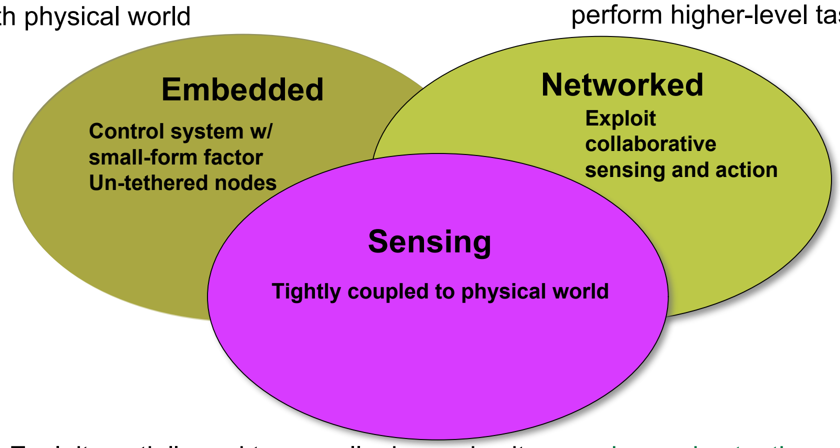
Wireless Sensor Networks

- Important trend in embedded computing
- Connecting the physical world to the world of information
  - Sensing (e.g., sensors)
  - Actuation (e.g., robotics)
- Wireless sensor networks are enabled by three trends:
  - Cheaper computation (Moore's Law)
  - Compact sensing (MEMS sensors)
  - Wireless networking (low-power radios)

What is embedded networked sensing?

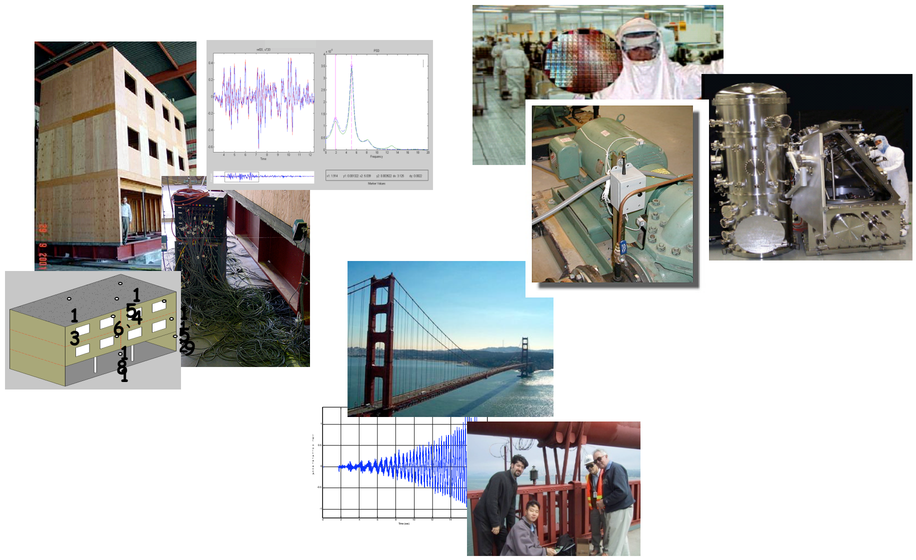
Embed numerous distributed devices to monitor and interact with physical world

