System Support for Micro-Harvester Powered Mobile Sensing

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Motivation: Home Automation for Paralysis Patients

12,000 Spinal Cord injuries/year

lifetime costs vary from 1-2 million

Estimated Lifetime Costs by Age of Injury

Severity of Injury	25 Years Old	50 Years Old
High Tetraplegia (C1-C4)	$4,53,182	$2,496,856
Low Tetraplegia (C5-C8)	$3,319,533	$2,041,809
Paraplegia	$2,221,596	$1,457,967
Incomplete motor function at any level	$1,517,806	$1,071,309

can we reduce the dependence on assistive care facilities?

What solutions are available for Paralysis Accessibility?

A Portable Wireless Eye movement-controlled Human-Computer Interface for the Disabled

Xiaoxiang Zheng, Xin LI, Jun Liu, Weidong Chen, and Yaoyao Hao

EOG-based Signal Detection and Verification for HCI

I. Y. Deng, Chun-Liang Hsu, Tzu-Ching Lin, Jui-Sen Tuan, and Yung-Hui Chen

the focus has been on design of sensors for capturing gestures...

Tracking Iris contour with a 3D eye-model for Gaze Estimation

H. Wu, Y. Kitagawa, T. Wada, T. Kato, and Q. Chen

A National Study of Assisted Living for the Frail Elderly: Results of a national survey of facilities

C. Hawes, M. Rose, and C. D. Phillips

Wearable EOG Goggles: Eye based Interaction in Everyday Environments

A. Bulling, D. Roggen, and G. Tröster

little effort on making sensors low maintanence, low cost, and minimally intrusive!

