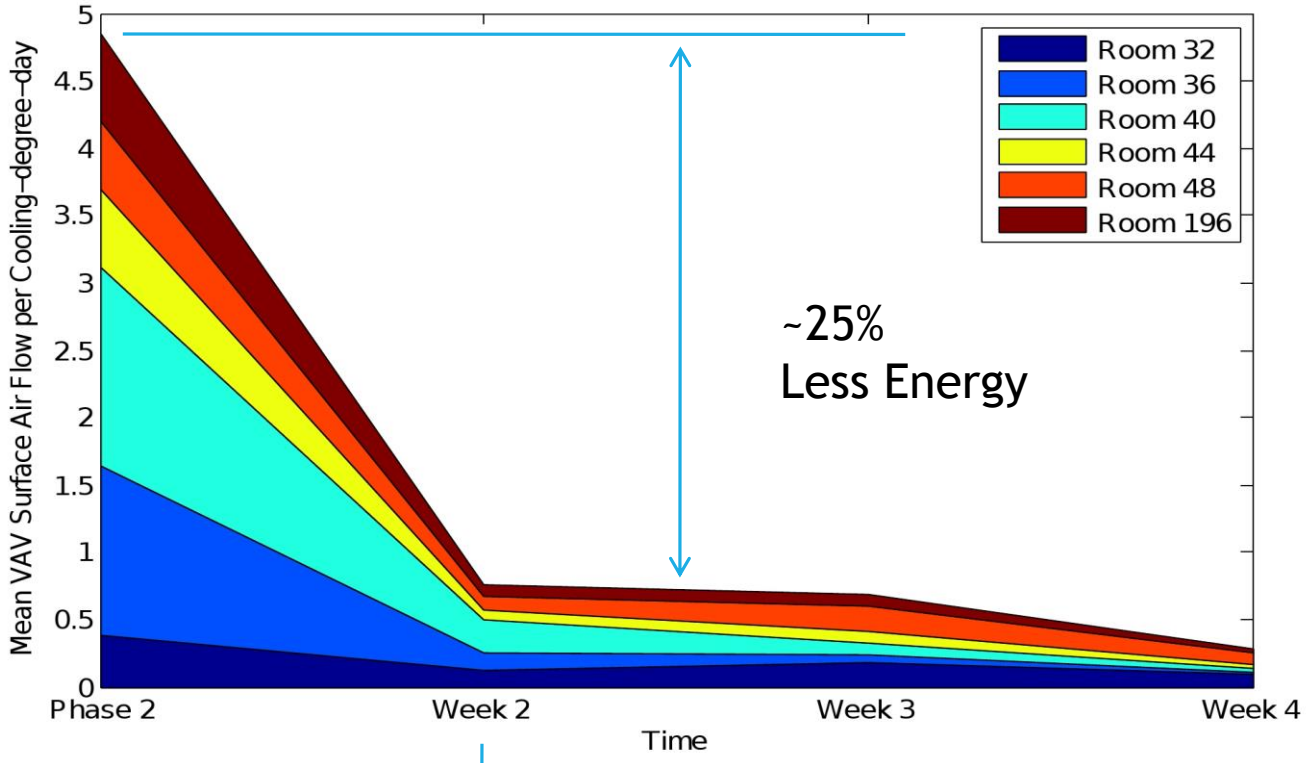
OPEN/CLOSE WINDOWS



WE ARE MORE COMFORTABLE..For Less Energy







Thermostat Control

Personalized Control

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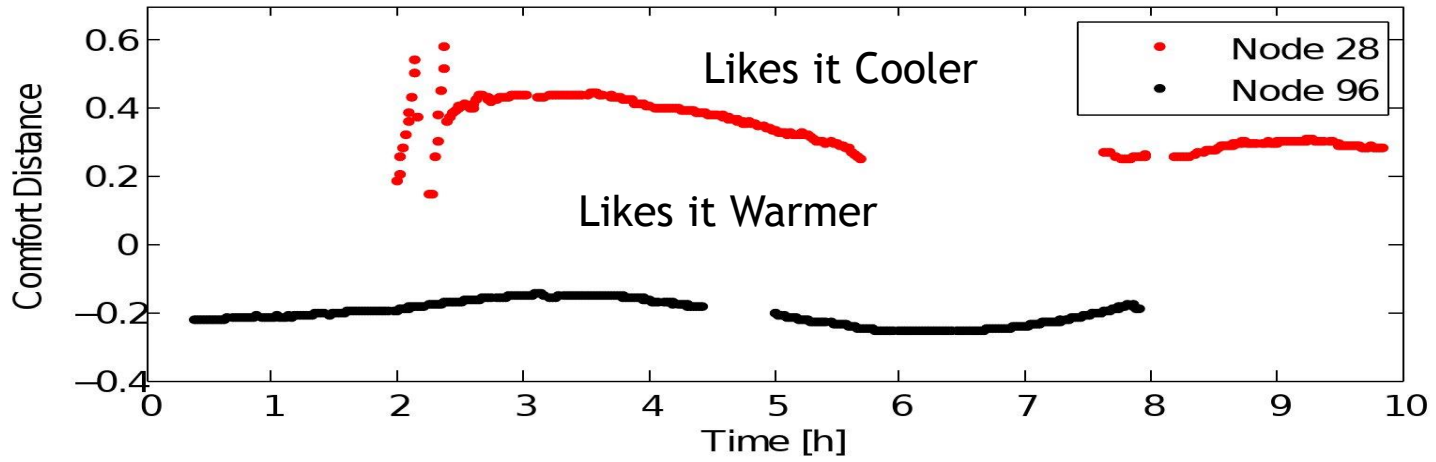
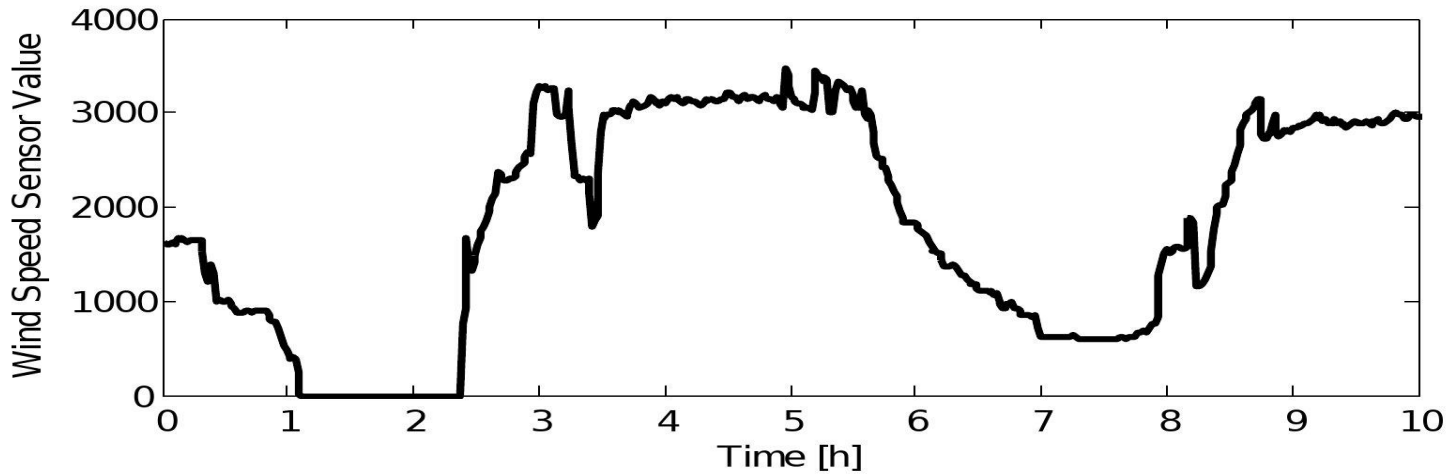
Mediating Conflicting Demands





More Cool Air

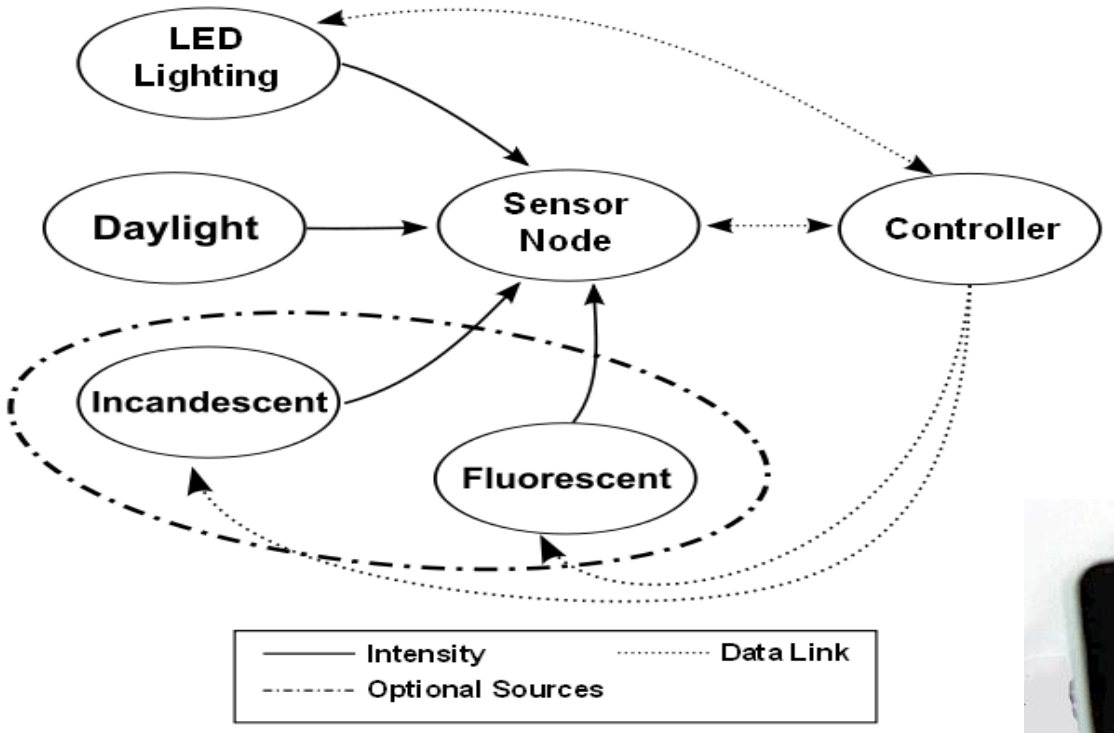
Less Cool Air

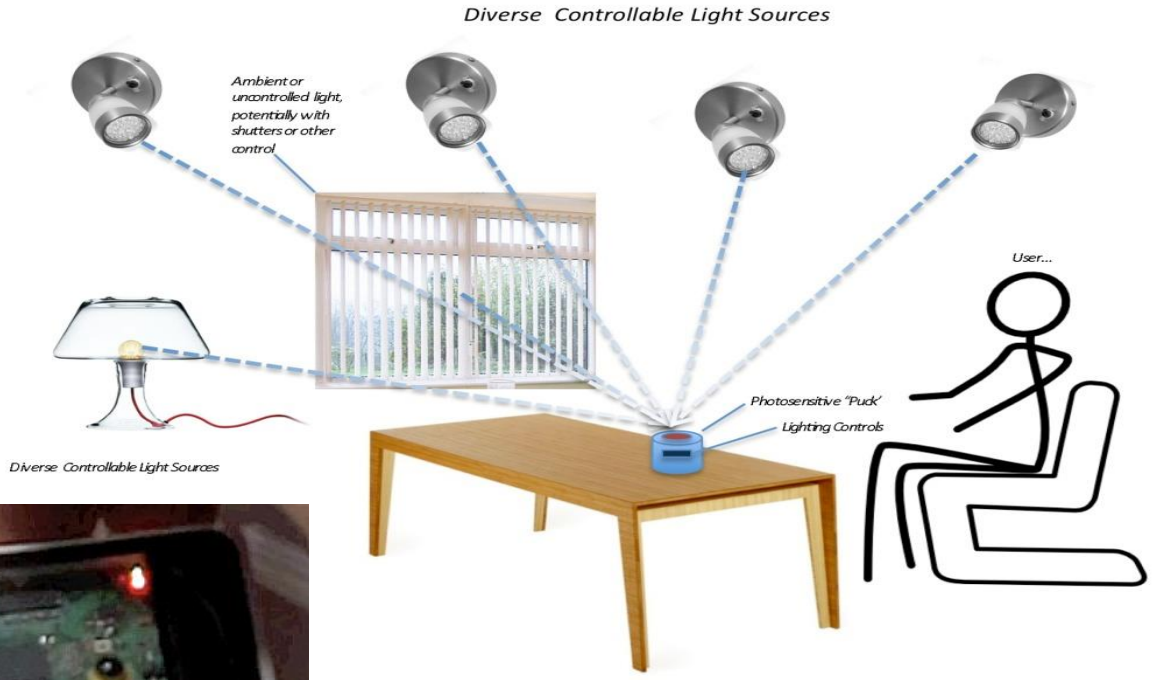
LIGHTING CONTROL IS BROKEN

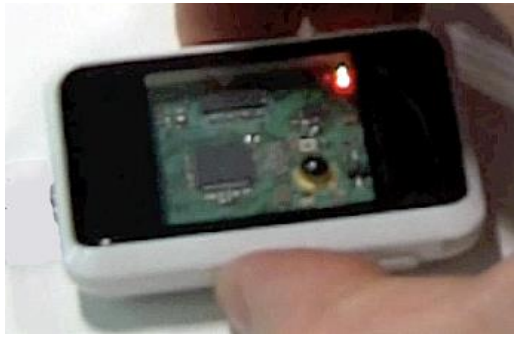
Commercial lighting control panel in the new (2010) Media Lab Building

