Communication and Sensing at the Extremities

Joe Paradiso

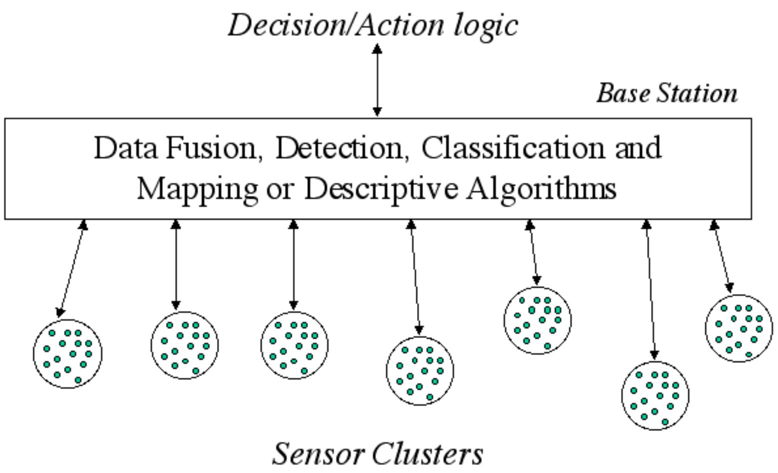
Responsive Environments Group, MIT Media Lab

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

Responsive Environments Interests

- We create new sensing modalities and enabling technologies for responsive spaces that create new forms of interactive experience and expression.
- Our work is highlighted in diverse application areas, which range from interactive music systems and wearable computers to smart highways and medical instrumentation.

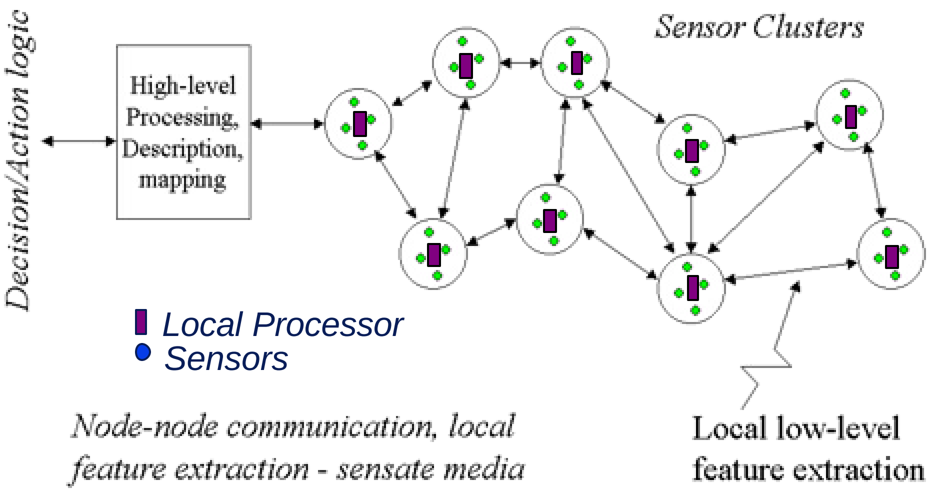
Intelligence at the Extremeties



Star Topology

- **Local processor detects, processes or compresses local features**
- **High data rates possible with limited node densities**

Wearable, medical applications



Peer-Peer

- **Feature extraction via local communication**
- **Results routed out node-node**
- **Potentially scalable to very high density**

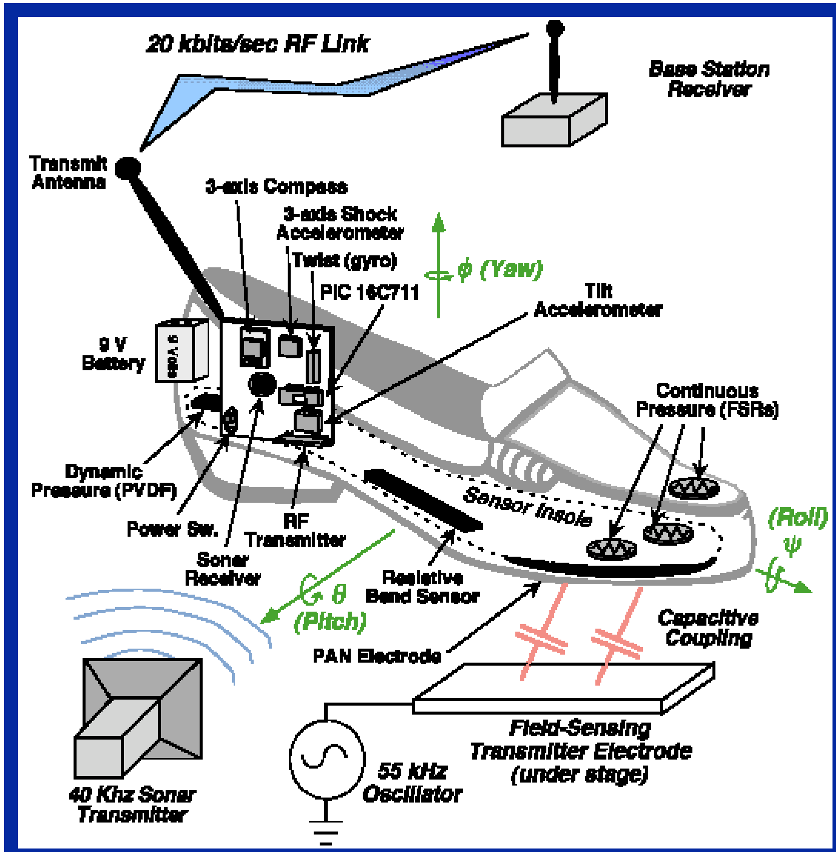
Electronic skins, sensate media

Expressive Footwear

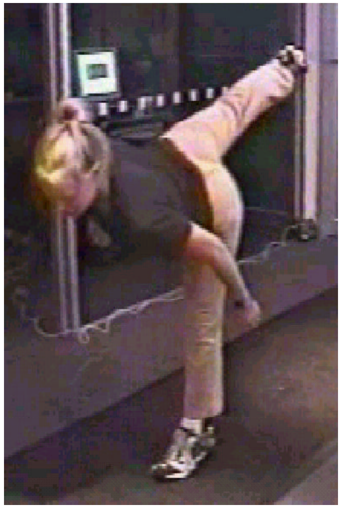
17 Data Channels

- 2-axis tilt sensor
- 3-axis compass
- 1-axis rate gyro
- 3-axis shock sensor
- Height sensor (EFS)
- Sonar receiver
- 1 PVDF strip (sole)
- 3 FSR pressure tabs (sole)
- Bend sensor (sole)
- 3 Volt Battery Reference
- Battery low detect

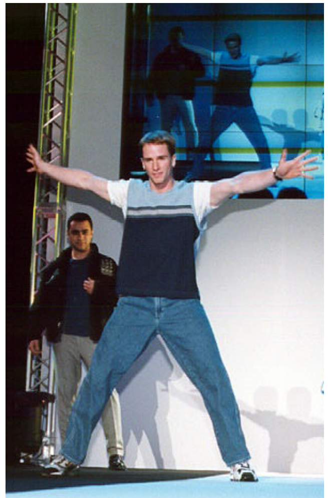
- 20 kb/sec wireless
- 413 & 433 MHZ
- PIC 16C711
- 50 Hz updates from each foot.
- ~ 50 mA draw
  - Half day or more of life



Applications – 1997-2001...