Robust Hand Gesture Recognition with Kinect Sensor

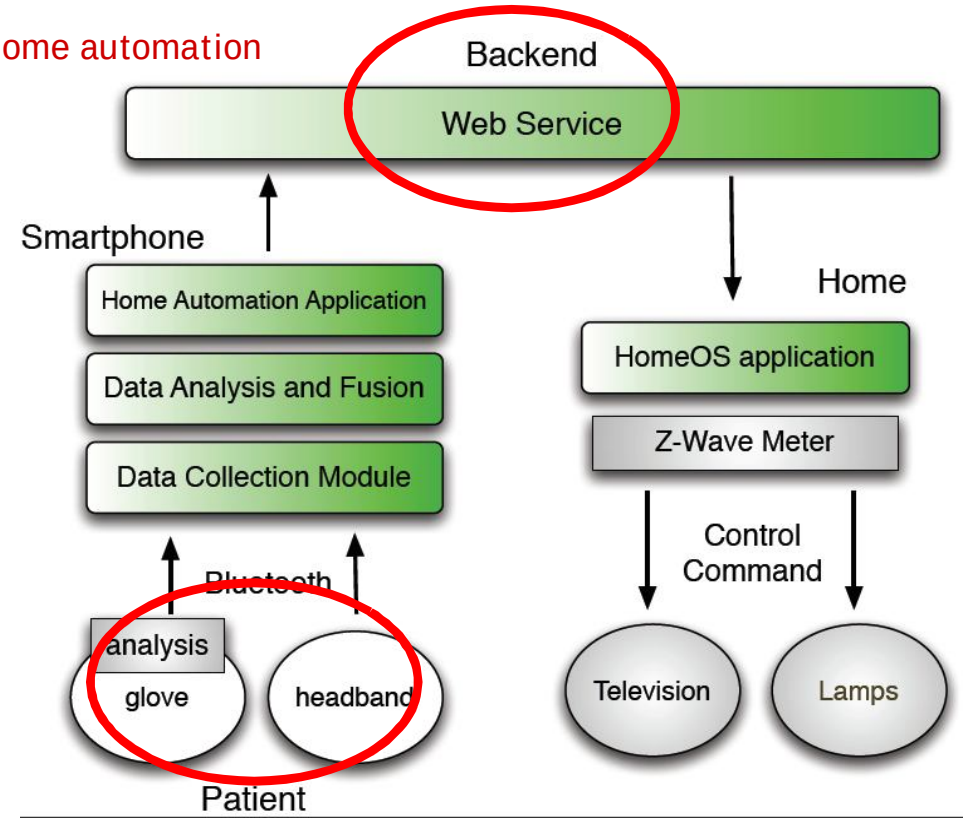
Z. Ren, J. Meng, J. Yuan, and Z. Zhang

A Real-Time QRS Detection Algorithm

J. Pan and W. J. Tompkins

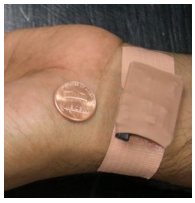
Vision: Non-intrusive Home control for Paralysis Patients

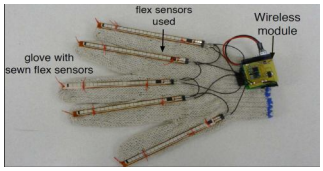
remote home automation



low cost
wearable sensors
for gesture recognition

What are the challenges in realizing this vision?