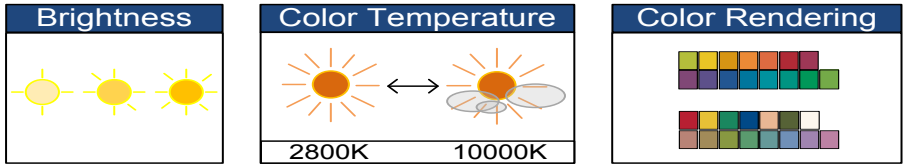
EFFICIENT SENSOR-ENABLED LIGHTING

MATT ALDRICH, NAN ZHAO, AND JOE PARADISO

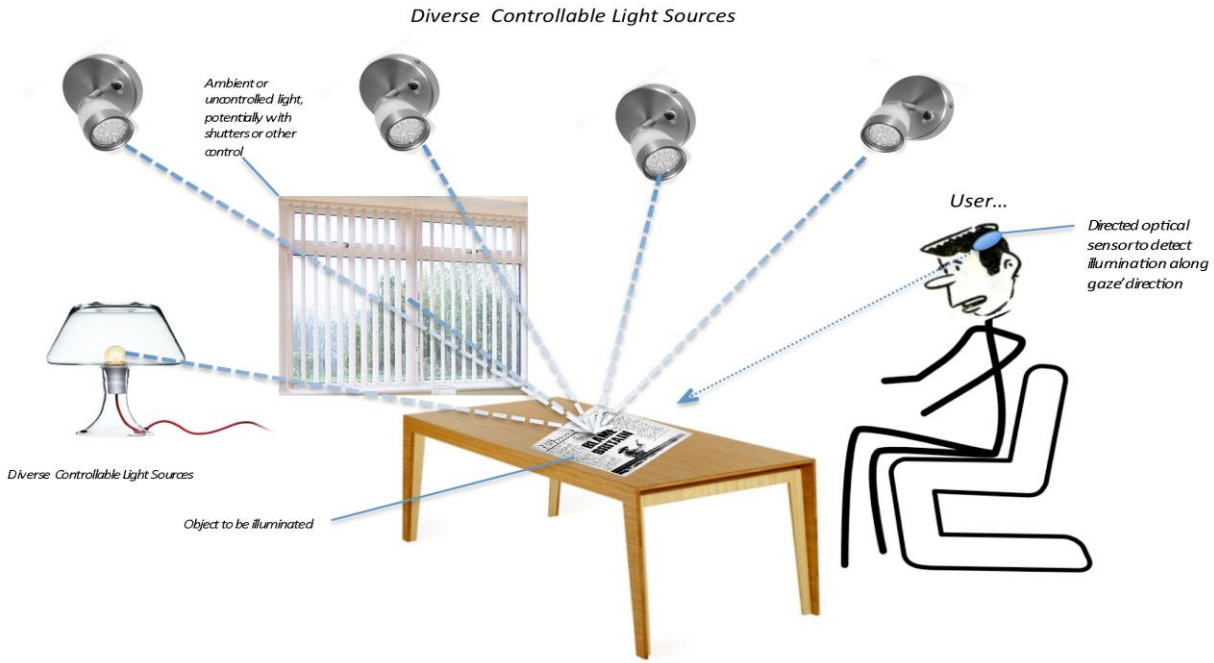








M. Aldrich et al, "Energy Efficient Control of Polychromatic Solid-State Lighting Using a Sensor Network," Proc. SPIE 2010



User Perspective – wearable adjusts reflected lighting to be optimal where user is looking

- Wearable Sensors and Cameras

Synchronized infrastructure cameras see area contributions from different sources

- Feedback control and gestural override
- "Put That There" for lighting

- Context Based Lighting

Nan Zhao – Computer Vision Feedback

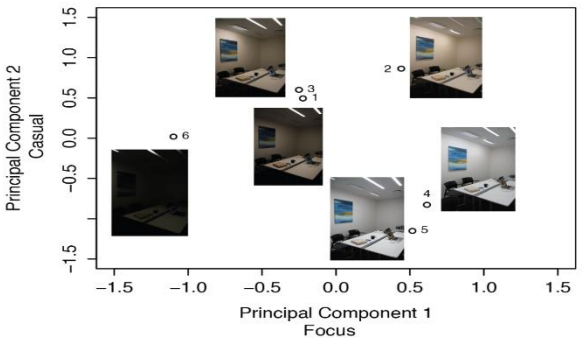
- MINDFUL PHOTONS - CONTEXT-AWARE LIGHTING

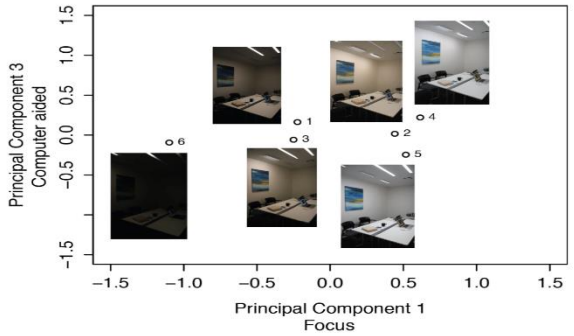
We collected user preference data on lighting and office related tasks

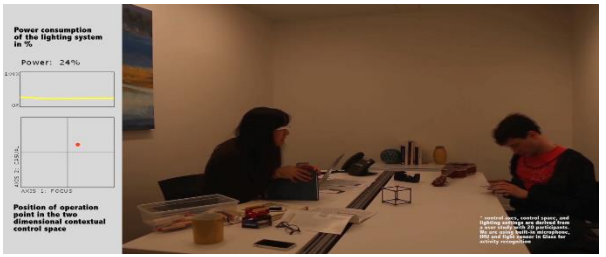
Based on these data we derived three contextual control axes for lighting control and their mapping to brightness and color settings of 10 fixtures.

Using Google Glass for activity recognition we evaluated the performance of the continuous contextual axes

Graphical illustration of the solution space in 2D. (left) focus and casual, (right) focus and computer aided.







Zhao et al, in Buildsys 2015 - Resenv.media.mit.edu/lighting

Nan Zhao et al, ‘A Multidimensional Continuous Contextual Lighting Control System Using Google Glass,’ in Proc. of BuildSys’15 - *Best presentation award*

