Power and Heat in Ubiquitous Computing

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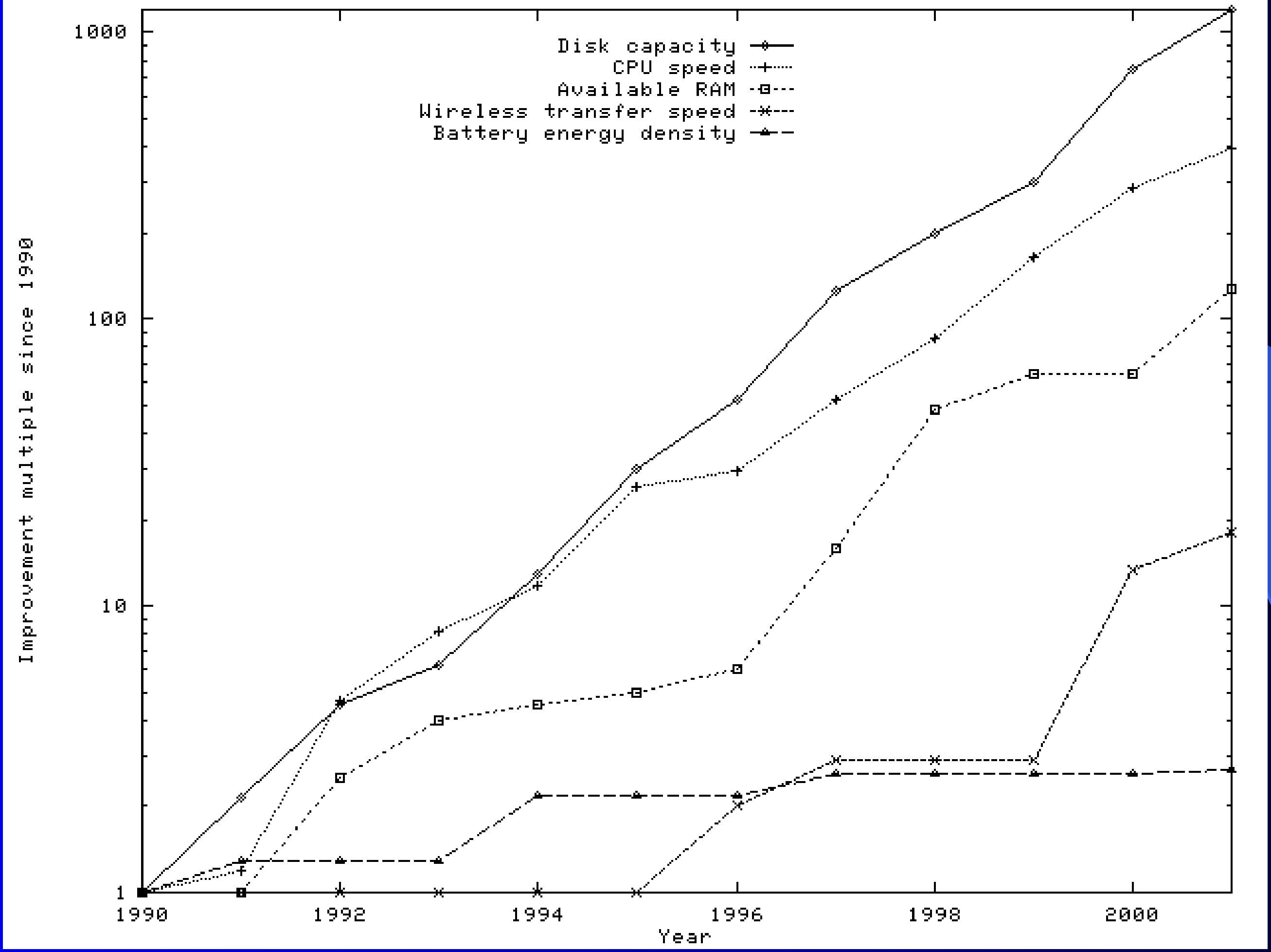
Challenges

- Power and heat (mips/watt)
- On and off-body networking (bits/joule)
- Privacy
- Interface (additional capability vs. load)
  - User Interface (cognitive load)
  - Ergonomics/human factors (weight, heat, etc.)