Mia Keinanen
Dancer

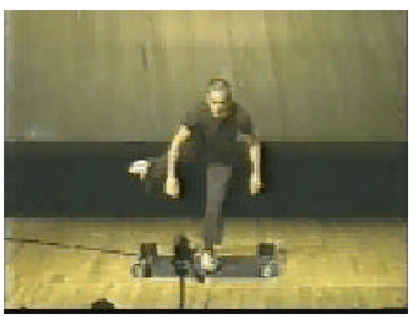


Brian Clarkson
Gymnast

Tokyo Toy Fair
Juggler

Byron Suber
Choreographer

Discover
2000 Award for Technical Innovation



Mark Haim
Dancer
Choreographer
Musician

4:10

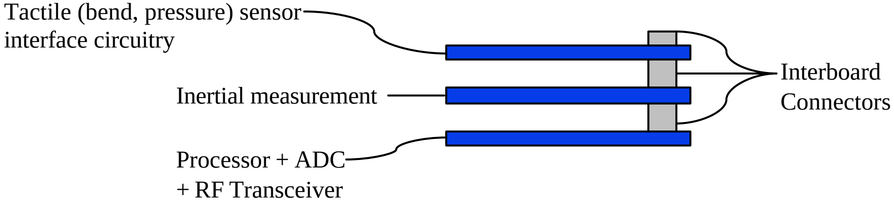
Chris Haring
Ars Electronica 01

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

Compact MultiSensor Wireless Stack

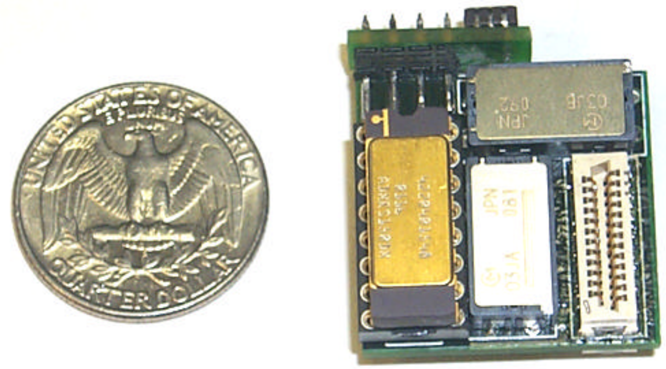
- Stack of ultracompact, low power circuit boards
- Inertial, tactile, location/displacement board layers
- Wireless RF layer – many nodes networked to base station
- Basis of configurable wearable system for interactive dance, medical monitoring

3-layer wearable board stack

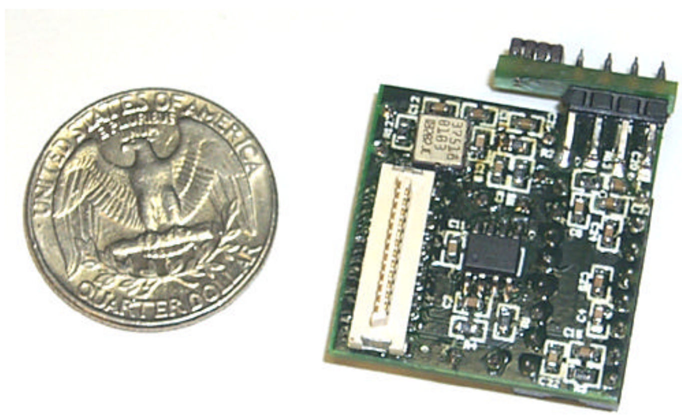


Ari Benbasat

Inertial Board – 6 axis IMU



Top

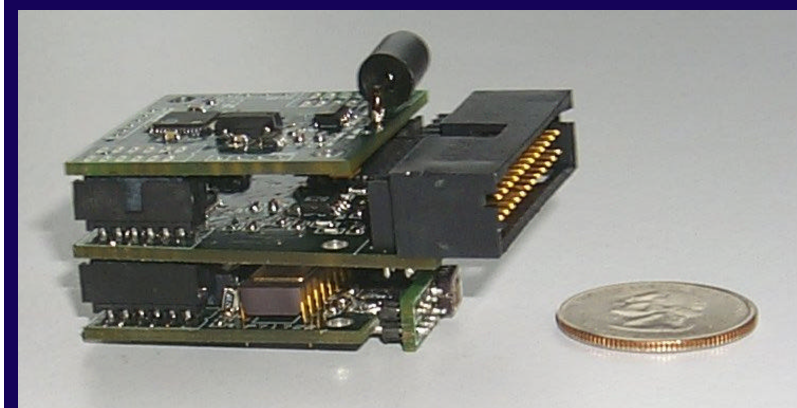


Bottom

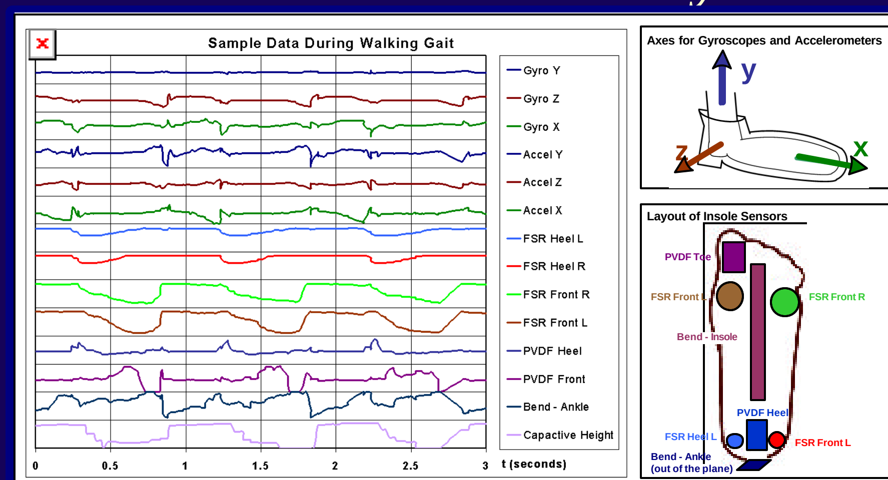
Connecting to the Body

- Collaboration with Mass. General Hospital Biomotion Unit
- Will be used for diagnosis, treatment of gait-related disorders, Parkinson's patients, interactive therapy, etc.
- Circa 20 sensors per foot
    - Chosen with gait specialists
    - Rich gait description
- Inertial, proximity, and tactile sensor array, wireless from each foot