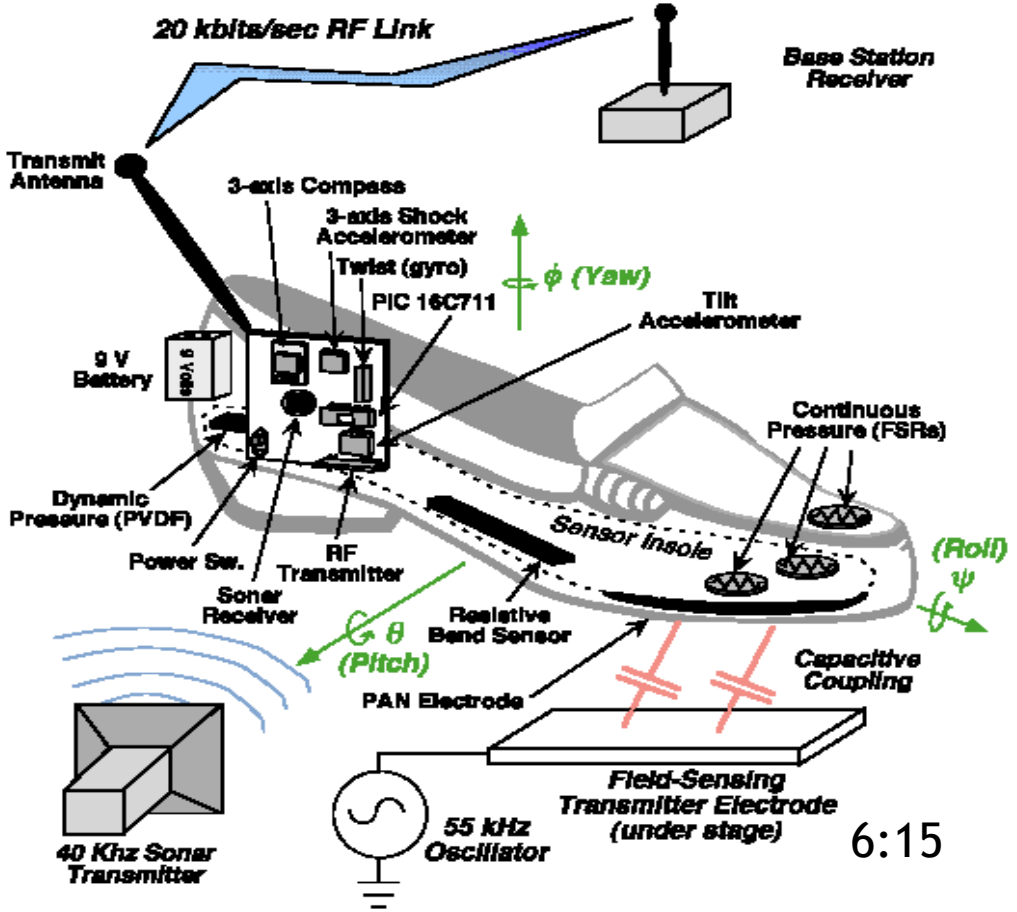
V) Wearables & IoT On-Body

Media Lab ‘Cyborgs’ – 1995

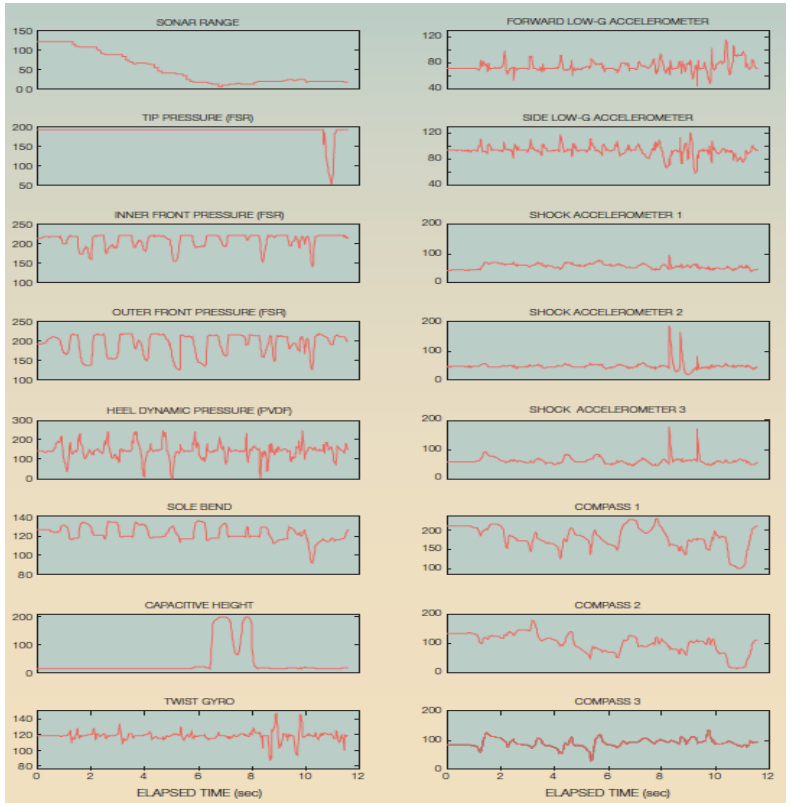
1997 - EXPRESSIVE FOOTWEAR

17 Data Channels

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

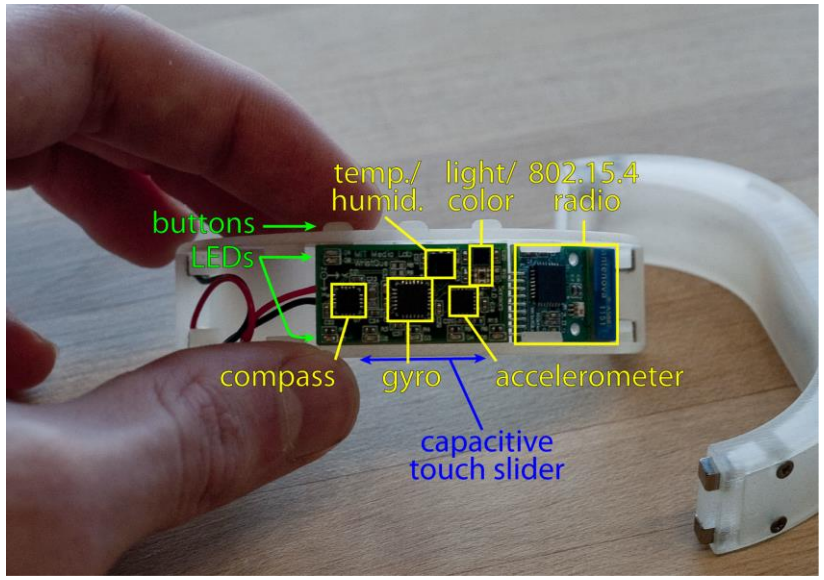


6:15



"Design and Implementation of Expressive Footwear," IBM Systems Journal, October 2000, pp. 511-529.

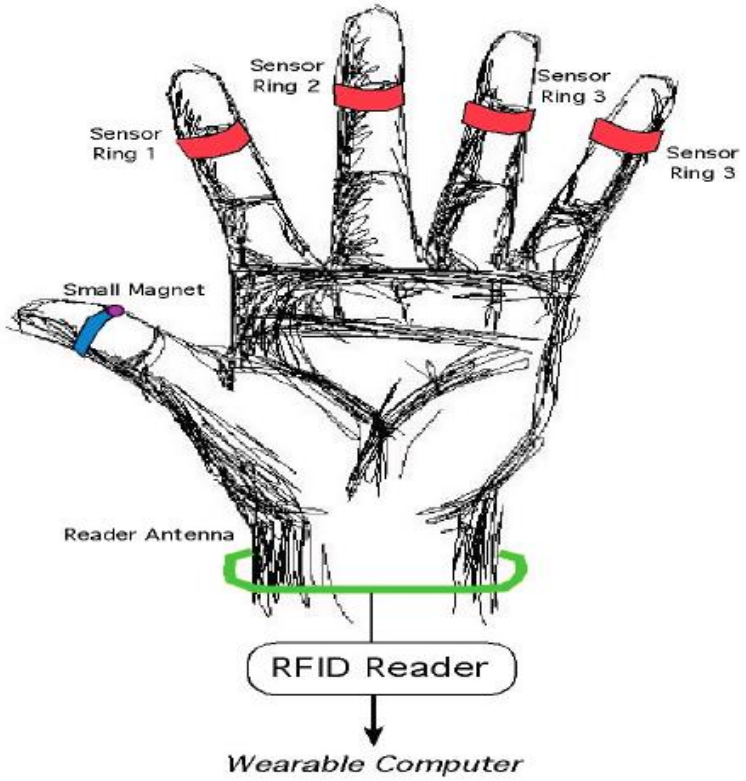
THE WRISTQUE



B. Mayton et al, “WristQue: A personal sensor wristband,” in Proc. BSN 2013

Video demo at: http://www.hgtv.com/remodel/mechanical-systems/home-technology-of-the-future-videos

FINGER TRACKING RINGS



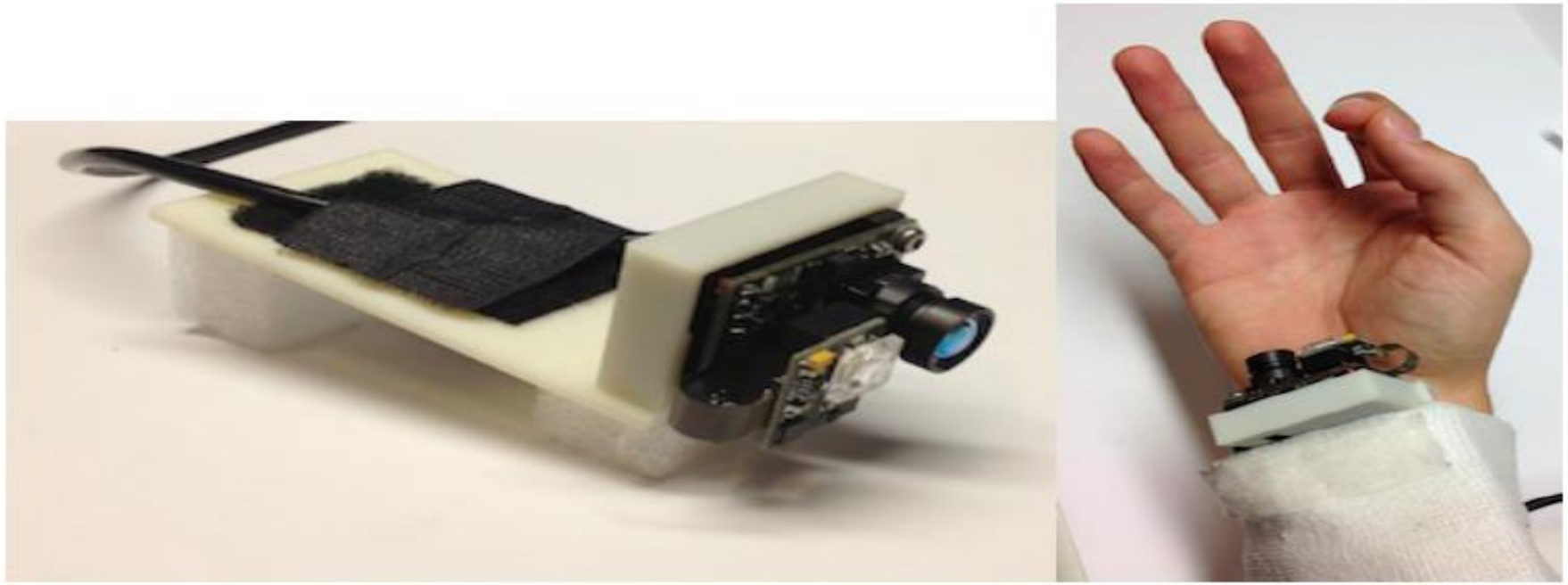
Concept

Working COTS Proof-of-Concept, 2010

Bainbridge, R. and Paradiso, J.A., "Wireless Hand Gesture Capture Through Wearable Passive Tag Sensing," in Proc. of the 2011 International Conference on Body Sensor Networks (BSN 2011), pp. 200-204.

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

EMGRIE: Ergonomic Micro-Gesture Recognition and Interaction Evaluation



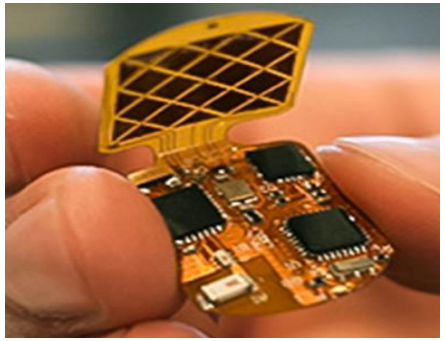
David Way

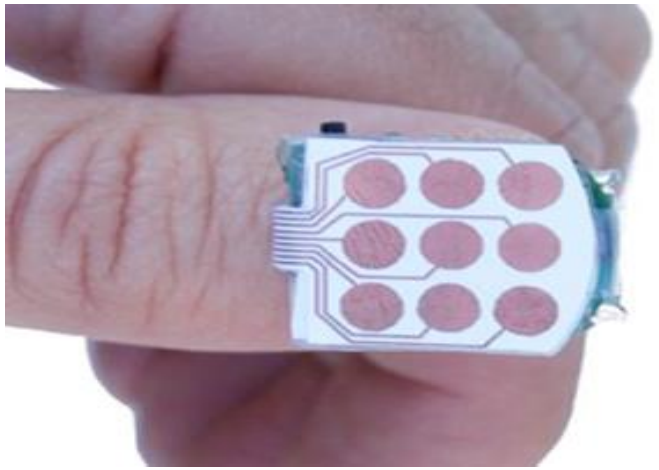
D. Way & J. Paradiso, “A Usability User Study Concerning Free-Hand Microgesture and Wrist-Worn Sensors” presented at BSN 2014

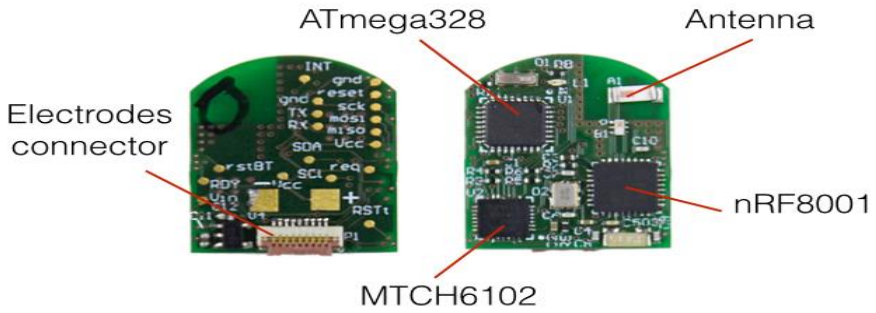
GESTUREBAND – IMAGING PRESSURE @ THE WRIST

Dementyev & Paradiso, “WristFlex: Low-Power Gesture Input with Wrist-Worn Pressure Sensors,” in Proc. of *UIST 2014*