(Intertwined – changing one effects the others)

(Starner01 IEEE Micro
"Challenges of Wearable Computing")

Mobile Computing Trends



(Starner01 IEEE Computer "Thick Clients…")

Thought Experiment: Distributed AR in San Diego

- Idea: make transponder system, like Metricom, installed by the public on every street sign (“blade”)
- Each street sign transmits information for local intersection and provides simple store-and-forward messaging
- Due to cost of wiring and legal issues, decide not to hook into power grid

Some Numbers

- Expected average battery life: 1 year
- Idle battery life: 10 years
- # street signs in San Diego: 48,000
- Problems
  - Who replaces batteries?
  - When does a battery get replaced?
  - 3500 street signs/year for accidents, vandalism, theft, and updates
  - Landfill of batteries

Solutions

- Social (government, reward the group, etc.)
- Longer lasting “batteries”
- Scavenge power (Locust)
- Use less power

Terms and Units

- Energy is the capacity to do work
- Joule = 1 kg m^2/sec^2 = 1 Newton of force acting through a distance of 1 meter
- 1 calorie = 4.19J
- 1 Calorie = 1000 calories
- 1g fat = 9000 cal = 38,000 J
- 1 jelly donut = 330,000 cal = 37g fat

Energy Sources

AA alkaline battery	10^4 J
Camcorder battery	10^5 J
Liter of gasoline	10^7 J
Daily human diet	10^7 J

Power

- Power is the time rate of doing work
- 1W = 1J/sec = 1kg m^2 / sec^3
- P = IV = I^2R (example, 12V bulb)
- Non standard units of energy: Wsec, Whr, kWhr
- 60 W light bulb for 24 hrs = 1440 Whr = 1.44 kWhr = 5.184MJ

Power Requirements

Desktop computer (w/o monitor)	10^2W
Notebook computer	10W
Embedded CPU board	1W
Low power microcontroller	10^-3W
Average human	121W

Energy Density

- Energy per mass (MJ/kg)
- Energy per volume (J/cm^3)

Lead acid	0.115 MJ/kg	426 J/cm^3
NiCd	0.134 MJ/kg	354 J/cm^3
Ni Hydride	0.171 MJ/kg	498 J/cm^3
Li ion	0.292 MJ/kg	406 J/cm^3
Zinc Air	0.490 MJ/kg	571 J/cm^3

Getting More Out of Batteries

- Controlled discharge
- Controlled charge
- Temperature
- Fluid flow

Incorporate Recharging into Life Routines

- Example for a wearable
  - 6 hours – long enough to replace at every meal
  - 8-10 hours – replace after work
  - 16 hours – recharge when go to bed

Alternative “Batteries”

- Compressed air tanks (5.75 Whr/kg)
- Ultracapacitors (3-30 Whr/kg)
- Fuel cells (548Whr/kg)
- Superflywheel (385Whr/kg)
  – Buckytubes give 10x this amount!

(Michael Johnson aries@media.mit.edu unpublished)

Small Nuclear Sources

Material	Half Life	Energy density
Po210	0.38 years	134W/g
Pu238	87 years	0.39W/g

- 6.6% conversion efficiency
- $1500/g Pu238
- Chinese have used Po210 on space program
- Plutonium used in pacemakers (1989)

Environmental Energy Sources

- Solar
- Moving air
- Moving water
- Barometric fluctuations
- Temperature fluctuations
- Cultural electromagnetic noise
- Galactic electromagnetic noise
- Power generation and distribution fields
- Radio and television broadcast stations
- Vibration

Locust: Environmentally Powered Location/Messaging

- PIC microcontroller
- IR xmit/receive
- >6m range
- Location beacon
- Upload location
  based messages

300 deployed

Next version: AM radio powered

(Starner97 ISWC "The Locust Swarm")

Electromagnetic Energy Gleaning

Band	W @10% eff.	Field strength v/m
AM	2.7x10^-4	10^-2
FM	2.7x10^-9	3.16 x10^-3
TV2-6	2.2x10^-8	5x10^-3
TV7-13	4x10^-9	7x10^-3
TV14-69	9x10^-9	10^-2