Networked devices that coordinate and perform higher-level tasks

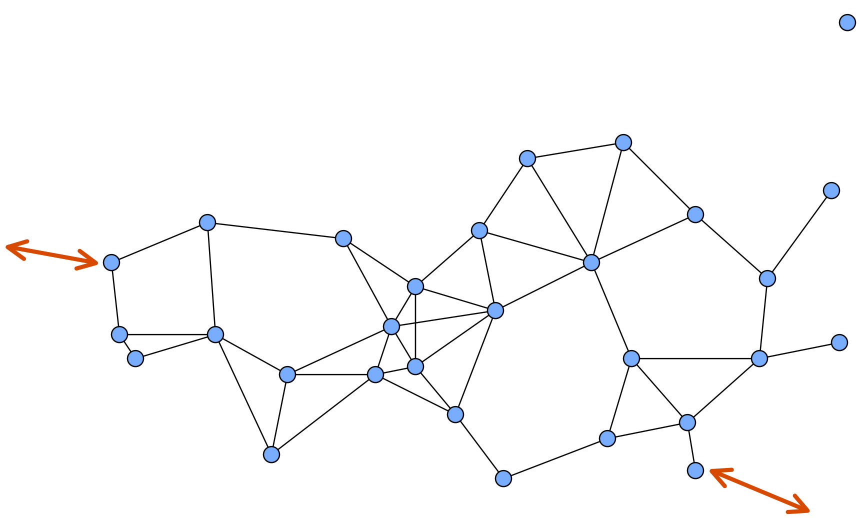


Exploit spatially and temporally dense, in situ, sensing and actuation

Wireless sensor networks



The Basic Idea

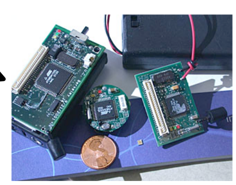


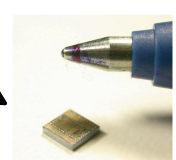
Applications

- Un-tethered micro sensors will go anywhere and measure anything – traffic flow, water level, number of people walking by, temperature. This is developing into something like a nervous system for the earth.
  - Horst Stormer in Business Week, 8/23-30, 1999.
- Applications
  - Environmental sensing
  - Habitat monitoring
  - Precision agriculture
  - Military operations
  - Condition-based maintenance
  - Health care

Range of Sensor Nodes

- Large
- Medium
- Small
- Tiny





- Resources
  - Computation/memory
  - Communication/range
  - Power
  - Sensors

Computation/memory

- Microprocessor
  - 8-bit microcontrollers
  - Xscale processors
  - Digital signal processors
- Memory
  - Flash for non-volatile logging of sensor data
  - Store and forward data from other nodes

Communication

- Radio communication (some infrared)
  - Power tradeoff with bandwidth
    - More power, more range, more interference
    - Less power, less range, may disconnect
- Protocol stack
  - Reliability
  - Routing
  - Naming
  - Broadcast, multicast, unicast

Power

- Battery
  - Rechargeable Li-ion, fuel cell, etc.
- Harvest from environment
  - Solar, piezo (vibration), RF energy, etc.

- Sleep
  - Minimize communication – use radio sparingly
    - What might it miss (sensing, from neighbors)?
    - How often should it communicate (stay connected to network)?
  - Minimize computation – distill data and store/send summaries
    - What info might it lose?
    - When is processing warranted (don't waste it)?