NAIL*IO* – WIRELESS TOUCHPAD FINGERNAIL

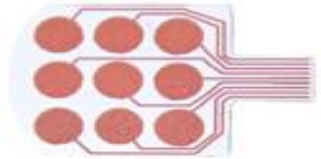






Layer 1: Art

Layer 2: Sensors



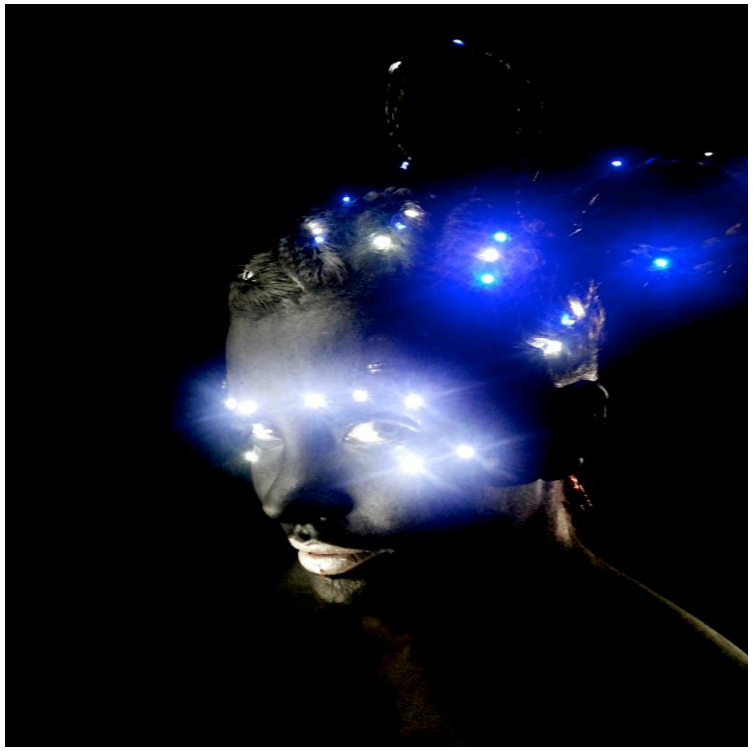
Layer 3: Circuit

Layer 4: Battery

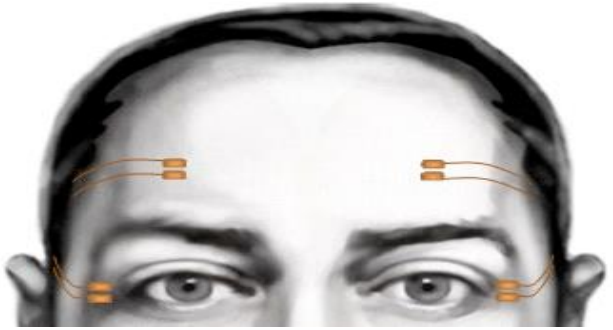
U.S. Quarter (for comparison)

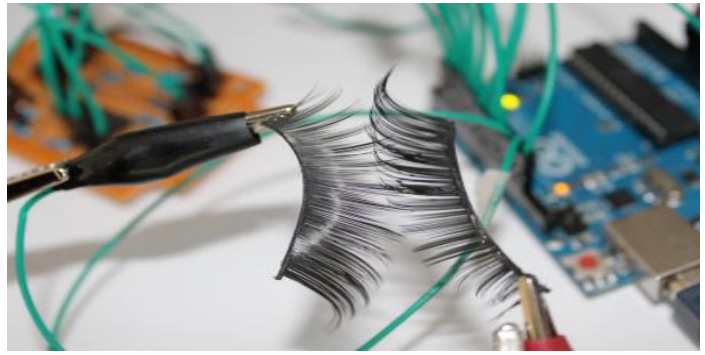
H.-L. C. Kao, A. Dementyev, J. Paradiso, C. Schmandt. 'NailO: Fingernails as an Inp ut Surface', CHI 2015. *Honorable mention award*

KATIA VEGA – BEAUTY TECHNOLOGY



Visiting researcher @ ResEnv





Electronics applied as ‘makeup’

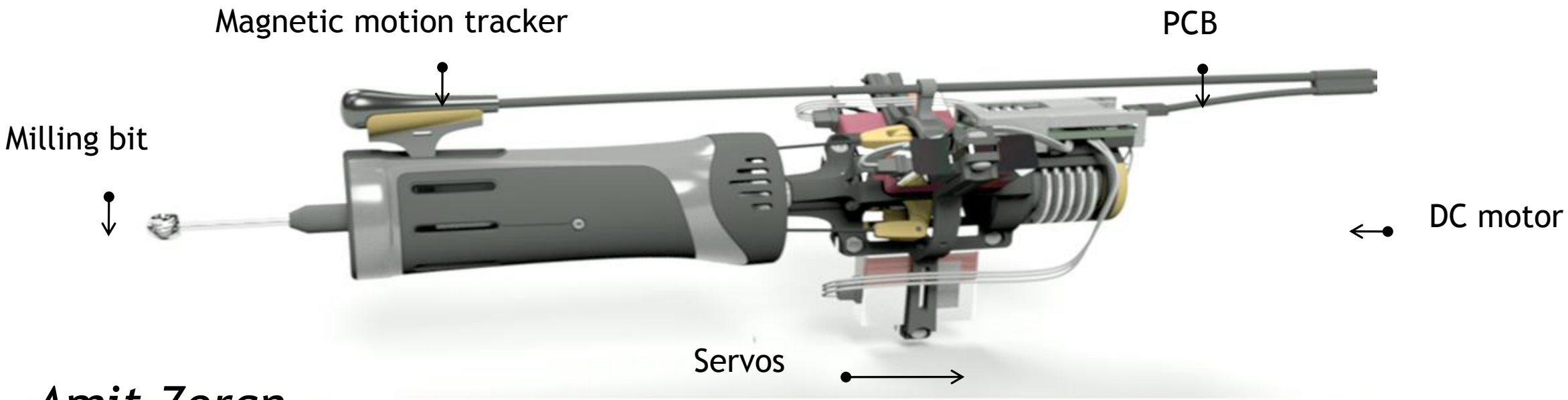
Form switches, strain gauges, etc.

http://www.katiavega.com

V) Smart Tools under IoT

The FreeD

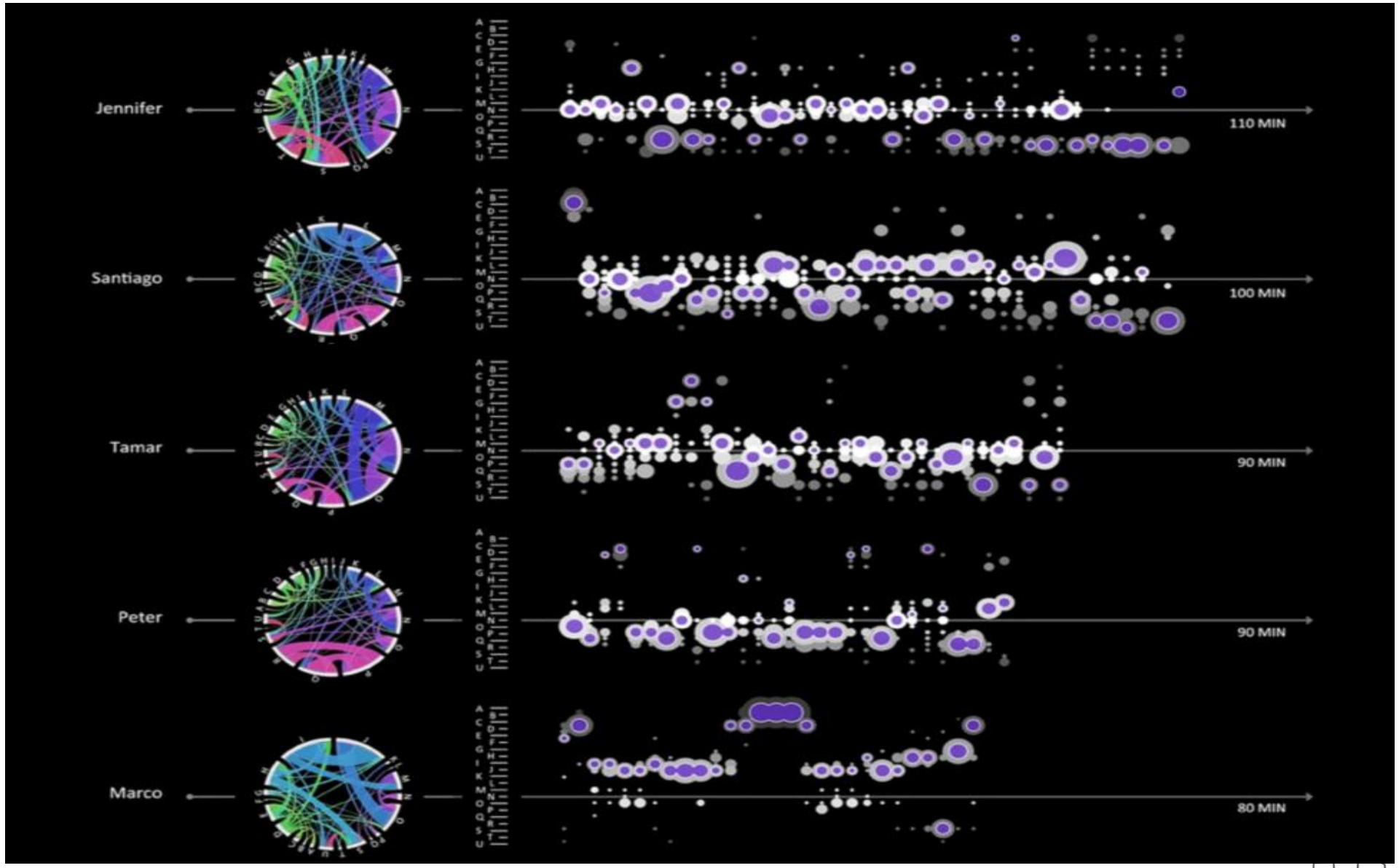
A handheld digital milling device for craft and fabrication



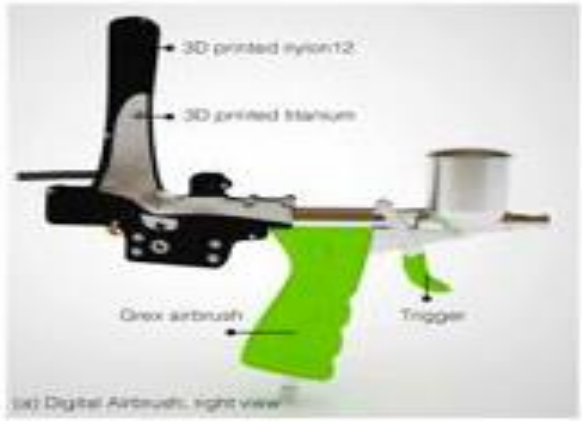
Amit Zoran

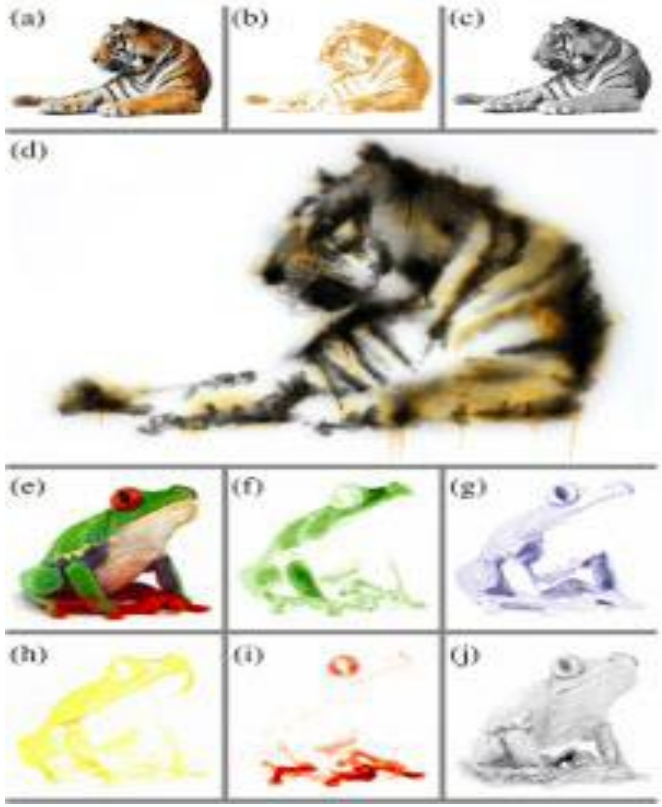
Zoran, Amit and Joseph A. Paradiso, 'FreeD – A Freehand Digital Sculpting Tool,' in Proc. of CHI 2013
BEST PAPER AWARD