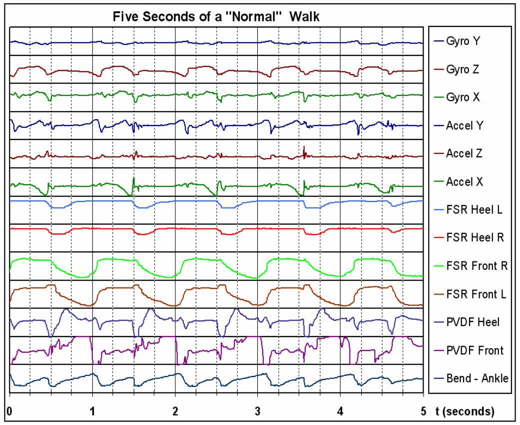
Stacy Morris



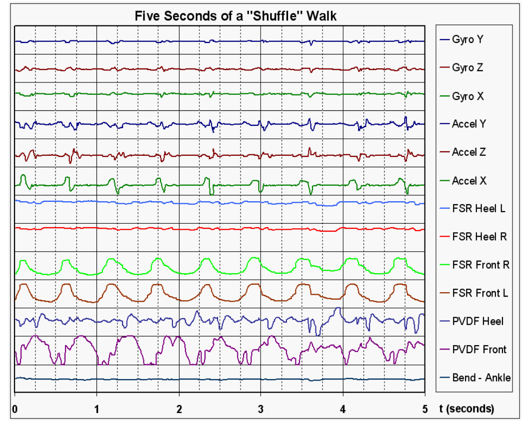
Latest configurable wireless stacking multisensor array



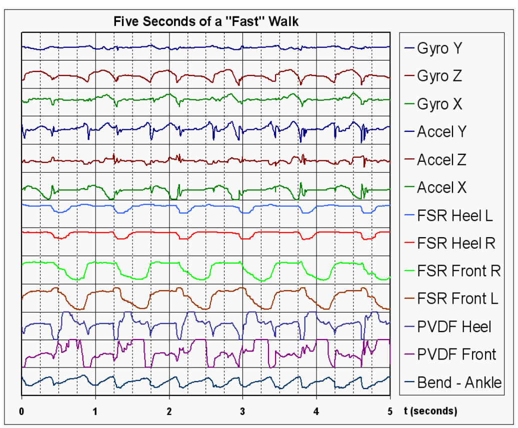
Signals for different walks



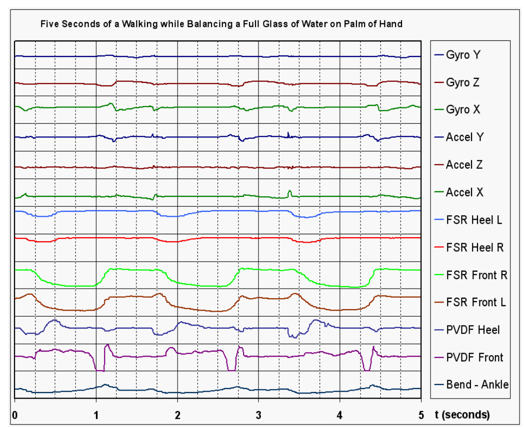
Normal Gait



Shuffling Gait

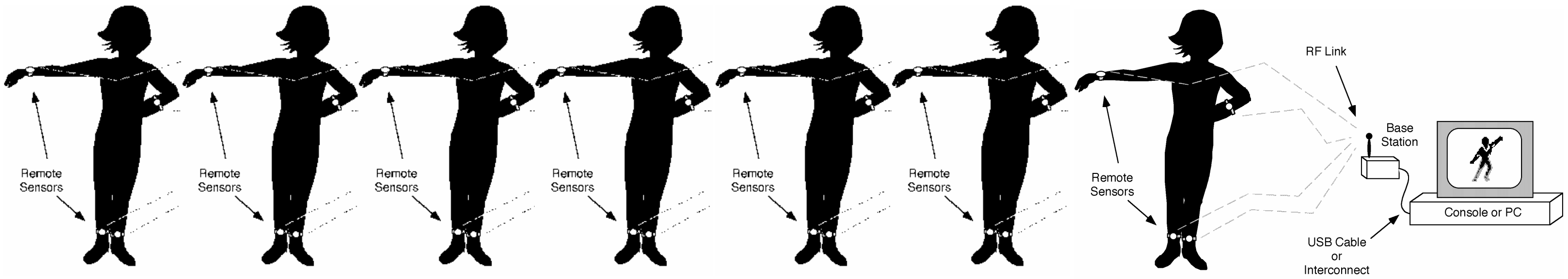


Fast (Normal) Gait



Gait while Performing a Difficult Task

Scaling to several dancers…

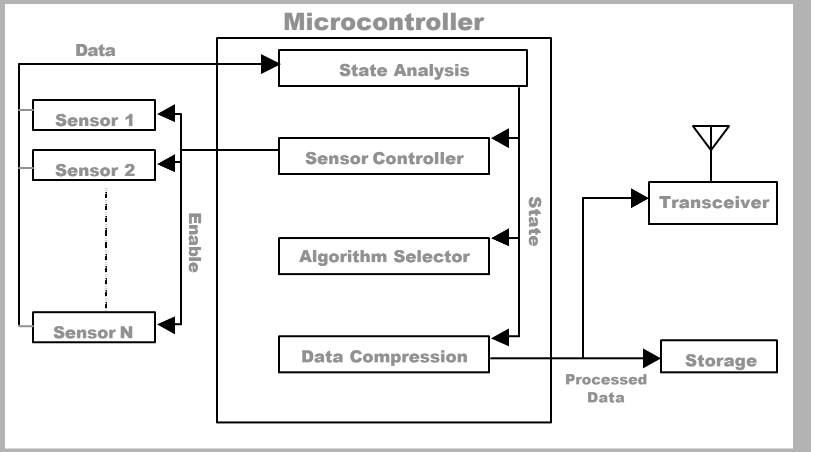


- Current Expressive Footwear system measures 16 parameters at each foot
- Scaling to upper/lower body of small (e.g., 5-person) ensemble produces 320 parameters
- Impossible to map content at sensor level!
- New techniques needed
- Low Power RF system with more bandwidth
  - 1 Mbit/second

Design Principles for Efficient Smart Sensor Systems

Ari Y. Benbasat

- **Limited power availability is one of the key problems in smart sensor systems**
- **Design smart sensor system to operate as efficiently (low-power) as possible**



•Application Scenarios:

– Medical logging device:

Stand-alone system (no outside data sources)

– Node in ad-hoc sensing network:

One of many similar sensor systems

•Possible Solutions:

- **–Real-time sensor selection**
- **–Variable accuracy processing**
- **–Selective Transmission vs. storage of data**

High Density Interconnect Technology Implementation

- Purpose-built Solutions for Embedding into Artefacts.