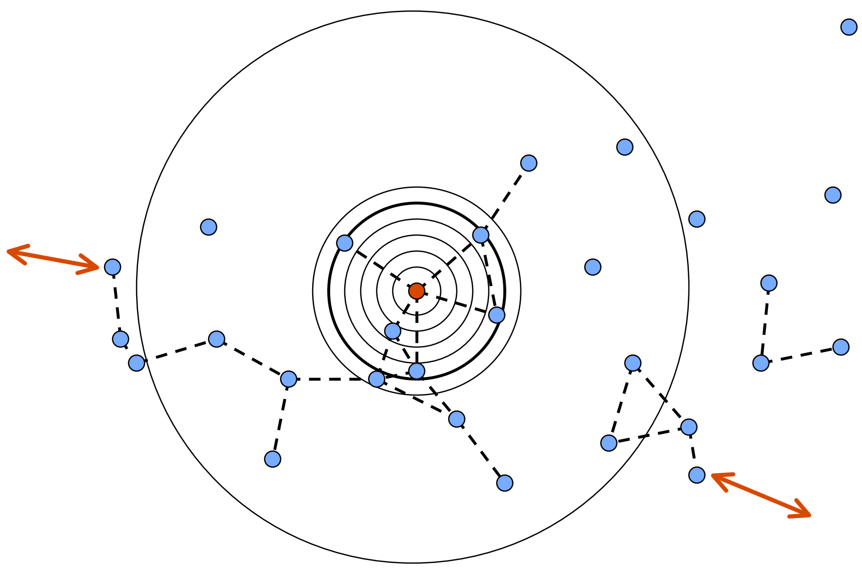
Sensing

- Microphones
- Accelerometers
- Magnetometers
- Light sensors
- Barometric pressure
- Thermopyle
- Humidity
- Temperature

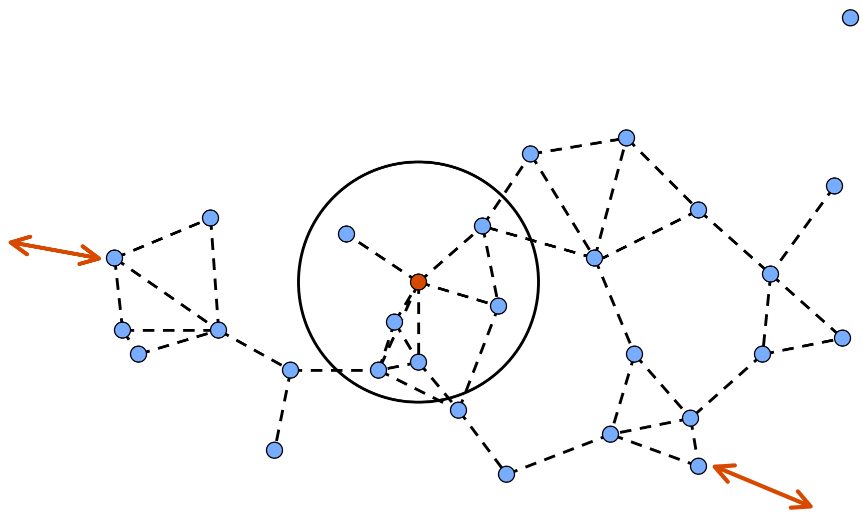
Issues

- Range and connectivity
- Localization and synchronization
- Routing protocols
- Power management
- Computation

Range and Connectivity



Range and Connectivity (cont'd)



Range and Connectivity

- How do sensor nodes discover their neighbors?
  - Transitively, who can their neighbors talk to?
- What radio range to use?
  - Smaller, less power, more bandwidth (less interference)
  - Larger, more power, more interference
- What to do when nodes are really close together?
  - Let one handle region and others sleep?
- What happens when there are isolated islands?
  - Use mobile nodes?
  - Add more nodes?
- Vary transmit power?
  - Adjust to situation?