Form Factor

Comfort for long term use

Impact

Increase the quality of life

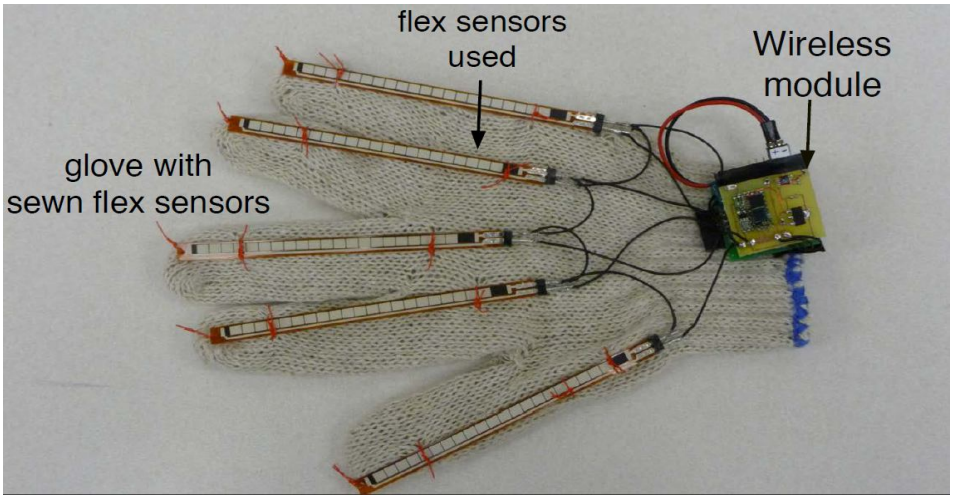
Cost

Reduce burden of expensive care

Maintenance

Prevent long term failure, reduce short term upkeep of systems

Our first attempt: data glove device



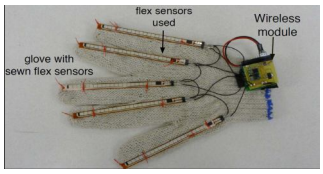
Nelson et al. IEEE Sensors '13

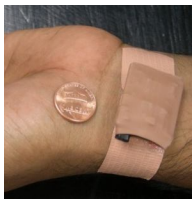
limitations

battery-driven: requires frequent battery recharge

high maintenance cost, especially for paralysis patients

Goal of this paper: Reduce maintenance cost





Form Factor
Comfort for long term use

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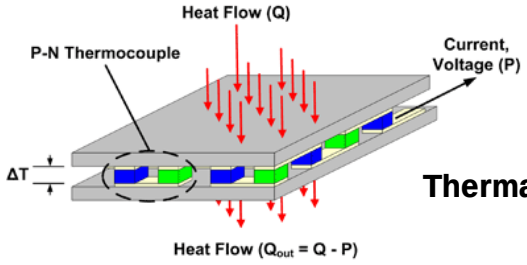
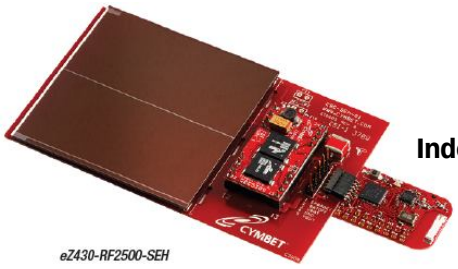
Solution: Self-sustainable system using micro-harvesting

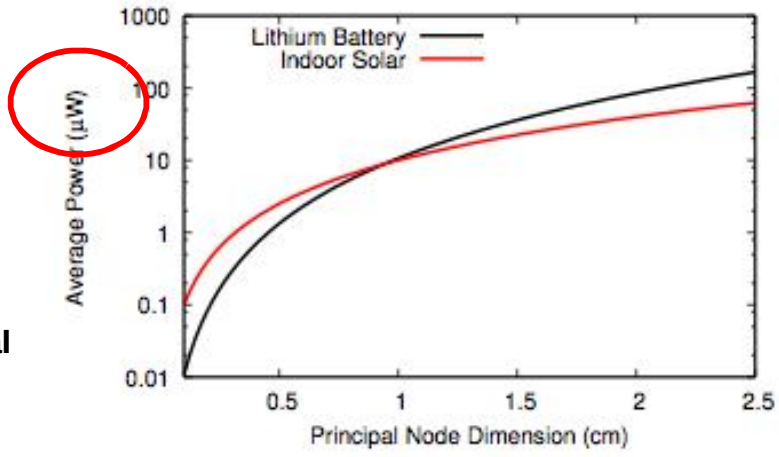
kinetic



Thermal



Indoor light

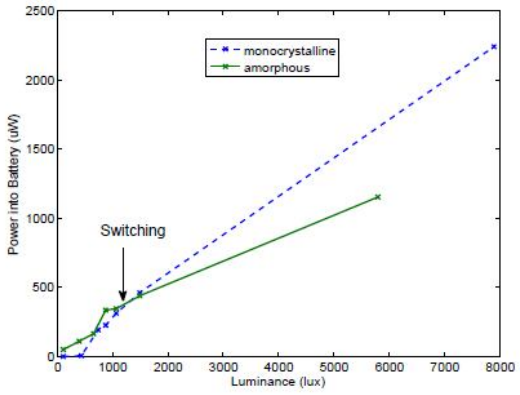


Grafting Energy-harvesting Leaves onto the Sensor Net Tree, Yerva et al., IPSN 2012

Two primary challenges

Maximize energy harvested

Energy harvested in both direct and ambient indoor lighting conditions



Operate energy-hungry modules

Bluetooth for data transfer

Micro-controller for data processing

Gesture-recognition sensors such as accelerometers and flex sensors

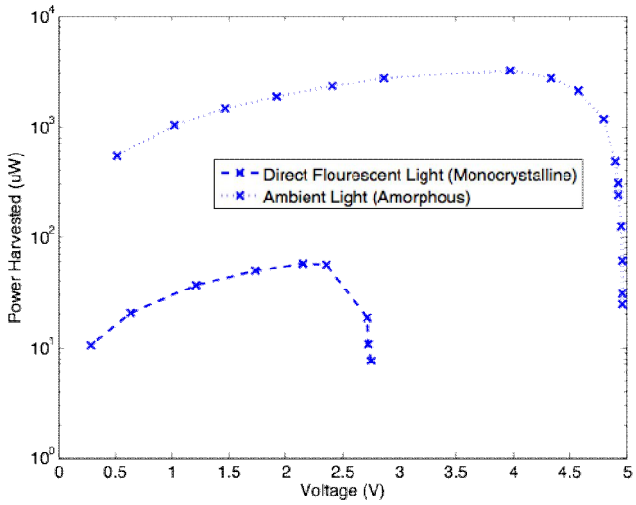
Subsystem	Avg. Power (μW)
Flex Sensors	300.3
MCU (low power sleep)	13.2
MCU (active)	1178.1
DAC (external)	1250.7 (4.6ms@ 369.8 μA)
ADC (MCU internal)	3330.0 (17.2ms@1.01mA)
Bluetooth (transmit)	85140
Bluetooth (idle, connected)	39600
Bluetooth (standby)	36960