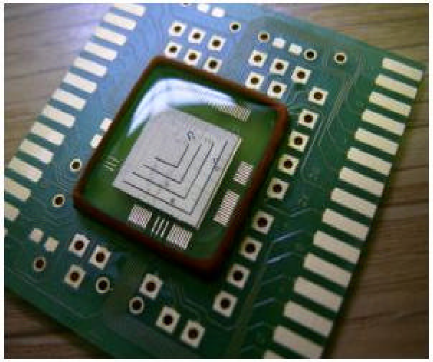
Multichip Modules (MCM)
- *Flip-Chip*

3-D Multichip Modules
- *Stacked ICs*
- *Thin Silicon ICs*

Flexible Modules
- *Multilayer Flex*
- *Thin Silicon ICs*

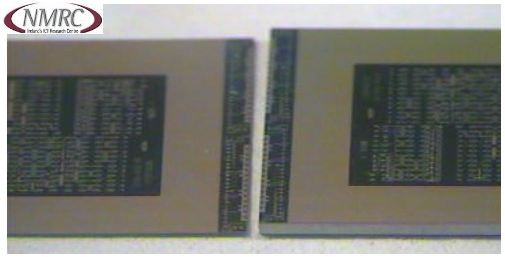
Molded Interconnect
- *Metal on Plastics*

Stacked ICs



Assembly with Five Stacked ICs.

Thin Silicon ICs



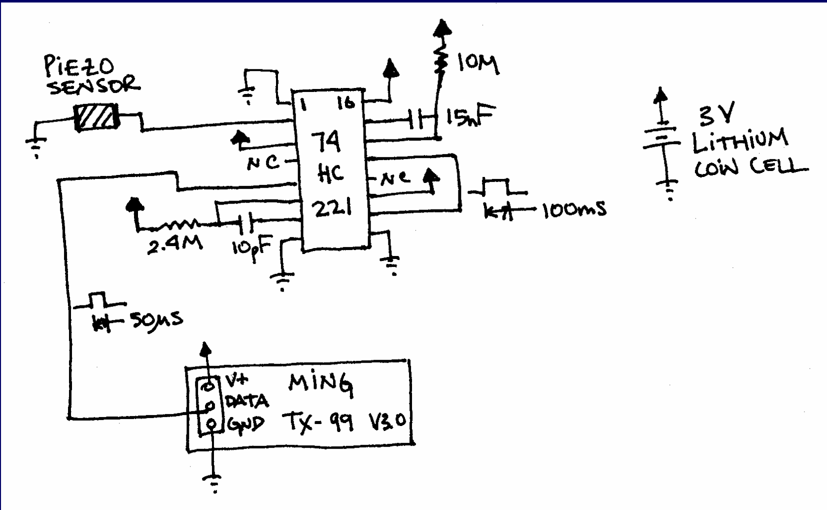
60μm Mechanical Sample IC.

Flex COB Assembly

Assembly on Flex

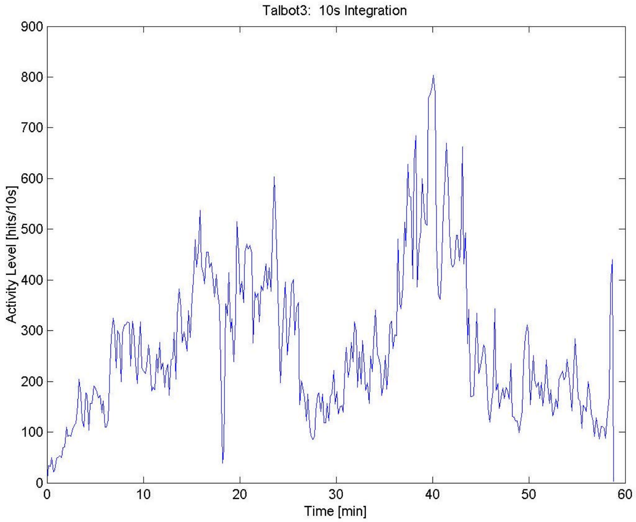
MCM – bare die bond @ NMRC, Cork

The Disposable Wireless Sensors



- Very simple 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

Interactive Raves at MIT



Activity (# hits per 10 seconds)

Power Harvesting Shoes

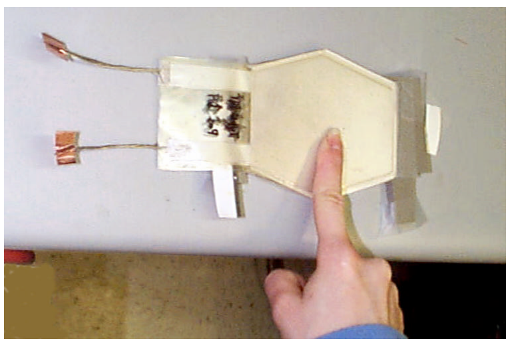
PVDF Stave

Molded into sole

Energy from bend

$P_{peak} \cong 10$ mW

$\langle P \rangle \cong 1$ mW



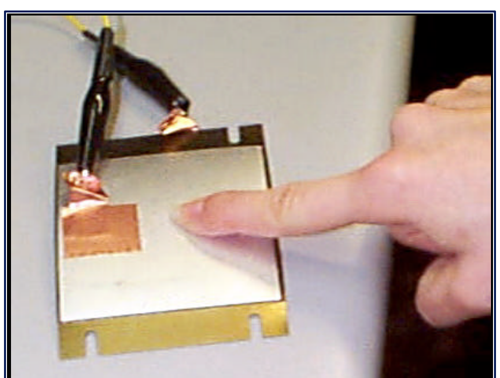
Flex PZT Unimorph

Under insole

Pressed by heel

$P_{peak} \cong 50$ mW

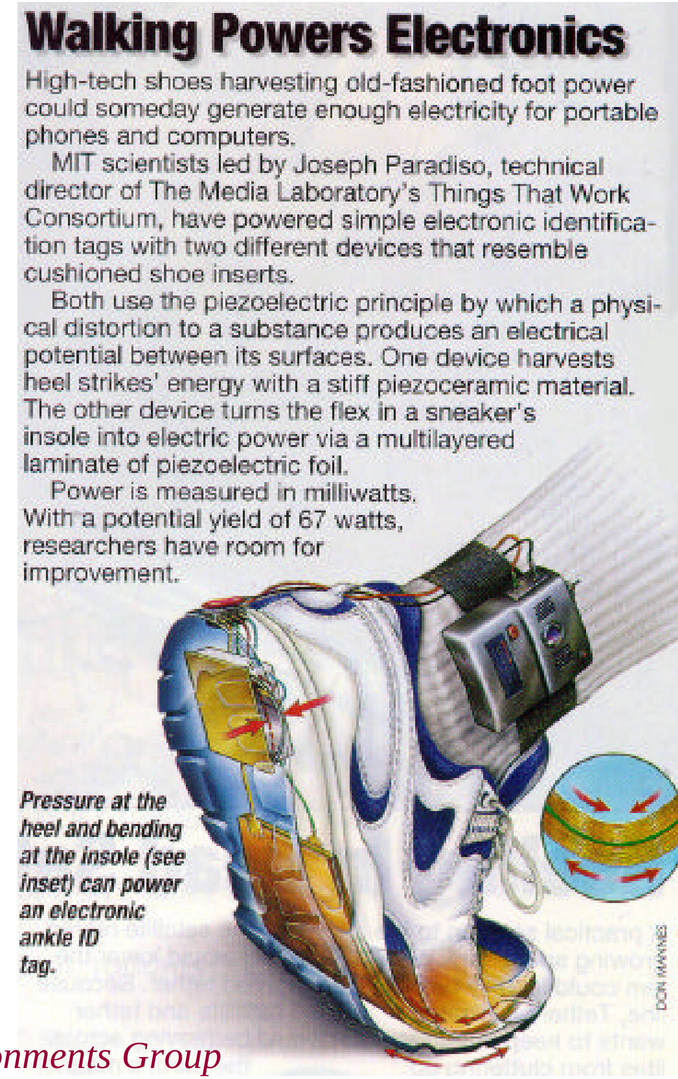
$\langle P \rangle \cong 10$ mW



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.