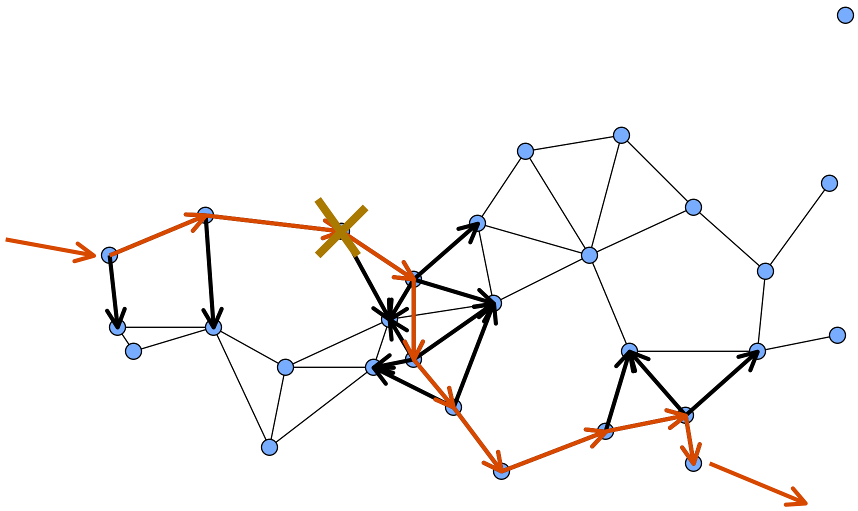
Localization and Synchronization

- Node location is important knowledge
  - Make decisions about which are active and which sleep
- Need synchronized clocks
  - Know the time an event is observed at each of multiple nodes
- Spatial signal processing
  - Determine location of sensed phenomena
  - Need to know relative locations for triangulation
  - Need to know time for time-of-arrival calculations

Routing Protocols

- Getting data from one point to another
  - Reliability of communication
  - Best effort or acknowledgements with retransmit
- Which nodes forward data
  - If all, then may saturate available bandwidth
  - If not enough, may not get to where it needs to go
- Adjust as nodes are added/removed
- Number of hops per packet
  - Loss at each hop
  - Power for each hop

Routing Protocols



Power Management

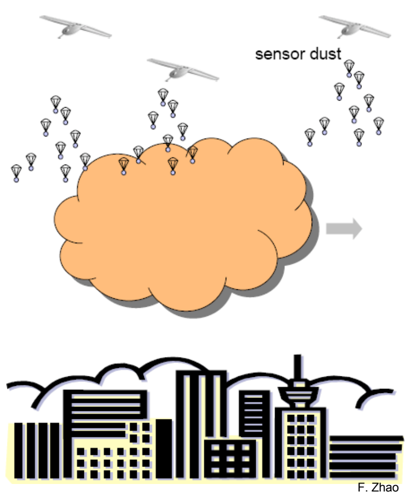
- Maximize lifetime of node
  - Independent power management
  - Rendezvous for communication
    - make sure both awake at same time
- Maximize lifetime of network
  - Judiciously choose which nodes sleep
  - Wakeup to fill in for others that run out of power

Computation

- How is data processed?
  - In network – more computation
  - At edges, after it is gathered – more communication
- How much aggregation is done?
  - Summary data vs. raw data
- Pushing new computation into network
  - Security concerns
- Collaborative signal processing
  - Multiple nodes working together
- Where is data stored?
  - Can I "google" the real world?
- What is the programming model?

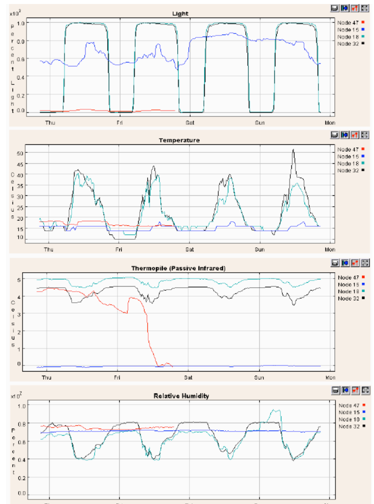
Application: Environmental Sensing

- Tracking a chemical cloud
- Emergency response
- Sprinkle sensors over affected area and vicinity
- Track movement of cloud and warn affected communities



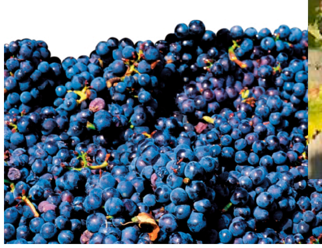
Application: Habitat Monitoring

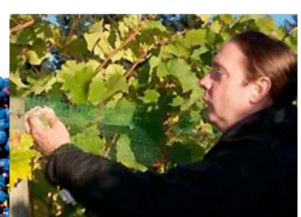
- Great Duck Island, ME
- Monitoring burrow nest and environment of petrels
- Data previously unavailable
  - Much too expensive to gather