Zoran, Schickelrot, & Paradiso



DIGITAL AIRBRUSH

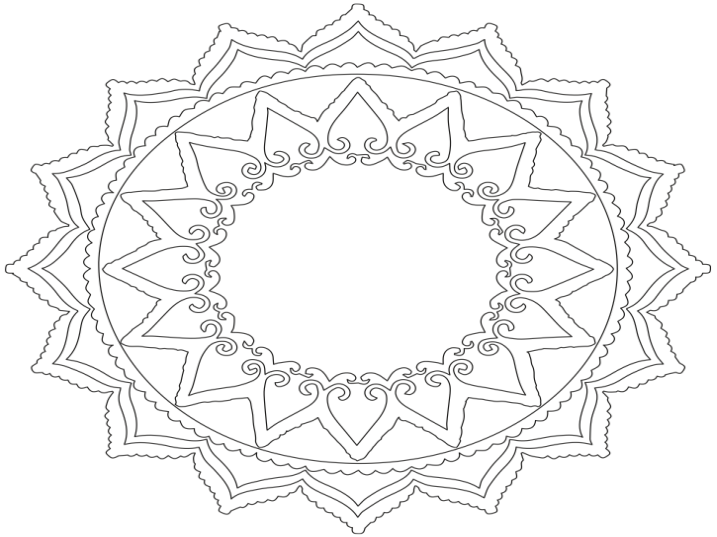


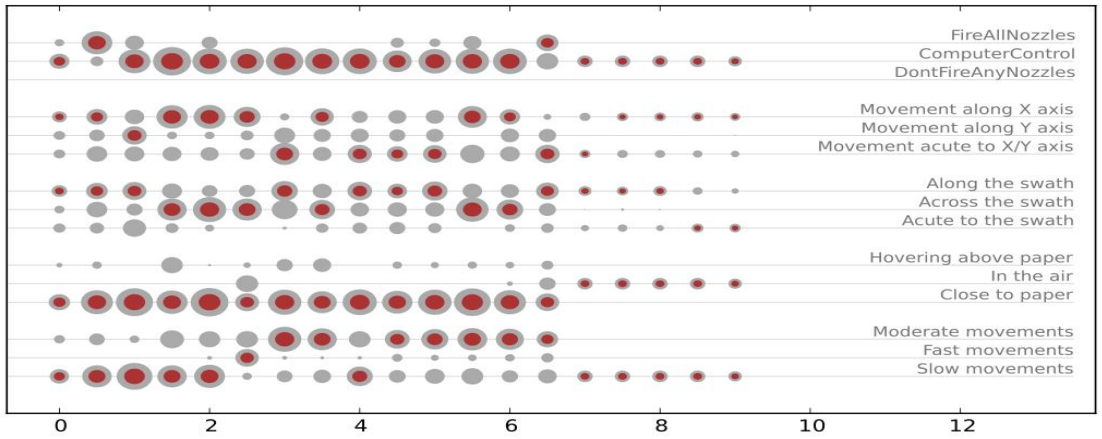


Zoran, A., Shilkrot, R., Nanyakkara, S., Paradiso, J., "The Hybrid Artisans: A Case Study in Smart Tools," ACM Trans. Comput.-Hum. Interact. (ToCHI), Vol. 21, No. 3, Article 15 (June 2014)

NISANCHI – SMART HANDHELD PRINTER FOR 3D NONCONFORMAL SURFACES

PRINTER RESULTS





BoardLab

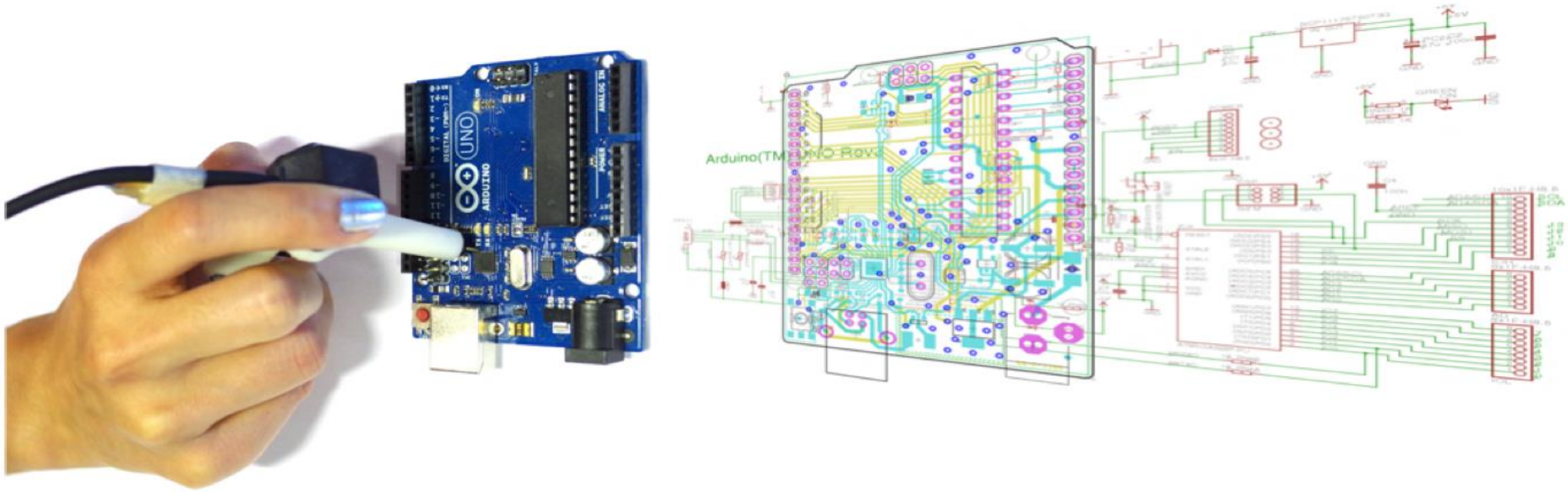
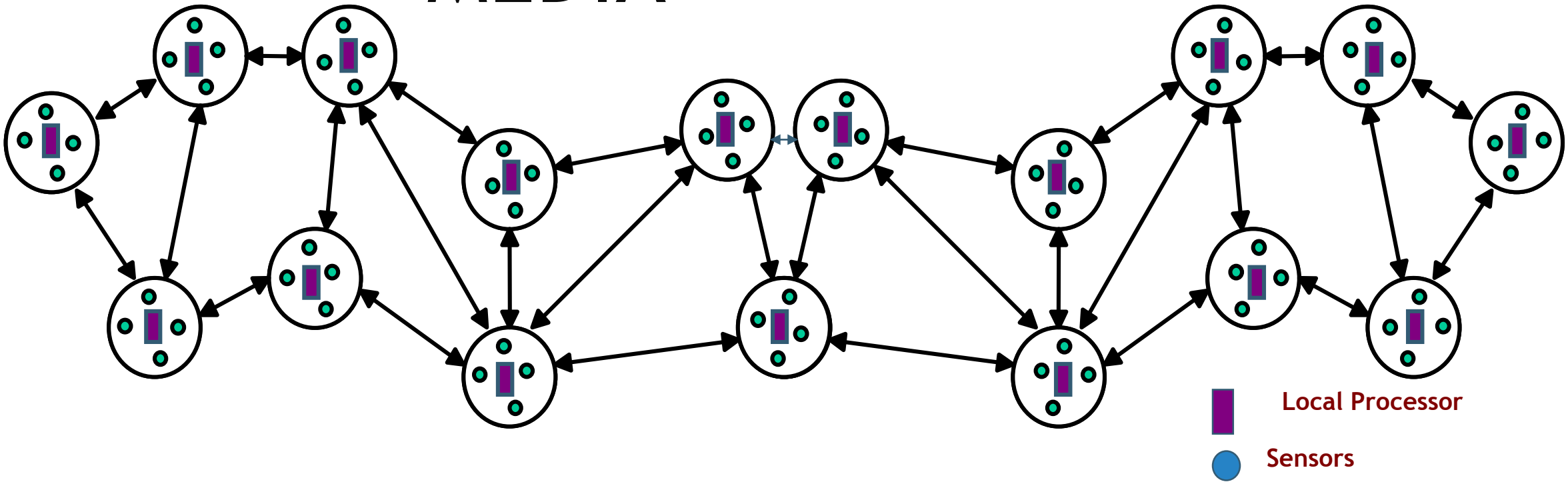


Figure 2-1: BoardLab conceptual diagram

Goyal et al, demo at UIST 2013

VII) Sensate Materials

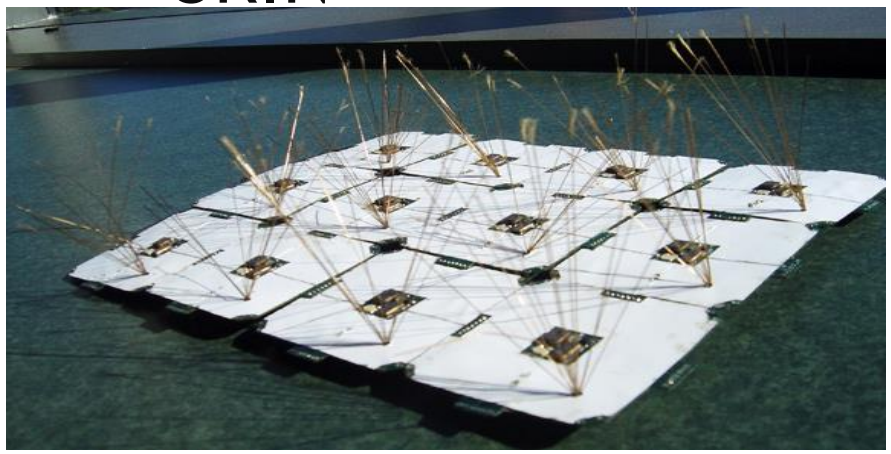
SENSATE MEDIA

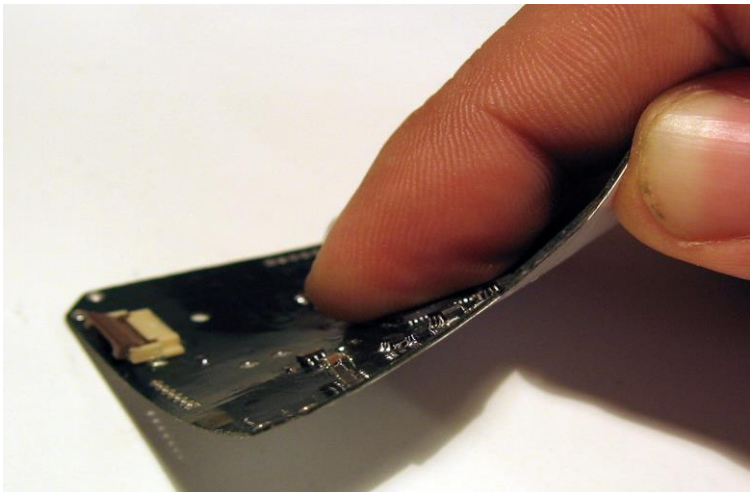


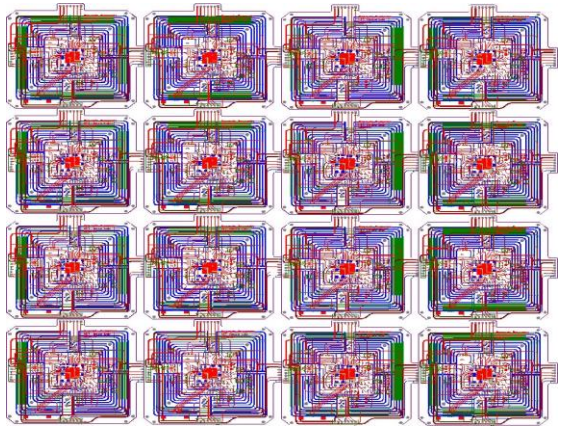
Densely-networked sensor-processor 'Soup' – Electronic skin, etc.

Paradiso, J.A., Lifton. J., and Broxton, M., Sensate Media – Multimodal Electronic Skins as Dense Sensor Networks, *BT Technology Journal*, Vol. 22, No. 4, October 2004, pp. 32-44.

