

# **2.996 / 6.971 Biomedical Devices Design Laboratory**

Fall 2007

Instructor: Dr. Hong Ma

# Origins

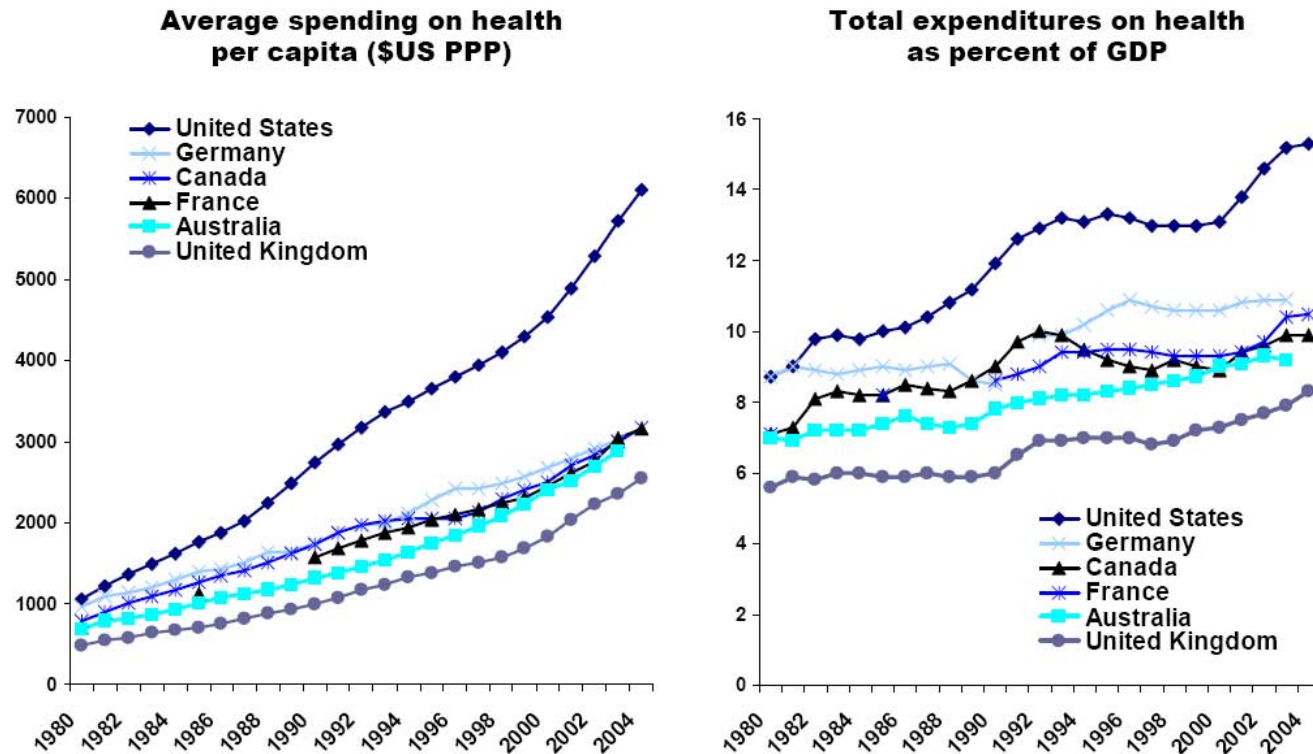
- 2.75 Precision Machine Design – Alexander H. Slocum
  - Medical devices starting in 2003
- CIMIT – Center for Integration of Medicine and Innovative Technology
  - A consortium of Boston area teaching hospitals and engineering schools
  - “CIMIT connects the champions who understand the clinical problems with technologists who provide the solutions” – J. Parrish

Images removed due to copyright restrictions. Logos for various partners.

CIMIT members include Massachusetts General Hospital, Beth Israel Deaconess Hospital, Children's Hospital Boston, Draper Laboratory, Brigham and Women's Hospital, MIT, and Partners Healthcare.