TABLE II. POWER CONSUMPTION CHARACTERISTICS.

Insights: Maximizing Energy-harvested indoors

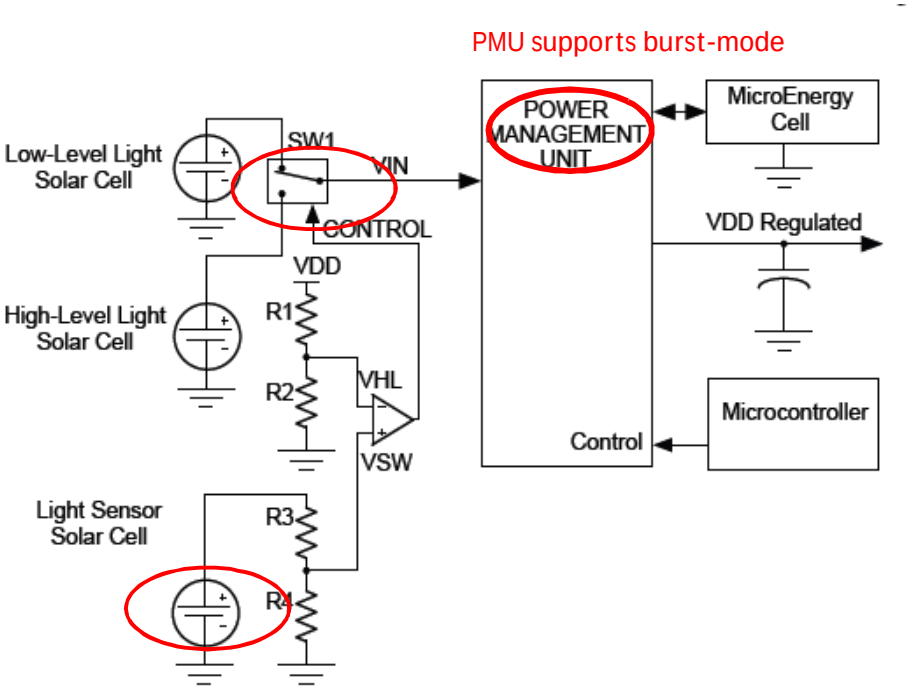
Max Power Density (μW/cm^2)			
Panels	**Direct (Incandescent, 14K Lux)**	**Direct (Fluorescent, 15K Lux)**	**Ambient (400 lux)**
KXOB 22-04X3 (Mono.)	8105	338	3.3
SLMD 600 H10L (Mono.)	7673	411	3.8
Sanyo AM-1417 (Amor.)	348	240	11.9
ECS300 1607 (Amor.)	242	123	4.5
ECS300 2505 (Amor.)	205	74	8.0