Application: Precision Agriculture

- Monitor micro-climates throughout vineyard
- Add water, heat, and fertilizer where needed
- Cost-savings, maximum yield, customize grape





Application: Military Operations

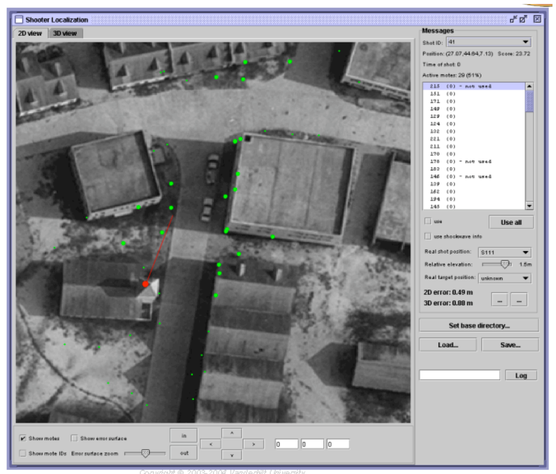
- Sniper detection
- Vehicle tracking

Red circle:
→ Shooter position

Red line:
→ Shot direction

Large green circle:
→ Sensor node (good measurement)

Small green dot:
→ Sensor Node (no or unused measurement)

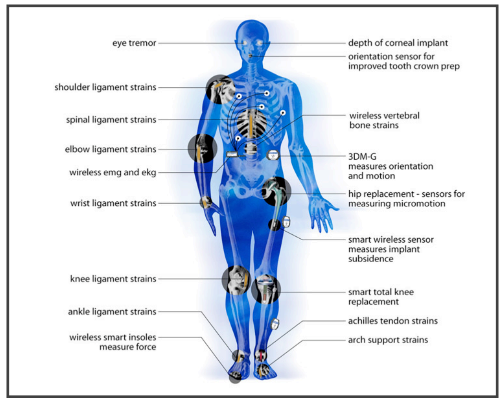


Application: Condition-based Maintenance

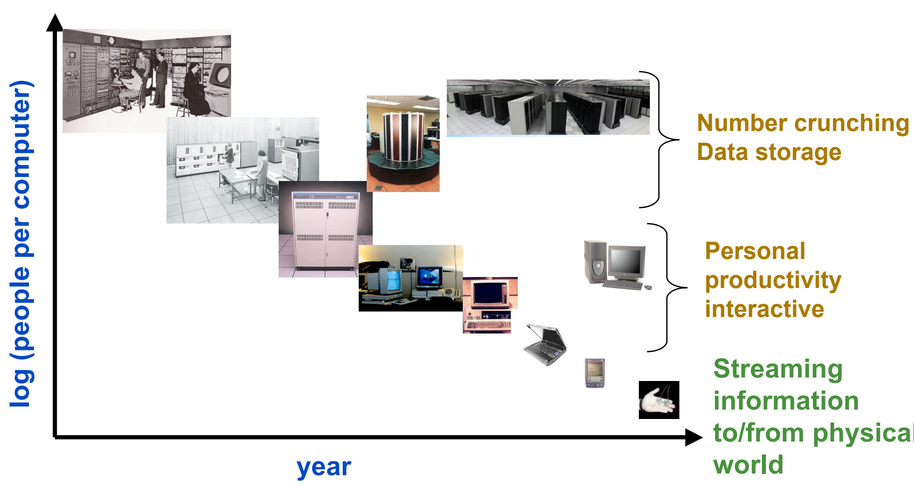
- Monitor structural stresses
- Data collection from vehicle driving by
- Early warning of problems

Application: Health Care

- Monitor all aspects of human activity
  - Mechanics/chemistry of body
  - Trends over time
  - Detect problems early
  - Monitor effects of medication
  - Elder care

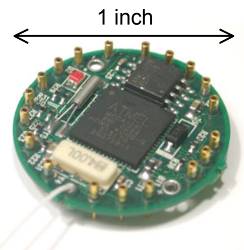


Sensor networks are the next IT revolution

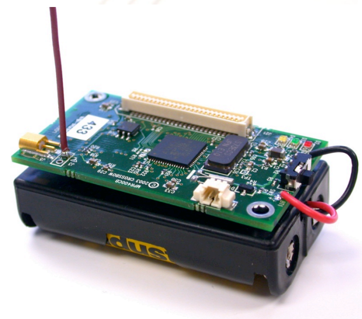


Ultimately used in many ways not previously imagined!