# Why Should Engineers Care about Medicine?

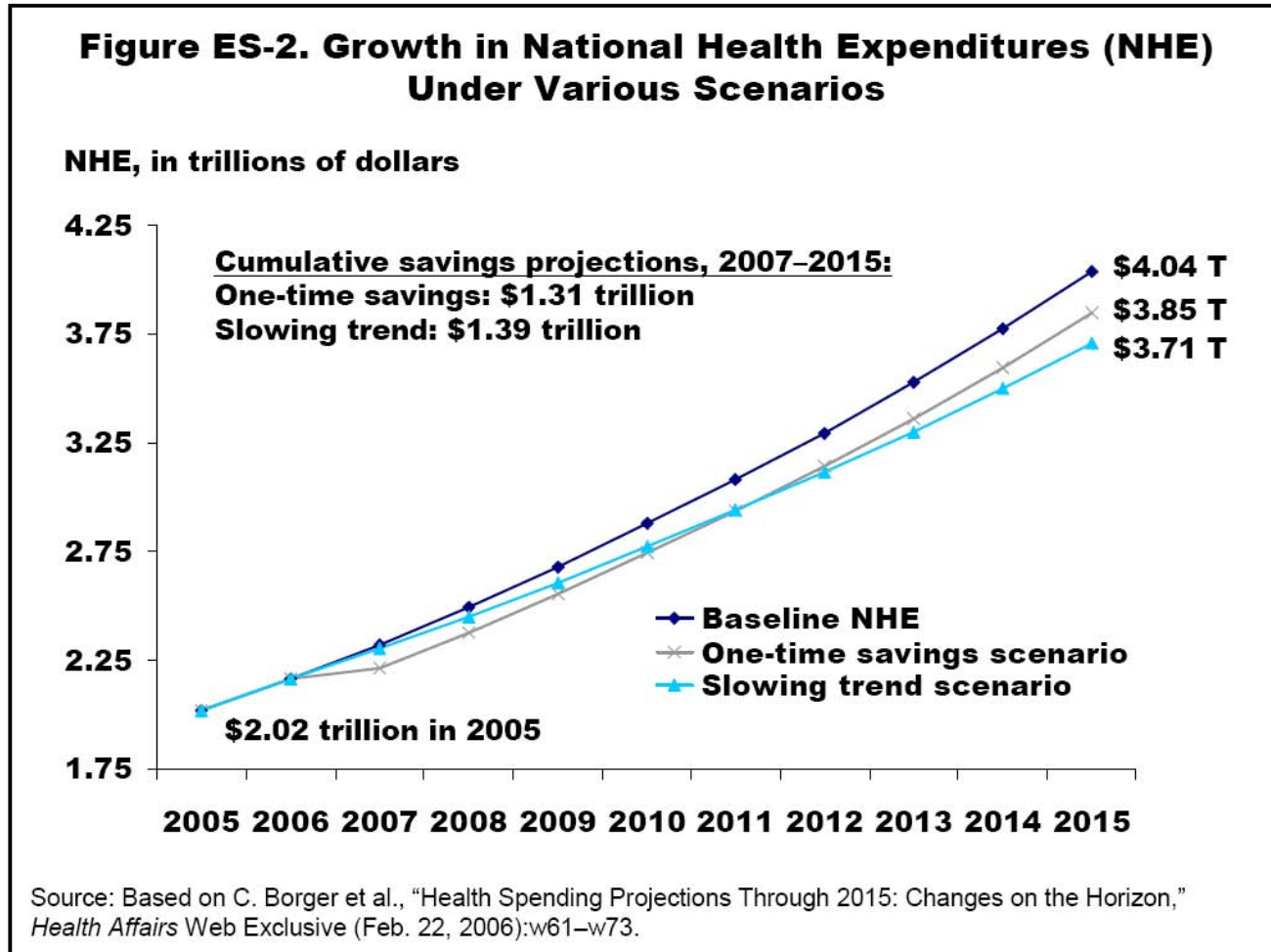
**Figure ES-1. International Comparison of Spending on Health, 1980–2004**



Data: OECD Health Data 2005 and 2006.

Source: Commonwealth Fund National Scorecard on U.S. Health System Performance, 2006.