Power Density of sample solar cells



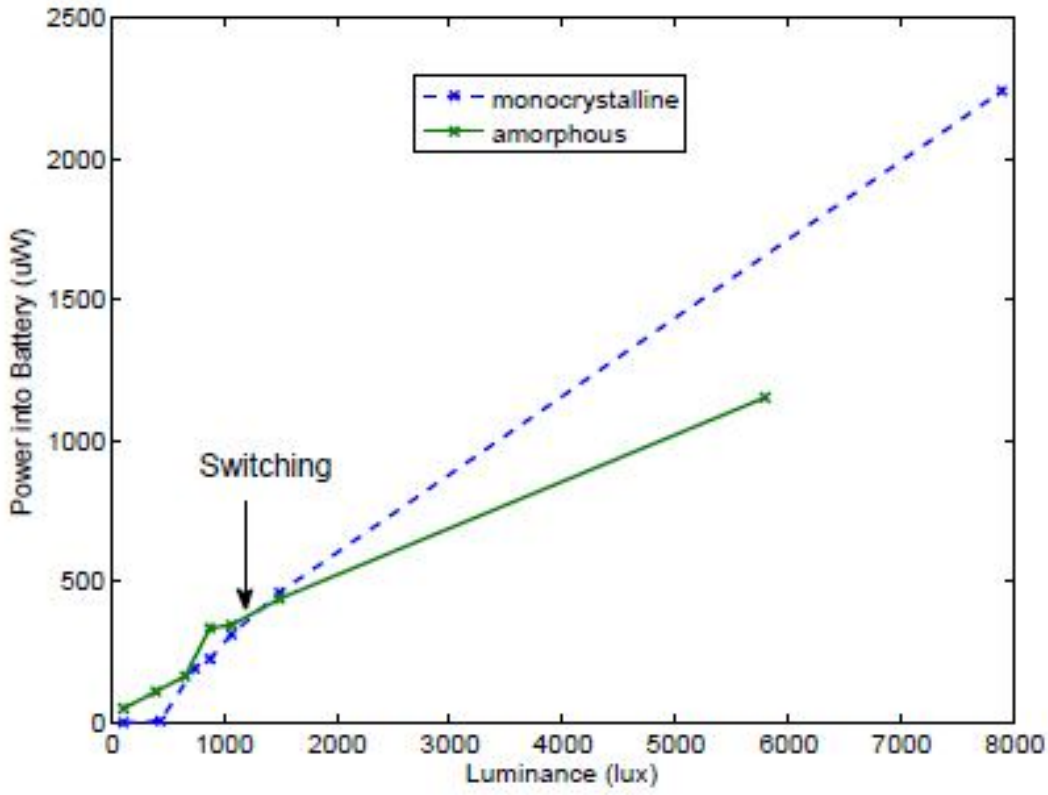
Maximum power point tracking Is unnecessary