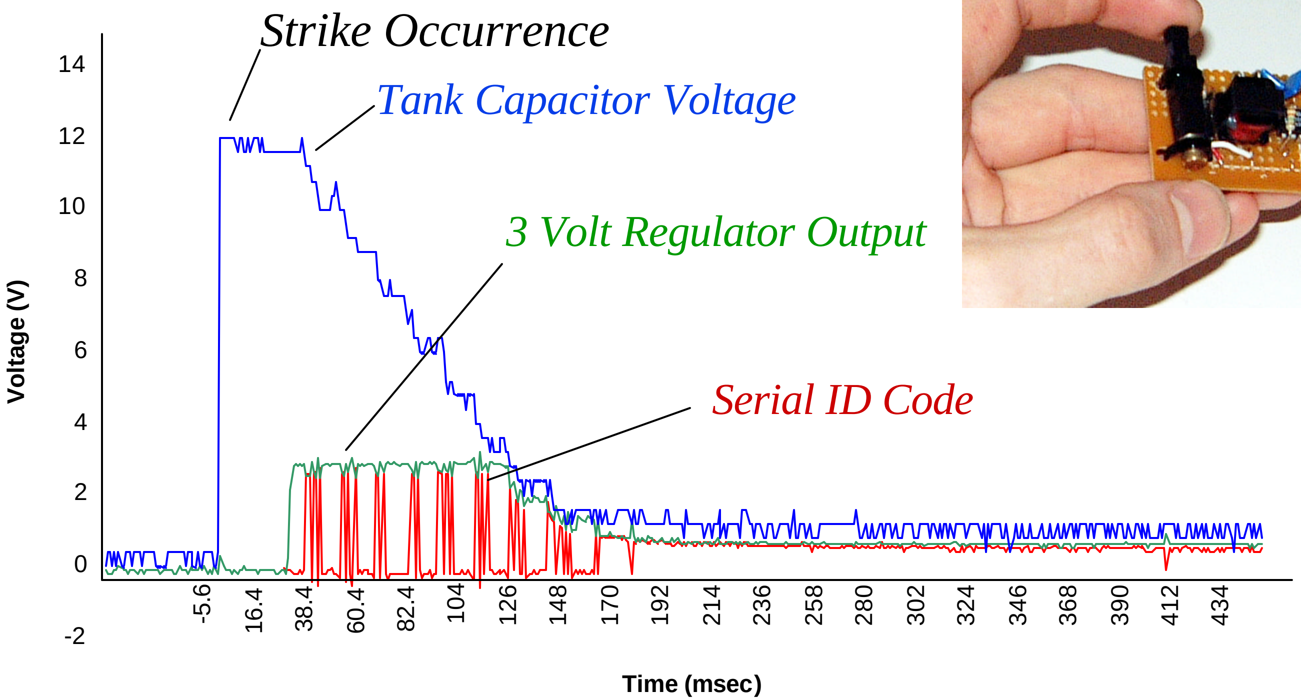
Power is measured in milliwatts. With a potential yield of 67 watts, researchers have room for improvement.

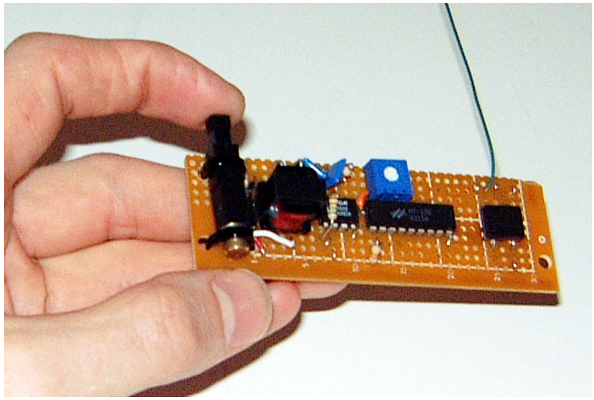
Pressure at the heel and bending at the insole (see inset) can power an electronic ankle ID tag.

DON MANNES

Responsive Environments Group
MIT Media Lab
1998 IEEE Wearable Computing Conference

Self-powered buttons

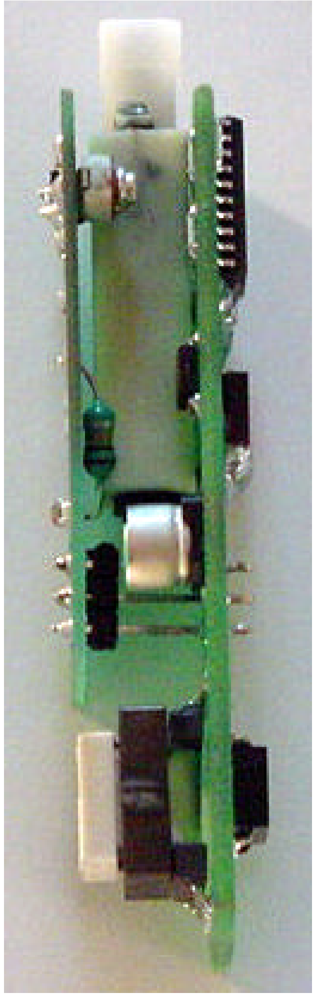


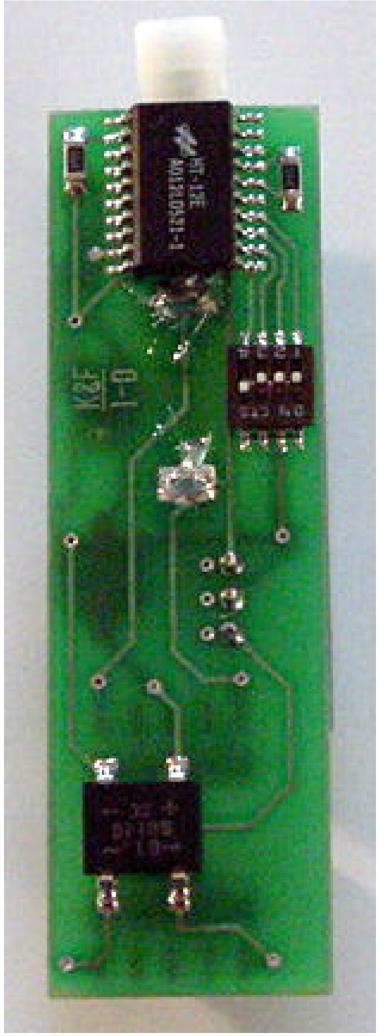


- ~0.5 mJ at 3 Volts per push
- Sends 12-bit RFID 12 x throughout floor (50 ft.)
- No need for battery, wire…