SENSOR NET ARRAY, KAPTON EMBEDDED (SNAKE) SKIN







'S.N.A.K.E.: A Dynamically Reconfigurable Artificial Sensate Skin ,' Gerardo Barroeta Péerez, M.S. Thesis, August 2006

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

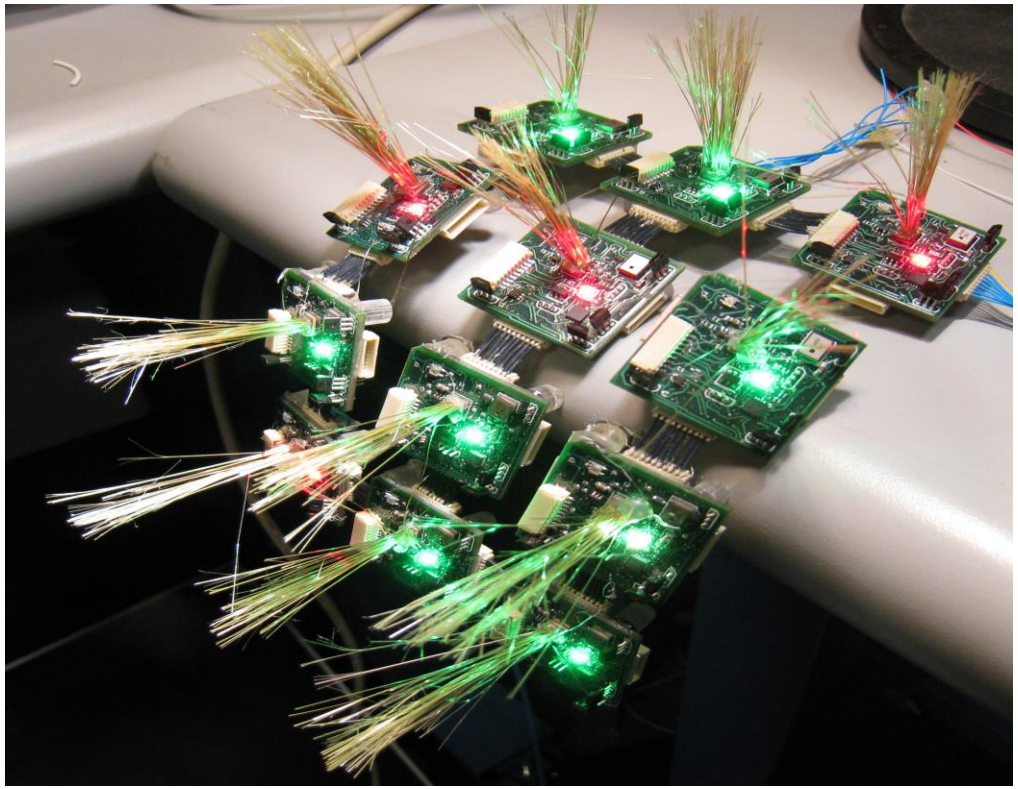
Scalable!

CHAINMAIL - SCALABLE SENSATE SURFACE

Rigid nodes, flex connects

Multimodal:

- Light
- Sound
- Whiskers
- Pressure
- Temperature
- Bend

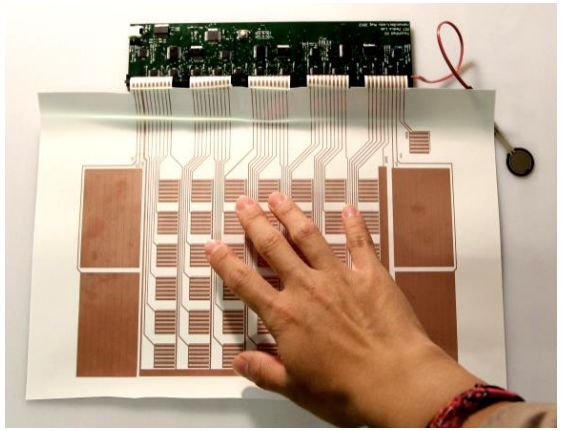


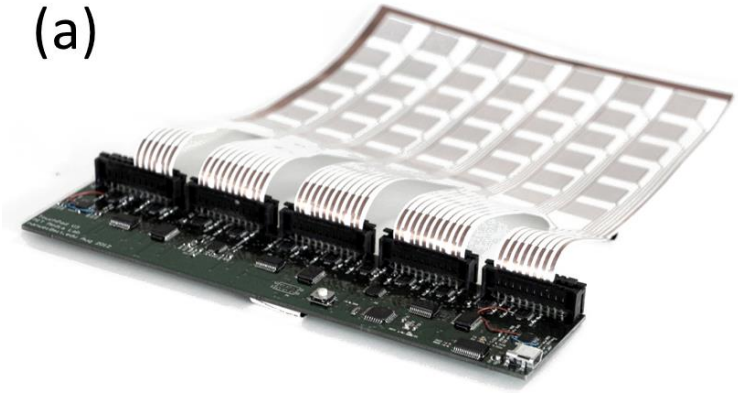
Mistree, B.F.T., and Paradiso, J.A., 'ChainMail – A Configurable Multimodal Lining to Enable Sensate Surfaces and Interactive Objects,' in Proc. of TEI 2010

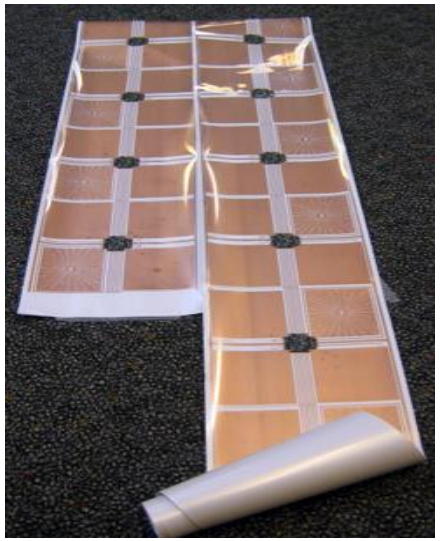
Printable Multimodal & Conformable Sensate Linings

Nan-Wei Gong, Nan Zhao, Yoshi Kawahara, Joe Paradiso
Responsive Environments Group

-A low-cost sensing surface plus electronic circuitry based on roll-to-roll printing process







N.W. Gong et al, "PrintSense: A Versatile Sensing Technique to Support Multimodal Flexible Surface Interaction," *CHI 2014*

Multimodal EM Sensor

CSAIL
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

PRINTABLE AESTHETIC CONTROL SURFACES

NanWei Gong & Amit Zoran

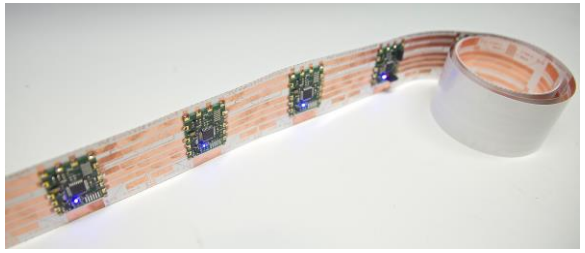
PROFESSIONAL EDUCATION

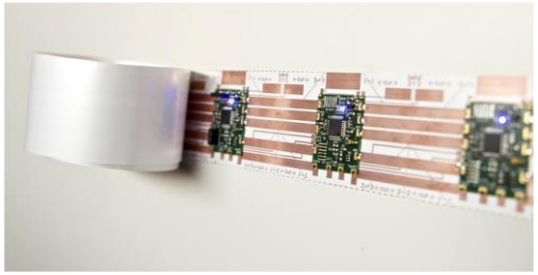
Demo at UIST 2013

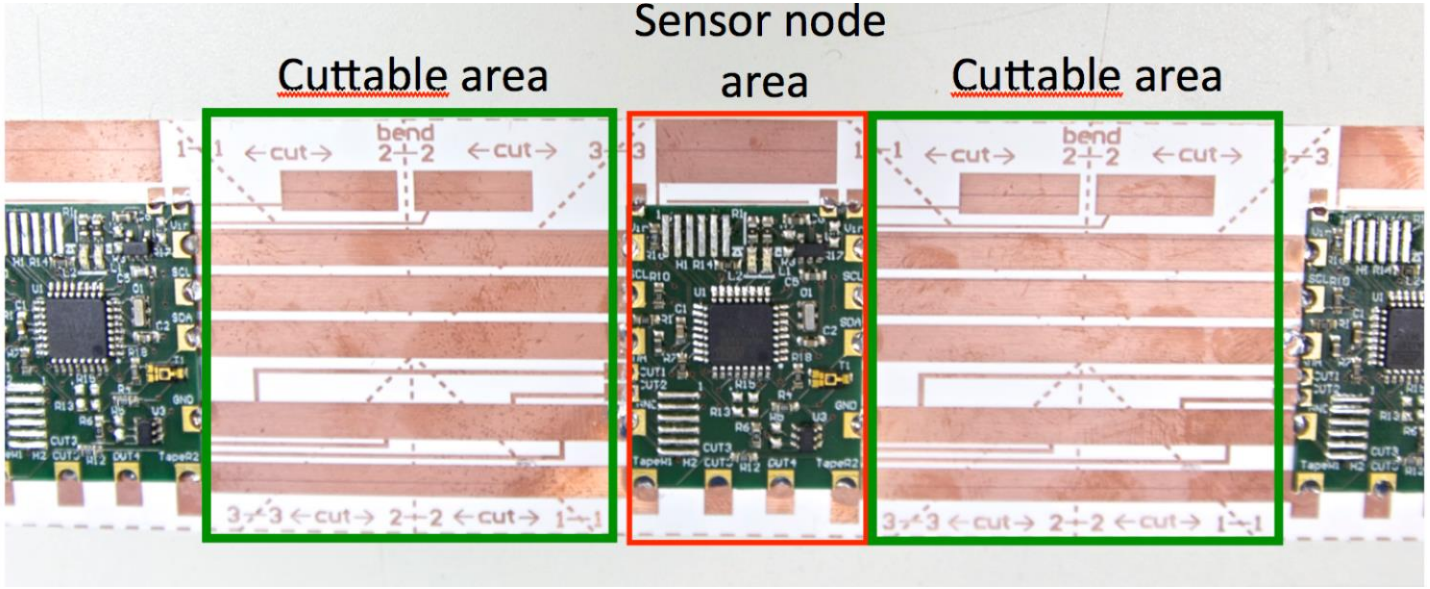
The Internet of Things: Roadmap to a Connected World