Solution: Mixed Solar Cell Array

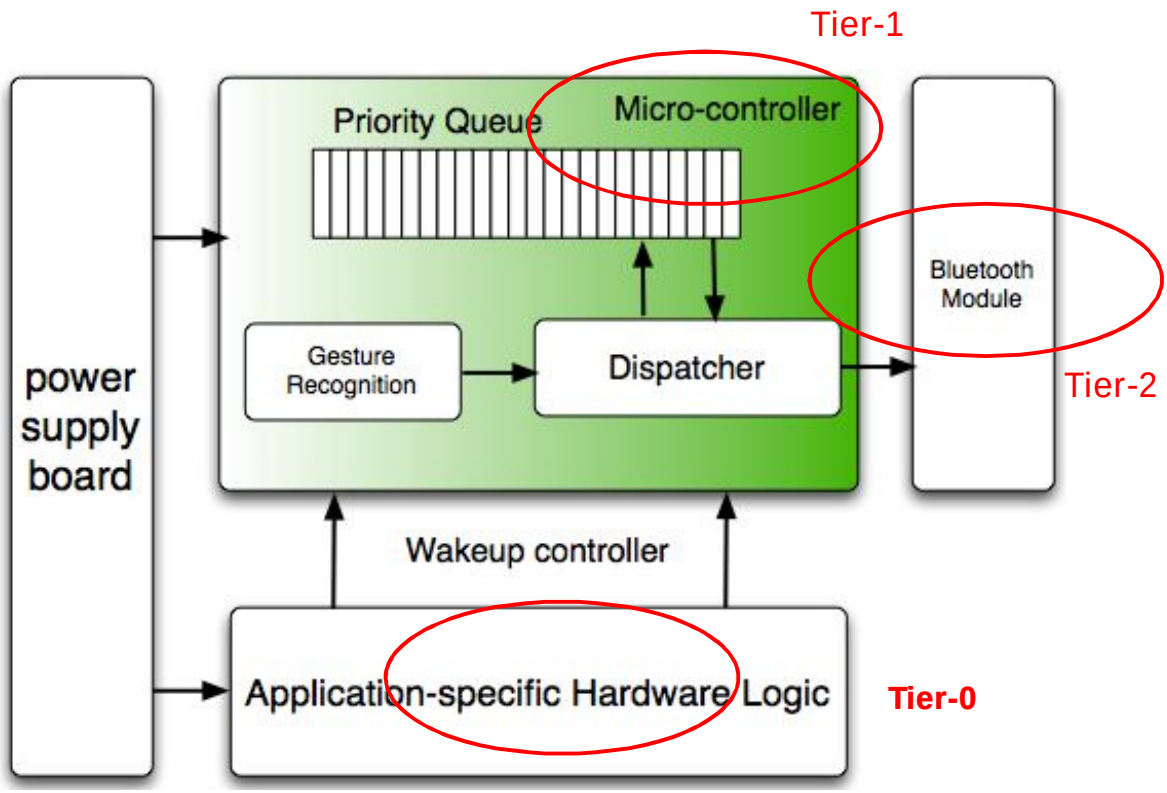


Amorphous Silicon – Ambient Light
Mono-Crystalline – Direct Light
Solar cell used as light sensor to drive switching