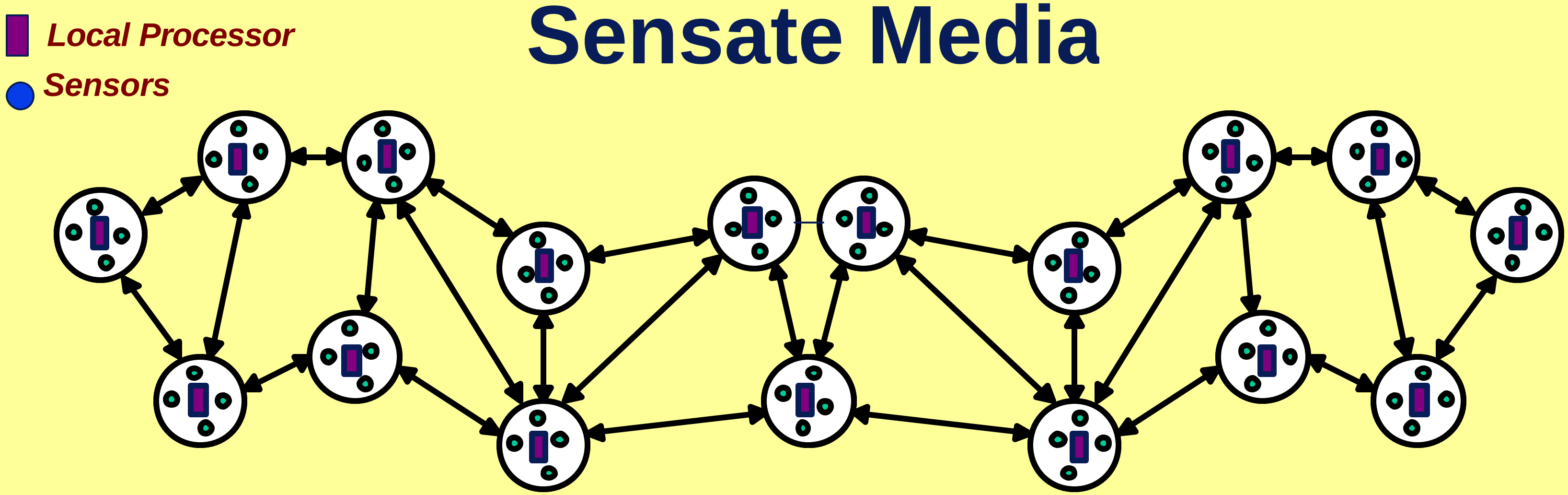
Mark Feldmeier

Cleaner Prototype (ML sponsor)



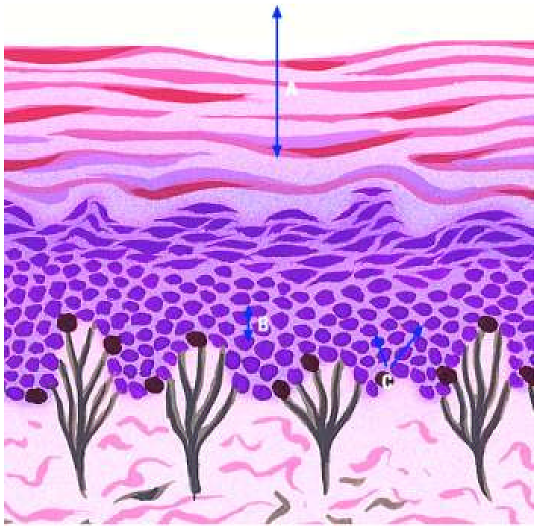


Sensate Media

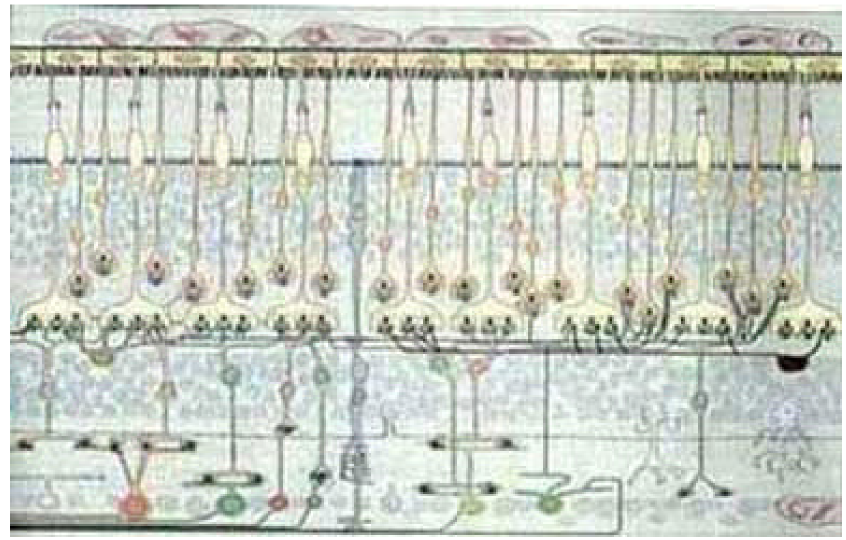


- Push the frontier of Ultradense, multimodal sensor/processor networks
  - Things That Think on a surface
  - Enables things to immersively sense as we do
    - Revolutionary apps in robotics, telepresence, medicine
  - Interesting challenges in decentralized processing and estimation, fabrication