Solar-Photovoltaics

- Max solar intensity 1000W/m^2
- Average 250W/m^2
- Max efficiency for solar cells would be 33%, but will not get that
- Best two absorbers would be 37-46% eff.
- 1996 7-17% eff.
- 2000 (predicted) 10-20%
- 2010-2020 15-25%
- Energy payback in 2-3 years for single crystal silicon

Solar->Electric Conversion

- Direct of photons 350W/m^2 + indirect sun
- Thermal conversion 400W/m^2
- Thermal photovoltaic tpv 350W/m^2 direct
- Fuel drive tpv 20-30%
- Atmospheric conversion – winds
  - 20 W/m^2 at 5m/sec
  - 160 W/m^2 at 10m/sec
- Land/sea thermal gradients – small delta T
- Atmospheric pressure changes <4uW/liter works underground

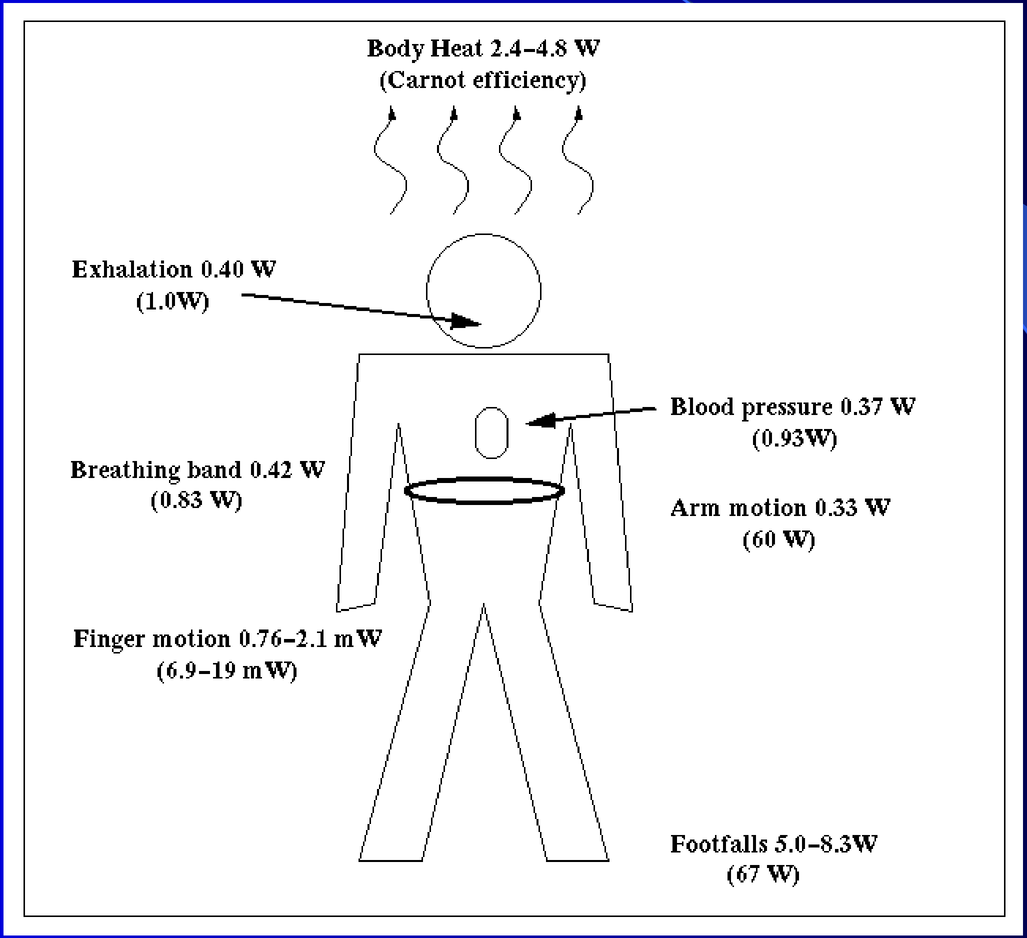
Scavenger Robots

- 10kg robot
- Gathers 1kg/hr of combustables
- 10 kWhr/kg
- Does not compete favorably with solar cell