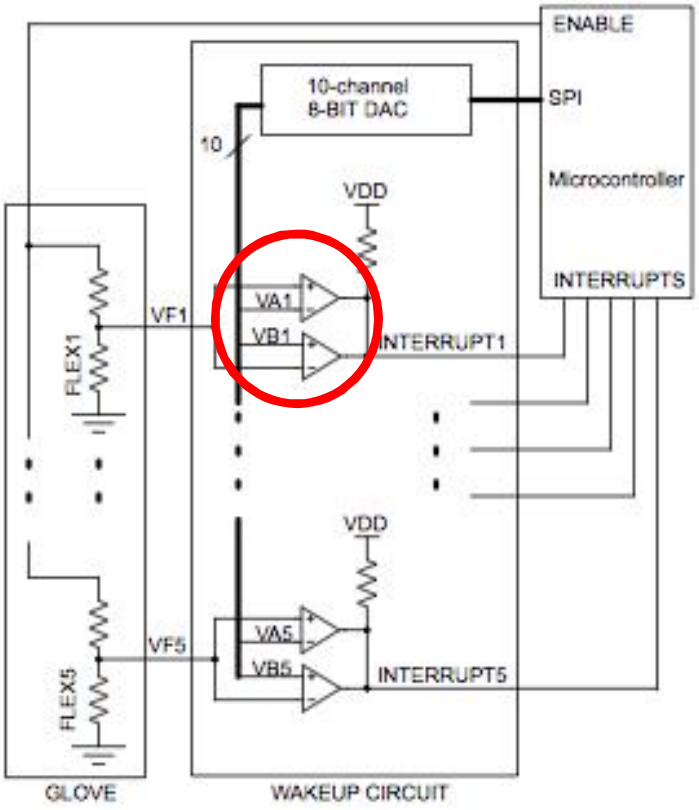
Static Switching instead of MPPT



Tiered Architecture to provide maximal responsiveness

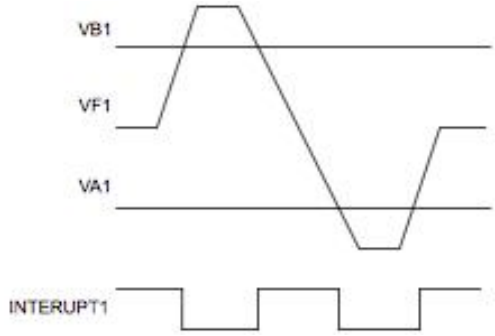


Application-specific low power wakeup module



Interrupts trigger microcontroller

Microcontroller sets threshold values per finger



Scheduling Algorithm

Gestures are priority and deadline driven

- alarming a security system: low latency
- switching off a TV: moderate latency

Implements variant of **earliest-deadline first(EDF) algorithm**

Batches all messages in one Bluetooth packet

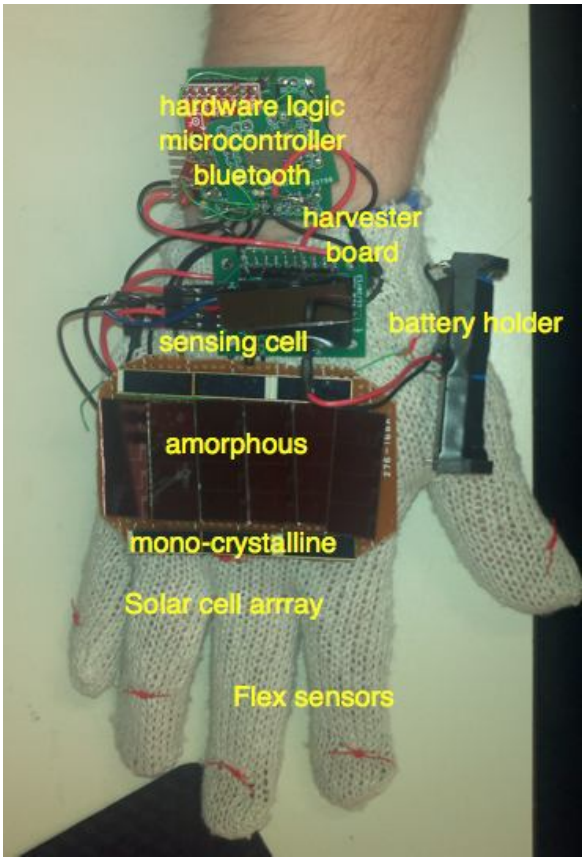
Why batch gestures instead of ship immediately?

- Bluetooth consumes 9 mA idle consumption
- takes 5-7 seconds to start and connect to Smartphone
- sending a message once on takes ~10ms

What about high priority gestures?