Approximate Biology Comparison



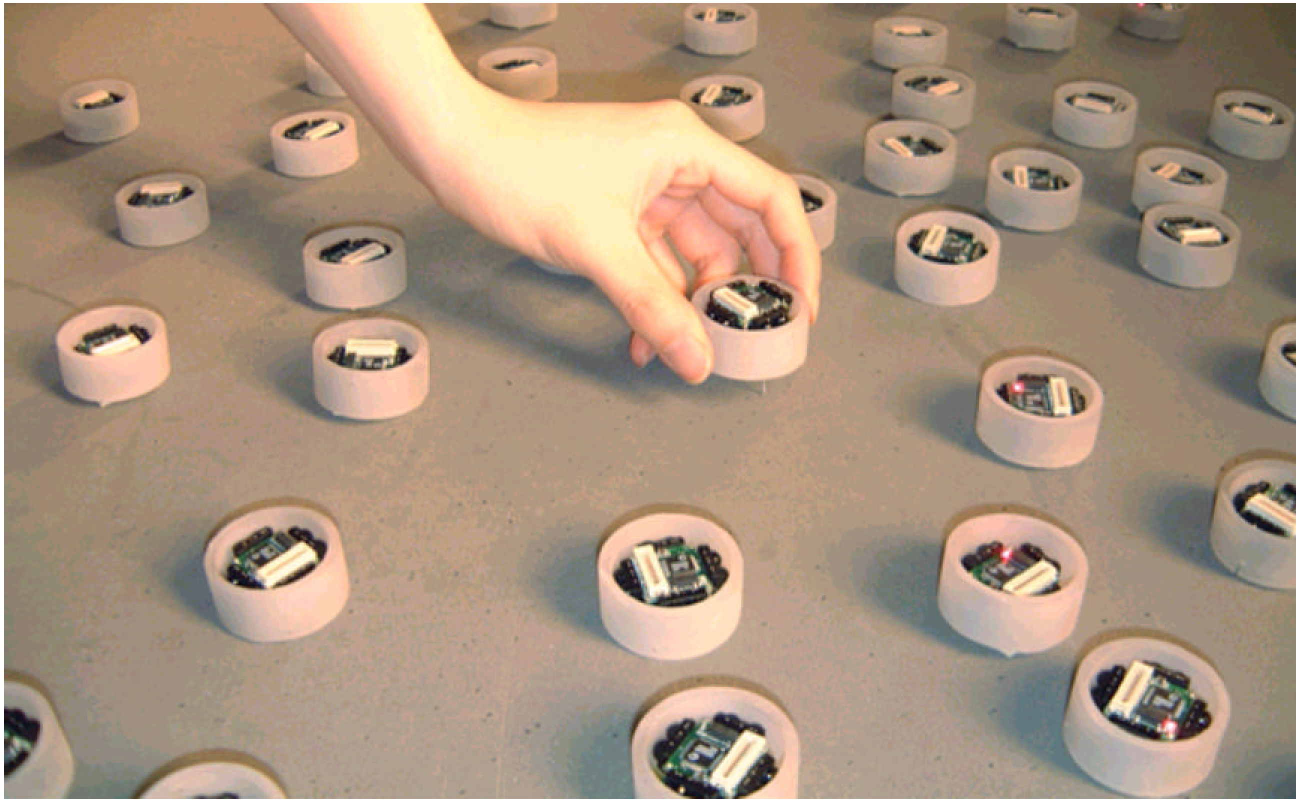
Skin



Retina

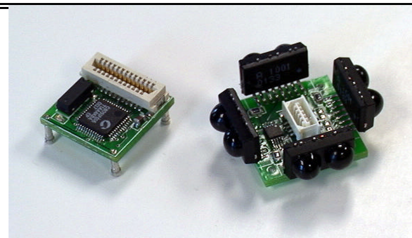
- Biological analog
  - Distributed processing mixed with sensors

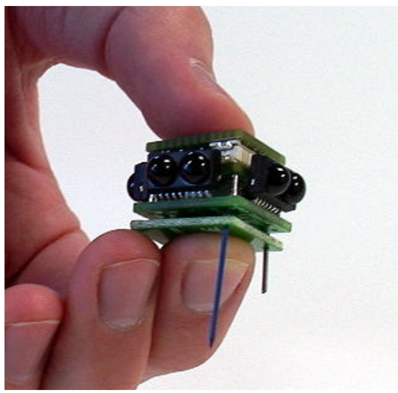
Completely Configurable Topology

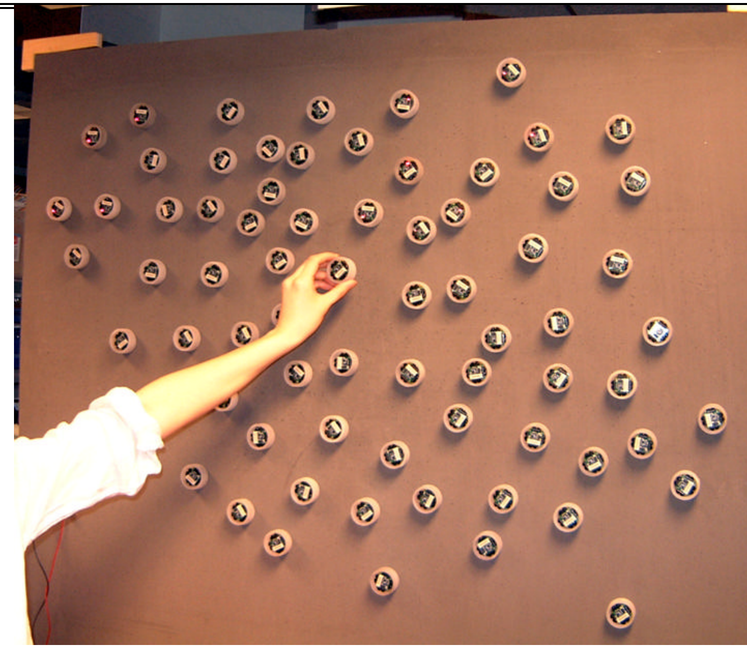


- Place nodes wherever one wants
  - Dynamic density
  - Easily block or shield parts of network
  - Easy to access each node directly

Pushpins – October 02

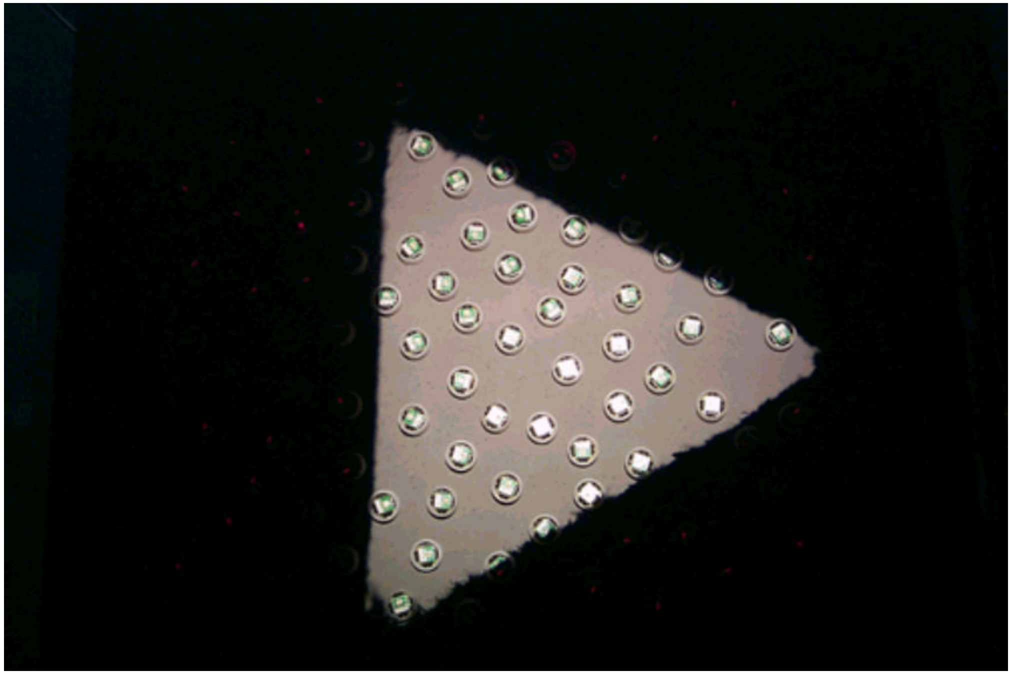


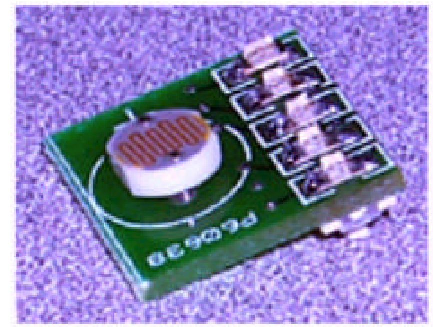




- Over 100 constructed (Currently IR communication)
  - Capacitive (low-power RF) layer coming – more isotrophic
- Sensor layer (photo sensor with LED outputs)
- Toolkit – all over ML, MIT
- New pushpin design with much more powerful μP under design