Human Activities

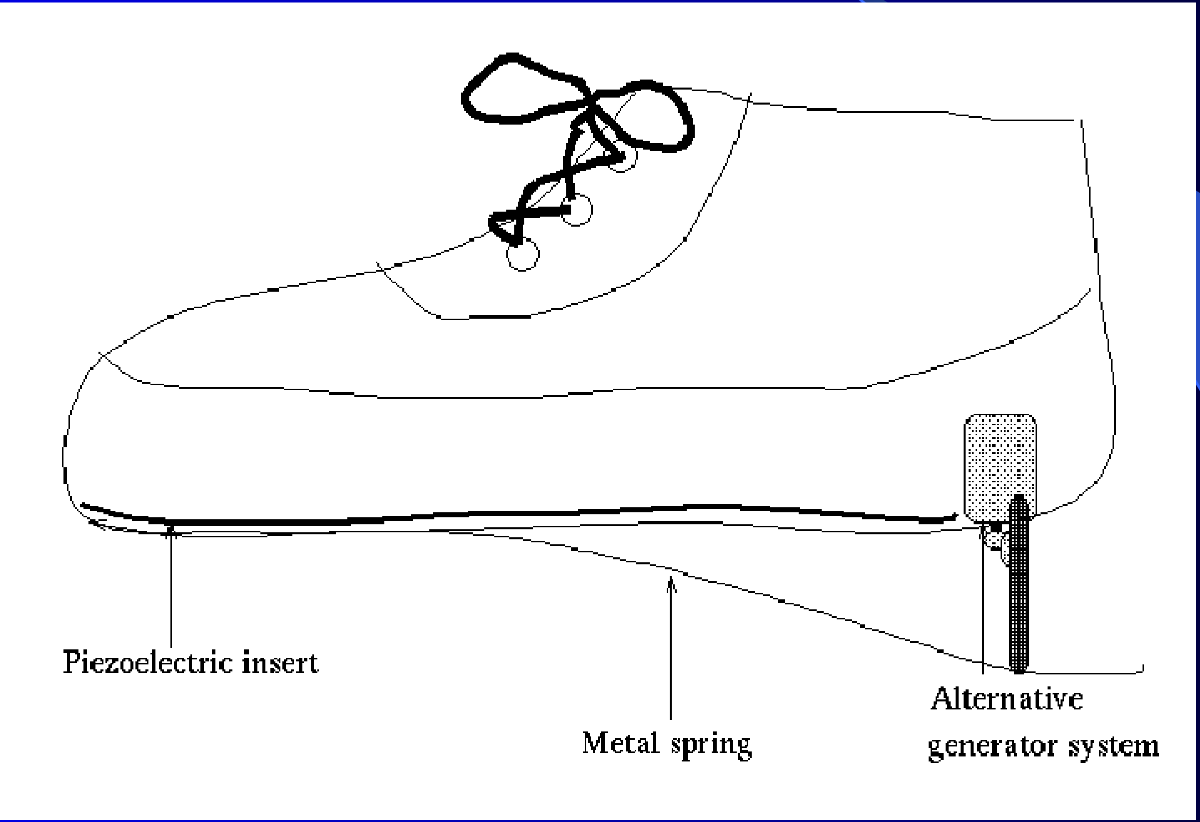
Sleeping	81W
Sitting	93W
Conversation	128W
Strolling	163W
Hiking	407W
Sprinting	1630W

Body-driven power



(Starner96 IBM Systems J "Human-Powered Wearable Computing

Shoe Power



(Kymissis98 ISWC "Parasitic Power Harvesting in Shoes")

Riddle:

- What do you call a Pentium-based pocket computer?