- Highest priority messages trigger immediate batch send

Earlier Prototype



MSP430 Microcontroller

ADXL345 3-Axis Accelerometer

Flex resistors

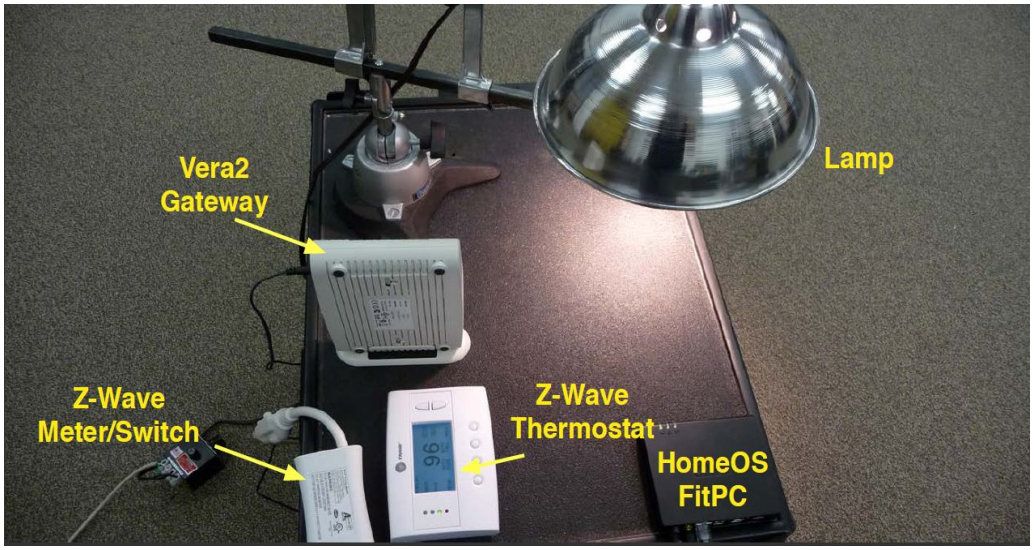
NiMH rechargeable AA battery

Analog Devices external hardware

Large amorphous silicon array for ambient light

Smaller mono-crystalline array for direct light

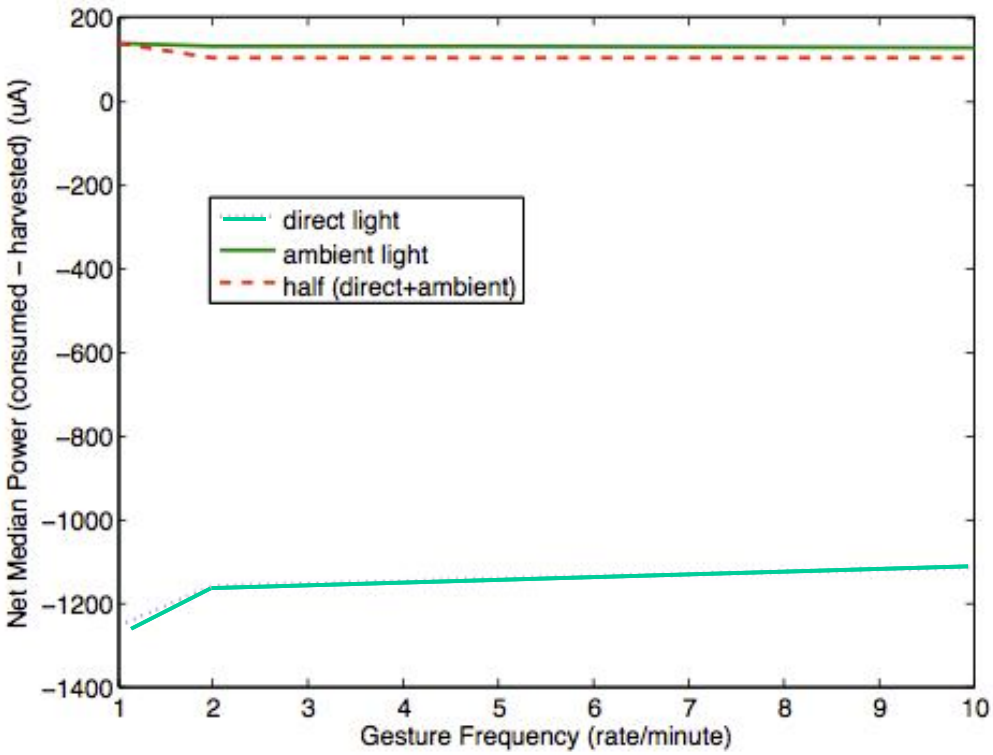
Experimental Setup



Tested in laboratory setting for array of gestures

- Ambient light
- Direct light
- Half ambient, half direct

Results



Produces ~150uW constant in direct or half light

Loses ~ 1.2mW in ambient light

Limitations

Form Factor

- Size of solar array and external circuitry makes assembly cumbersome
  - Contingent upon solar array
- External circuitry can be reduced with custom IC, solar array fixed size

Power Consumption

- Bluetooth major energy draw
  - Can be reduced with BLE standard, now compatible with devices
- Custom IC for external hardware could further reduce power consumption

Conclusions

- Designed, implemented, and tested micro-harvester driven gesture-recognition system for paralysis patients
- Designed variable panel solar charging array
- Designed tiered architecture to leverage higher-power devices while reducing overall power consumption

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