Distributed Pattern Recogniton

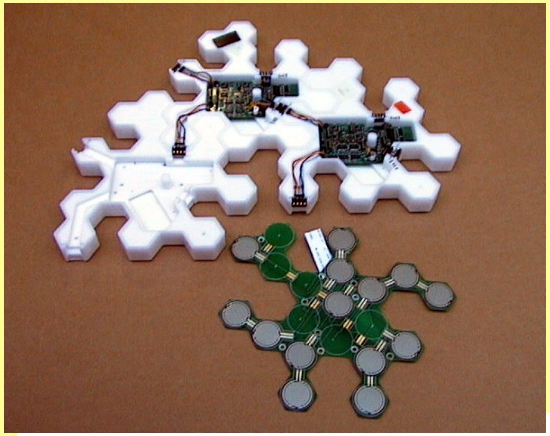


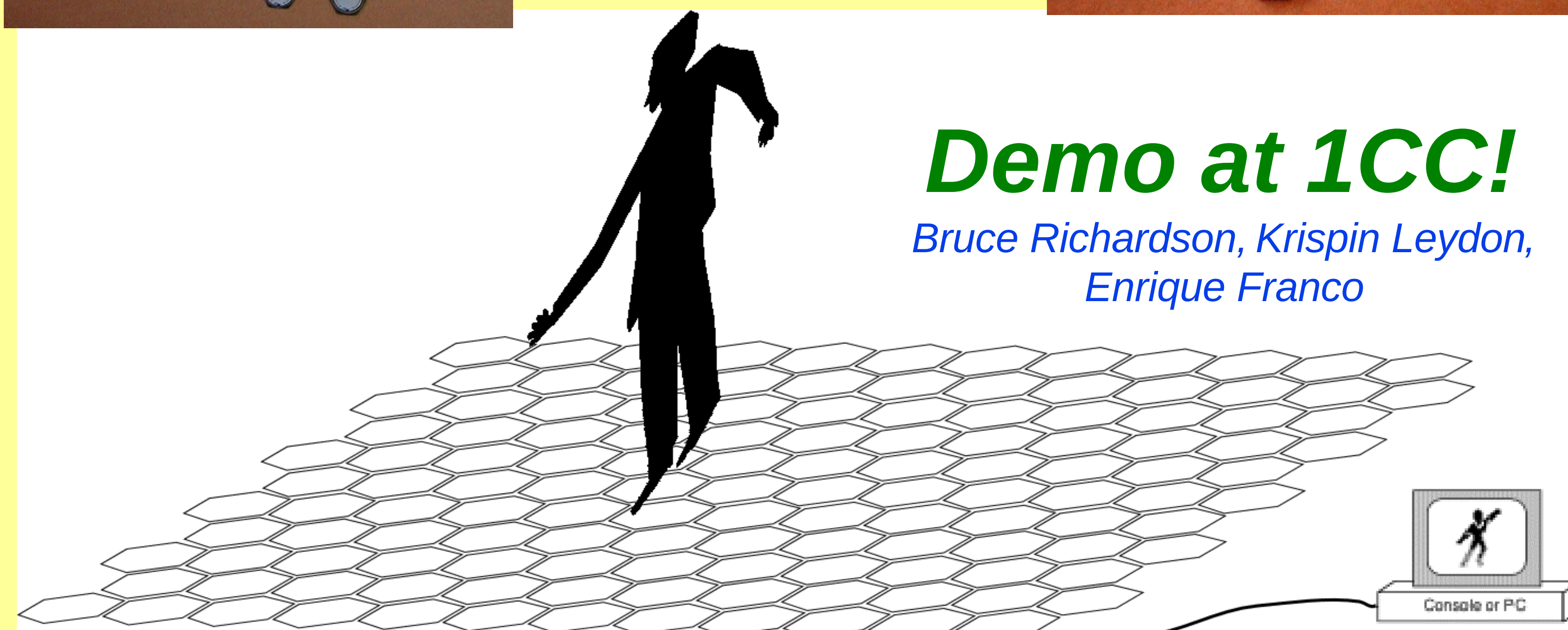


Light sensor & LED top layer

- **Developing rules for distributed (viral) pattern recognition**
  - **Project simple object (circle, square, triangle)**
  - **Discriminate via accumulated perimeter, area, etc.**
- **Tangible interface for group dynamics (Steelcase)**

Z-Tiles (collaboration with U. Limerick, MLE)



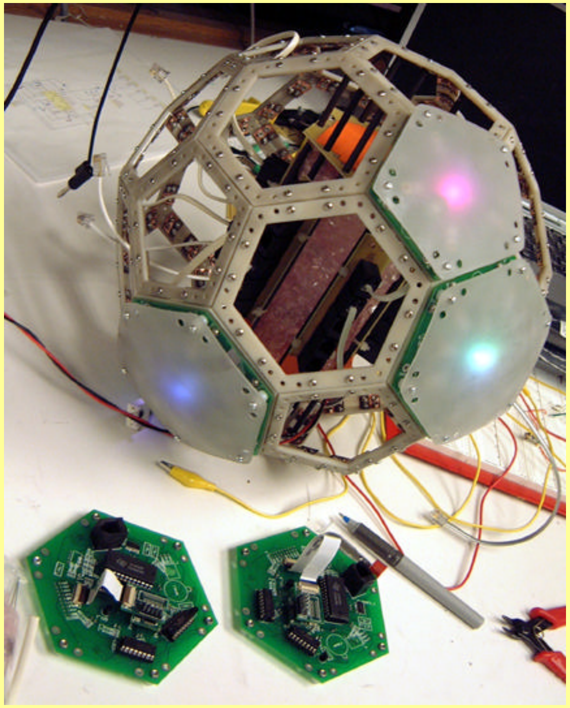


Demo at 1CC!

Bruce Richardson, Krispin Leydon, Enrique Franco

The "Trible"

Tactile Reactive Interface Based on Linked Elements



Josh Lifton,
Mike Broxton
Demo in 1CC

- First step at a multimodal electronic skin
- 32 networked elements
  - Each measuring up to 12 channels of fur, distributed pressure, temperature, sound
  - Each with local speaker, pager motor, RGB LED
- Elements talk to neighbors
  - No central processor
  - Decentralized algorithms
- Research platform for distributed computing
- Purrs…