CSAIL
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY

NEW TWISTS TO SENSOR TAPE

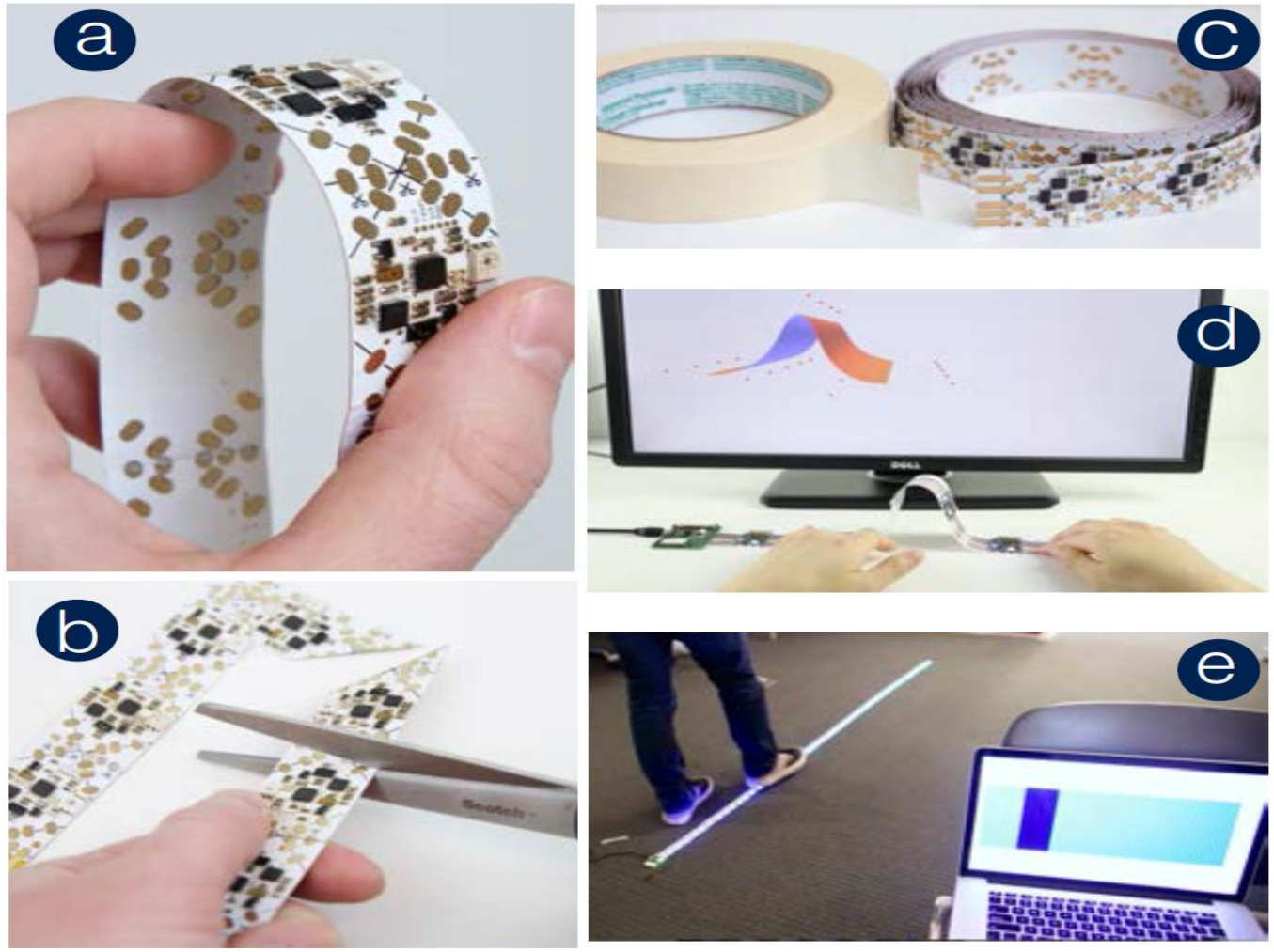




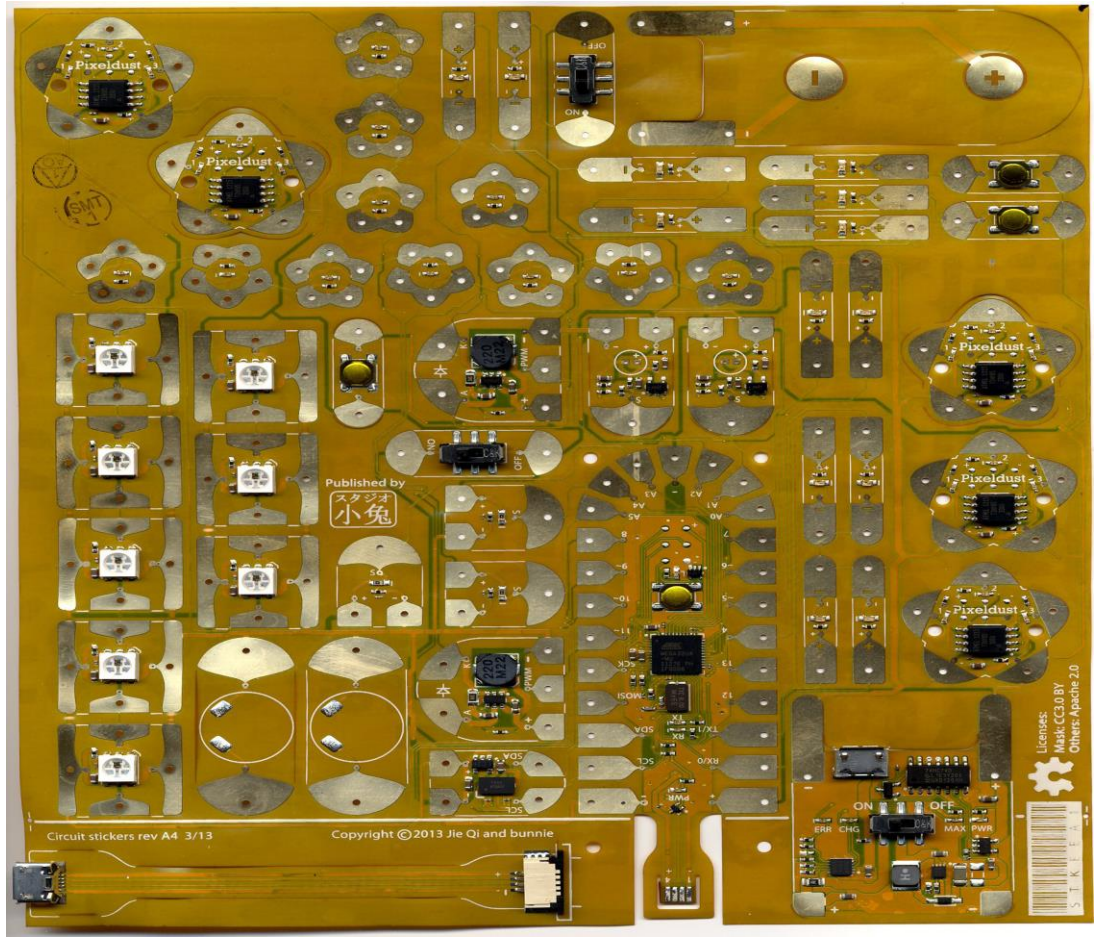


Artem Dementyev

NEW DESIGN ALL ON FLEX

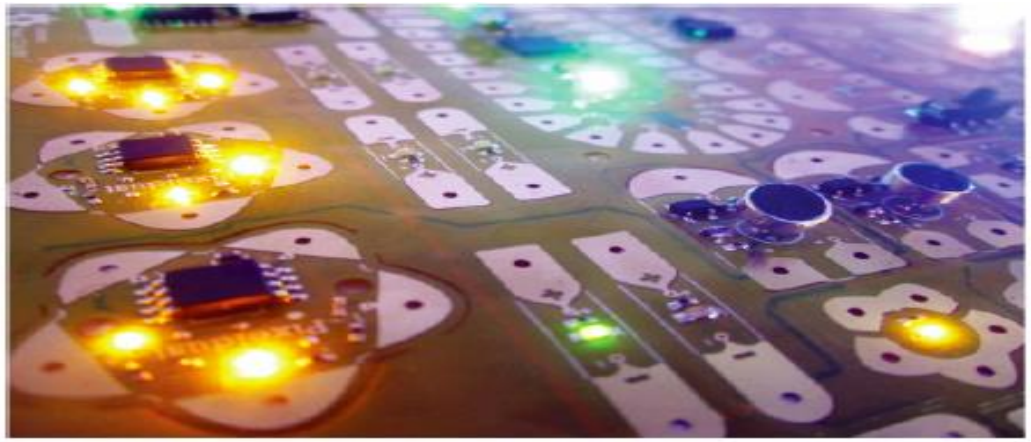


SENSOR & ELECTRONICS ‘STICKERS’



Diverse kit of sensors, circuits, components

Z-Tape sticky backing (conducts only vertically)