A Popular Sensor Network Platform



- UC Berkeley sensor “mote”
  - ATmega 8-bit microcontroller
  - 40Kb/sec radio (433MHz)
  - 128K code, 4KB data
- Mainstay platform for the sensor network research community
- Used in CSE466 over the past three years
- Two form factors
  - Mica2
  - Dot
- Now distributed by Crossbow (xbow.com)

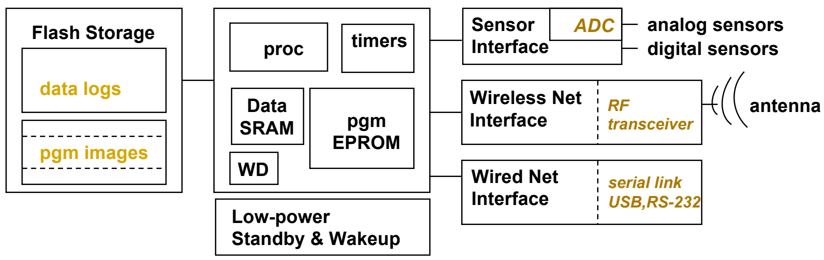


Platform details

- ATmega microcontroller (103L, 128)
  - 32Khz crystal and 4Mhz crystal
    - 10 bit ADC
    - 2 UARTs
    - SPI bus
    - I2C bus
    - Radio (RFM or Chipcon 1000)
- External serial flash memory (512K byte)
- Connectors for interfacing to sensor and programming boards
- 3 programmable leds (1 for dot)
- JTAG programming port

Key Design Elements

- Efficient wireless protocol primitives
- Flexible sensor interface
- Ultra-low power standby
- Very fast wakeup
- Watchdog and monitoring
- Data SRAM is critical limiting resource

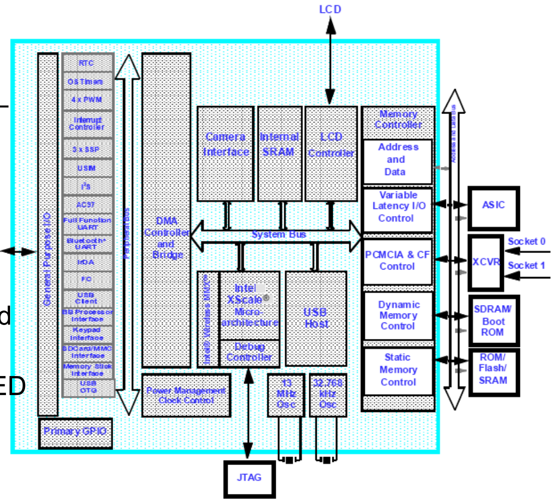


A newer platform – the Intel iMote2

- Developed by Intel Research
  - 13-416MHz 32-bit PXA271
  - 64MB memory (half Flash, half RAM)
  - IEEE 802.15.4 radio
  - 250 kbits/sec (2.4GHz)
- New for CSE466 last year
- Recently available commercially
  - again from Crossbow (xbox.com)