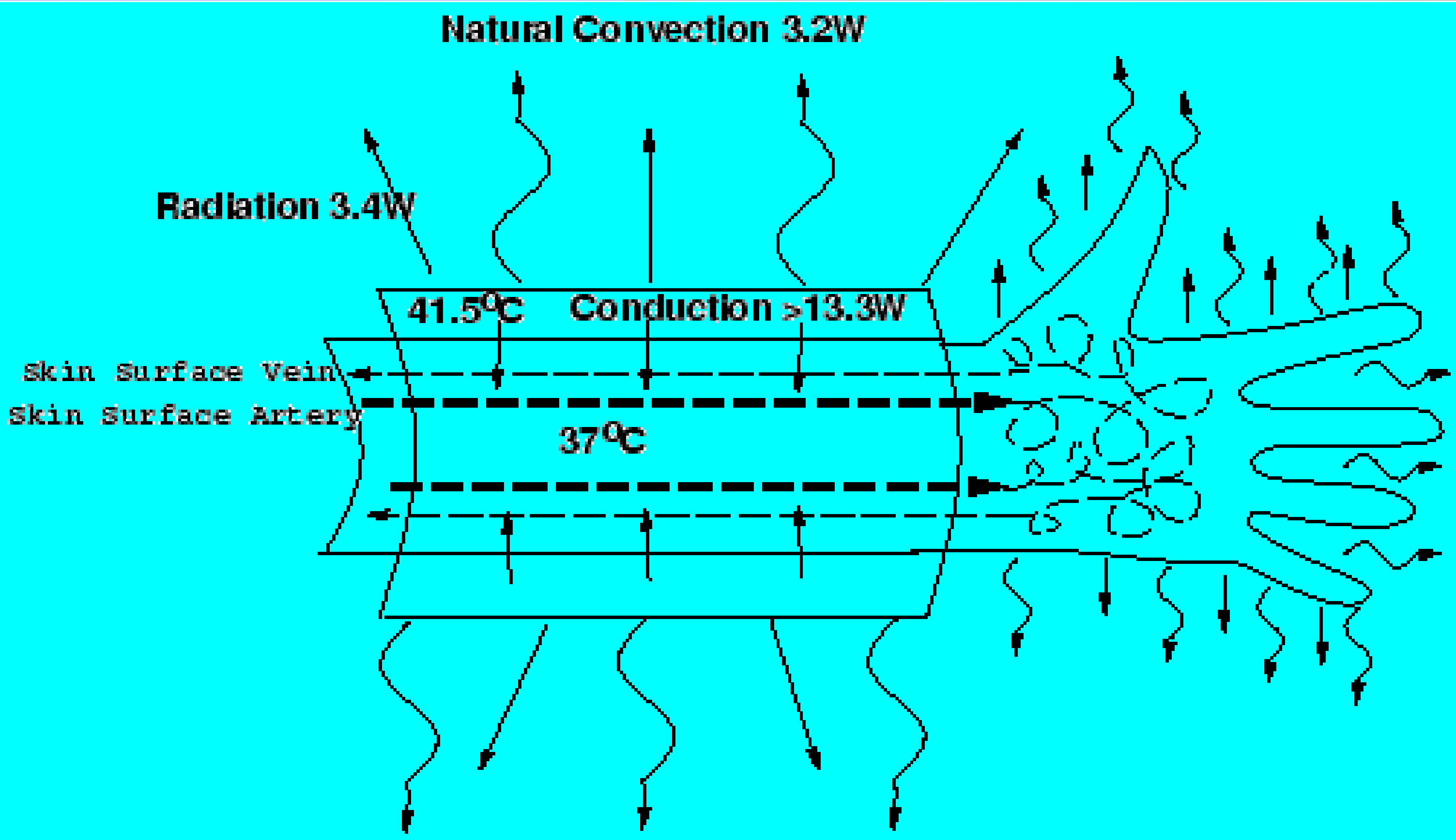
Answer

- A soldering iron

Heat

- #1 limiter in current laptop computers (23W)
- Methods of removing heat
  - Convection
  - Conduction
  - Evaporation
  - Radiation
  - Storage

Case Study: Forearm Wearable



(Starner99 MONET "Heat Dissipation…")

Aside: Science Is Beginning to Look Like Science Fiction

- Science fiction writers are paying attention and provide good scenarios/motivation based on current research!

- Fast Times at Fairmont High (recent Vinge)
- Historical Crisis (Kingsbury) in Far Futures anthology (Benford)
- The Diamond Age, Snowcrash   (Stephenson)
- Islands in the Net (Stirling)