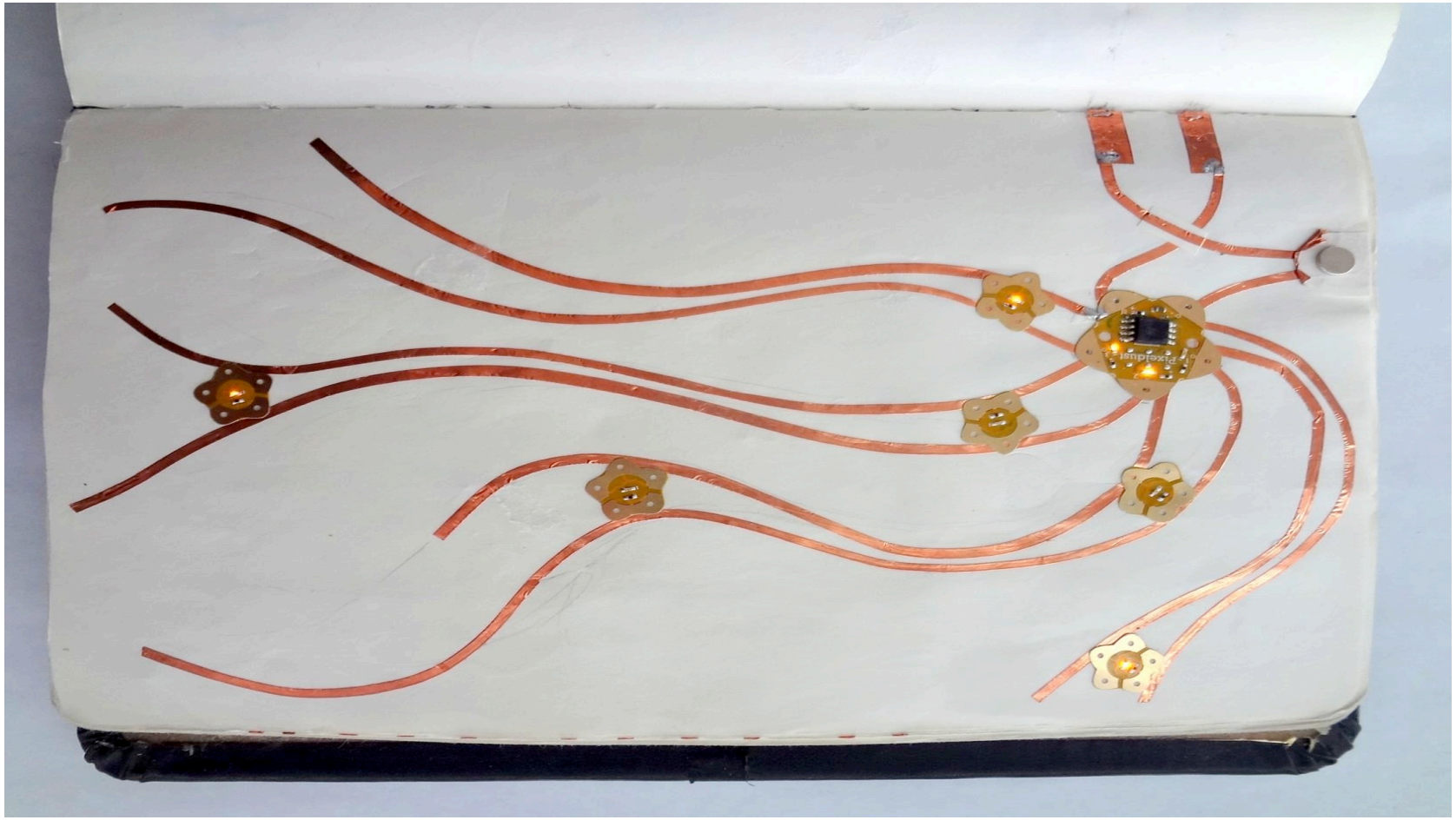


Jie Qi, Bunnie Huang

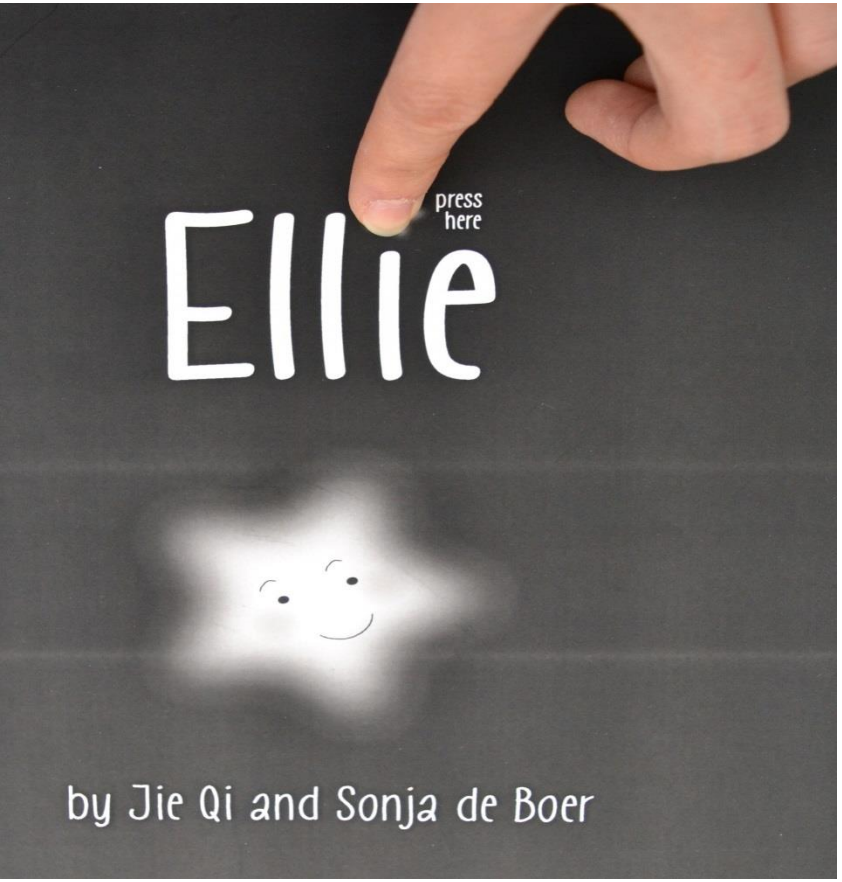
Jie Qi - Sketchbook

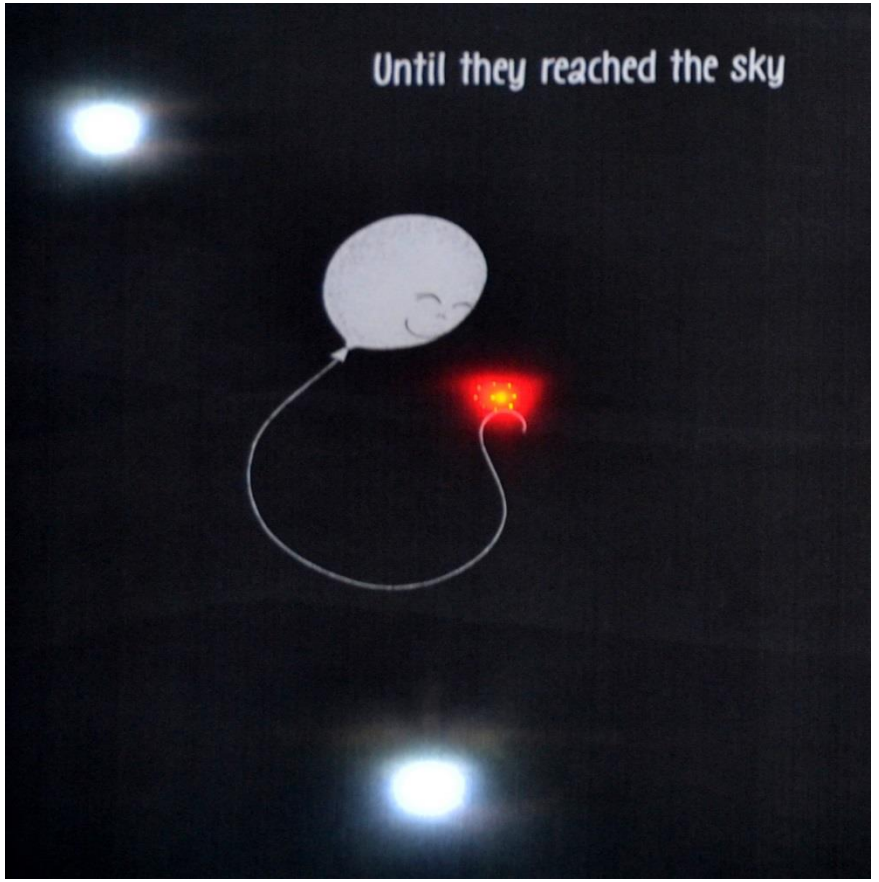
Circuit sketching with copper tape and stickers

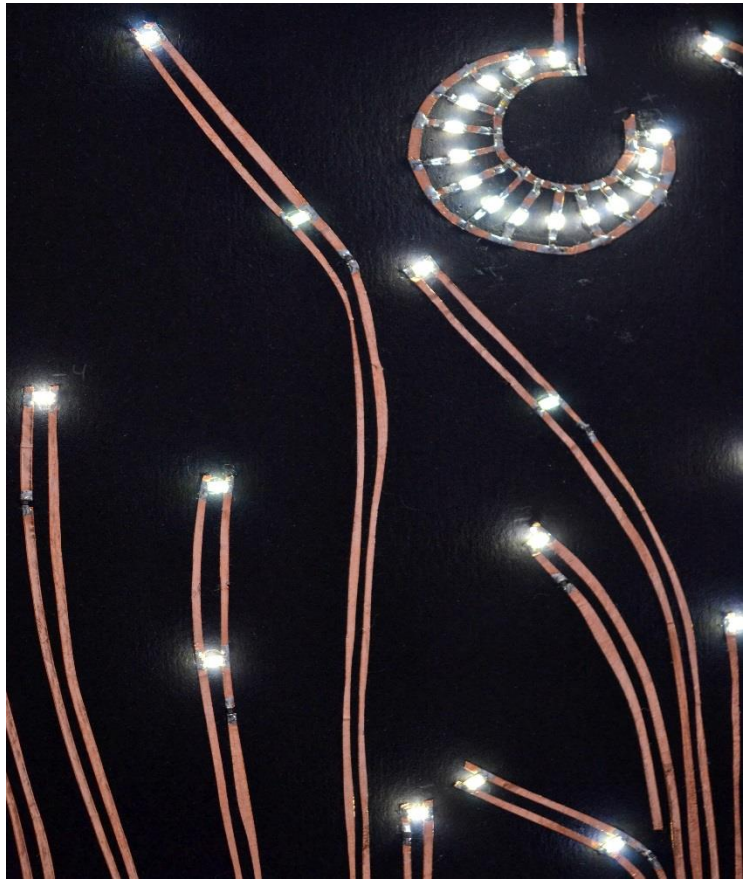
http://technolojie.com/circuit-stickers/



CIRCUIT STORYBOOK: ELLIE THE LED





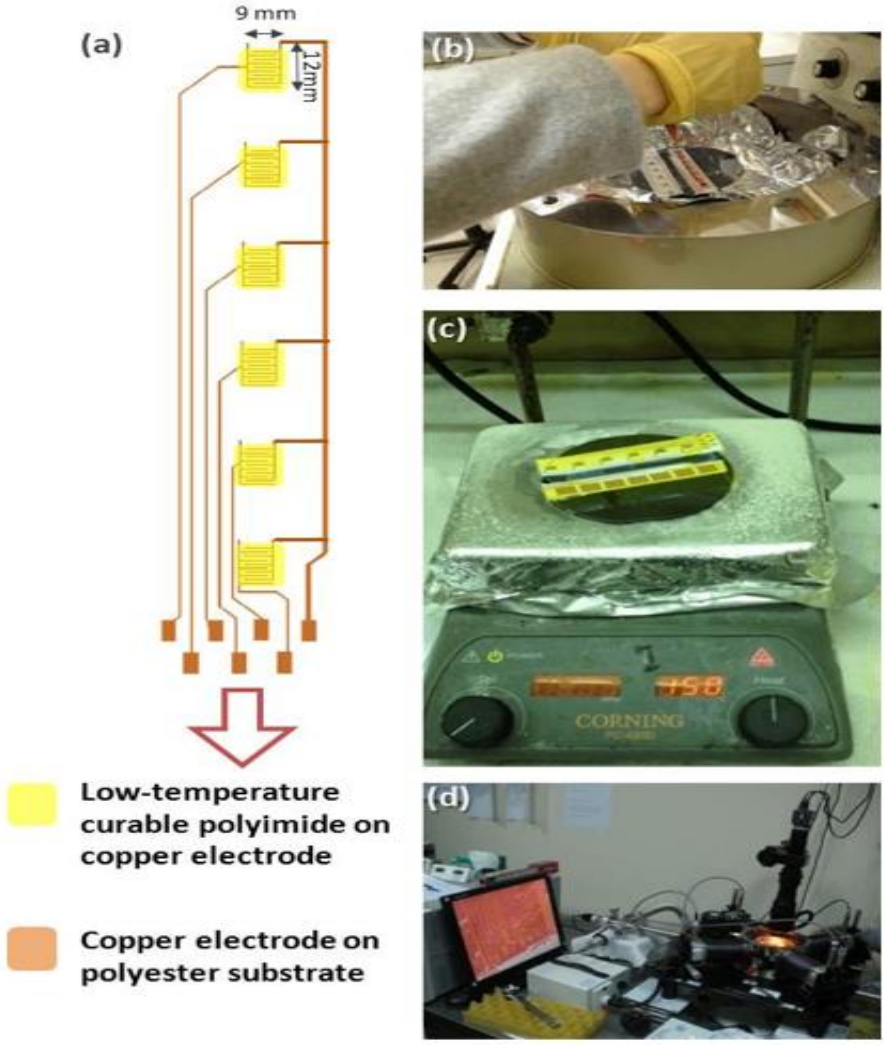


Combining circuitry with the picture book

to explore storytelling with light and sensing

The Internet of Things: Roadmap to a Connected World

TOWARDS "SENSOR TAPE"



Turn this into an extensible "tape"

Design dispenser, scaling topology

Explore Self-Power via RF

Multiple sensor modalities

Ink-jet print circuitry & sensors

"Low-cost Sensor Tape for Environmental Sensing Based on Roll-to-roll Manufacturing Process" – N.W. Gong et al, presented at IEEE Sensors 2012.

Yoshi Kawahara's printed self-powered plant sensor

EPILOGUE

Sensors are getting out there, piggybacking on commercial products

Once affordances are shared across devices, we're living in an ecology of devices & applications

- This will happen fast once started
- Phase transition into true Ubicomp

A prime challenge for our community is how to interface humans to this electronic nervous system

VIII) Resources

RESOURCES

MIT Media Lab's Responsive Environments Group Website

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

Ubiquitous Computing Research Conferences

- Ubicomp - http://ubicomp.org
- PerCom – http://www.percom.org
- Mobiquitous – http://mobiquitous.org
- IoT - http://www.iot-conference.org/
- PerDis - http://www.pervasivedisplays.org/

RESOURCES (CONTINUED)

Human-Computer Interface (HCI) Research Conferences

- CHI - http://www.sigchi.org/conferences
- UIST – http://uist.acm.org
- TEI - http://www.tei-conf.org/

Embedded Sensing and the Built Environment

- BuildSys – http://www.buildsys.org/

RESOURCES (CONTINUED)

Sensor Network Research Conferences

- Sensys – http://sensys.acm.org/
- IPSN - http://ipsn.acm.org/
- EWSN - http://www.ewsn.org/
- SenseApp - https://www.senseapp.org

RESOURCES (CONTINUED)

Wearable Computing and Sensing Research Conferences

- ISWC - http://www.iswc.net/
- BSN - http://www.bsn2015.org/
- BodyNets - http://bodynets.org/
- IEEE EMBC - http://embc.embs.org/
- BioDevices - http://www.biodevices.biostec.org/

RESOURCES (CONT)

Sensor Technology, Energy Harvesting, etc.

- IEEE Sensors - http://ieee-sensors2016.org/
- PowerMEMS - http://www.powermems.org/
- IEEE RFID - http://2016.ieee-rfid.org/

Magazines & Periodicals

- IEEE Pervasive Computing - http://www.computer.org/pervasive
- Springer Journal of Personal and Ubiquitous Computing
  - http://www.springer.com/computer/hci/journal/779

THANK YOU!

Joe Paradiso

Responsive Environments Group, MIT Media Lab

Computer Science and Artificial Intelligence Laboratory (CSAIL)
Massachusetts Institute of Technology