Platform details

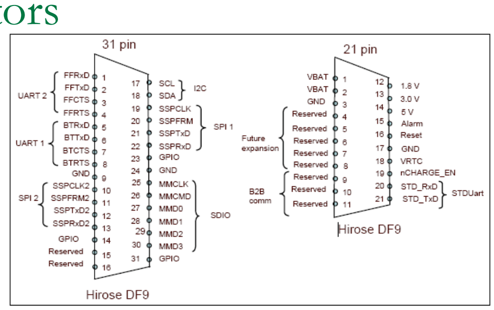
- Intel PXA271 XScale® at 13 – 416MHz
- Intel Wireless MMX DSP Coprocessor
- 256kB SRAM, 32MB FLASH, 32MB SDRAM
- Integrated 802.15.4 Radio and 2.4GHz Antenna
- Multi-color Status Indicator LED
- USB Client With On-board mini-BConnector and Host Adapters



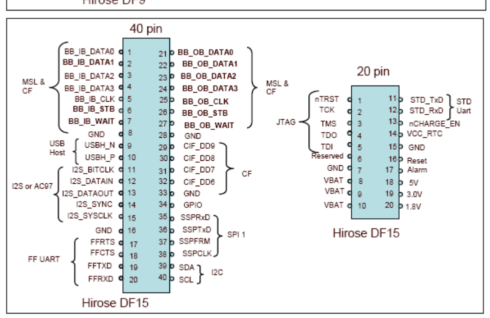
- Intel Wireless MMX DSP Coprocessor
- Rich Set of Standard I/O: 3xUART, 2xSPI, I2C, SDIO, GPIOs
- Application Specific I/O: I2S, AC97, Camera Chip Interface, JTAG
- Compact Size: 36mm x 48mm x 9mm, 12g (w/o battery)

iMote2 Connectors

- UARTs, SPI, I2C
- USB
- High-speed data transfer (up to 192Mbps)
- JTAG
- SDIO
- Camera
- Power



Basic Connector Set

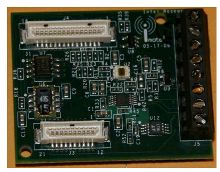


Advanced Connector Set

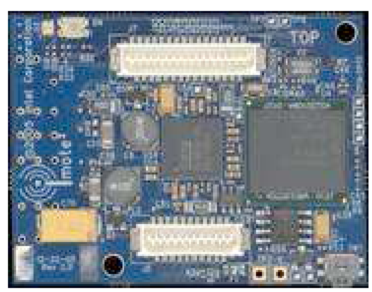
Other iMote2 elements

- Battery board (51g – 3 AAA)
  - 4x weight and 2x volume of main board
- Interface board
  - Expands USB ports and provides JTAG interface (up to 1MB/sec per port)

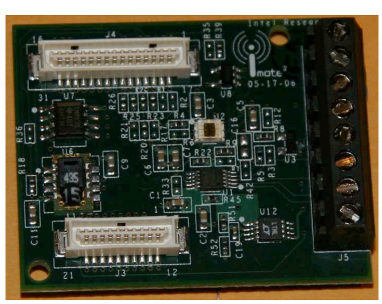
- Basic sensor board
  - 5 sensors for basic applications
- Other boards
  - Intel, UW, UCLA, Yale



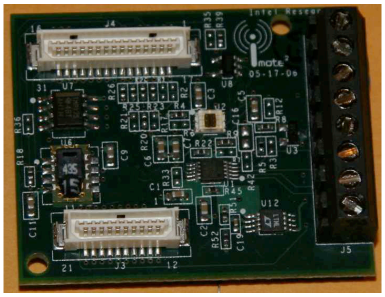
More detail



- In CSE466, we'll use the iMote2 base board and basic sensor board for Labs 5 and 6



iMote2 Basic Sensor Board



- ST Micro LIS3L02DQ
  3D 12 bit +-2g accelerometer
- High Accuracy, +/-.3°C
  Sensirion SHT15
  temperature/humidity sensor
- TAOS TSL2651 light sensor
- TI Tmp175 digital temperature sensor with two-wire interface
- Maxim MAX1363 4-channel general-purpose A/D

- We'll make use of the accelerometer and light sensors