# Trend: Increasing Cost



**2 Trillion =  $\$2 \times 10^{12}$  !!!**

# ROBOPSY:

*A Low-cost,  
CT-Guided, Tele-  
Robotic Percutaneous  
Lung Biopsy Assistant*

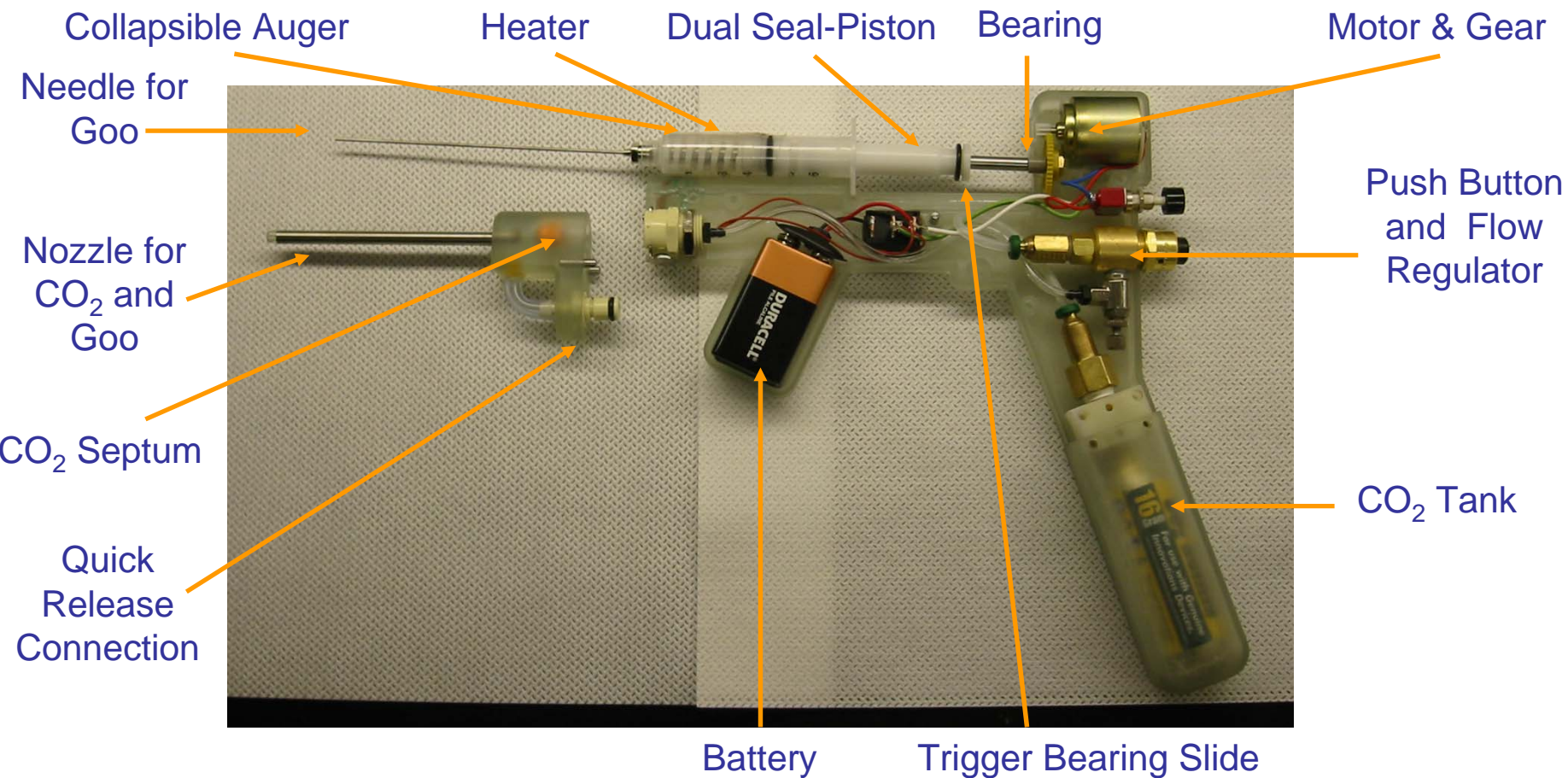
- Winners of the \$100k competition
- IDEAS Competition
- Further support from CIMIT

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# Streamline Injection System for Enhanced ACL Repair

•Dr. Martha Murray MGH

Images removed due to copyright restrictions.  
Diagram of ACL location in knee joint.



# Observations from 2.75

- “Technology that can be used to advance health care exist in other industries. And it is out there to be captured by medicine.” – J. Parrish, CIMIT
- Many projects require both electrical and mechanical expertise
- Solutions could be better optimized across both electrical and mechanical domains
- There is a tremendous demand for electrical expertise → a parallel electrical class to 2.75

# Class Goals

- Develop an understanding of electronic circuits and sensor systems (lecture and lab)
  - Basic principles of electronic circuits
  - Limitations of electronic components
  - Principles of accuracy and the tradeoffs involved
  - Signal conditioning techniques: the link between sensor and computer
  - PCB design, fabrication, assembly, and debugging
  - Some understanding of the electronics industry
- Develop new medical devices (project)
  - Formulate the concept
  - Design and manufacture a prototype
  - Test, verify, and publish (paper/patent)
- Have lots of fun building stuff!



# **This is not a circuits class!**

- ... although it will have a lot of circuits in it.

# **This is an electronics product design class.**

- We will be developing practical skills for creating real electronic products and then...
- Developing new medical devices.

# The Process of Electronics Design

- Electronics design is just like putting Lego's together. Except the pieces are unlimited and they don't always fit together.
- Define functional requirements
- Develop conceptual scheme
- Select and acquire components
- Develop detailed circuit, **fill-in the details**
- Layout PCB
- Assemble, test, and **debug**
- Write firmware / software

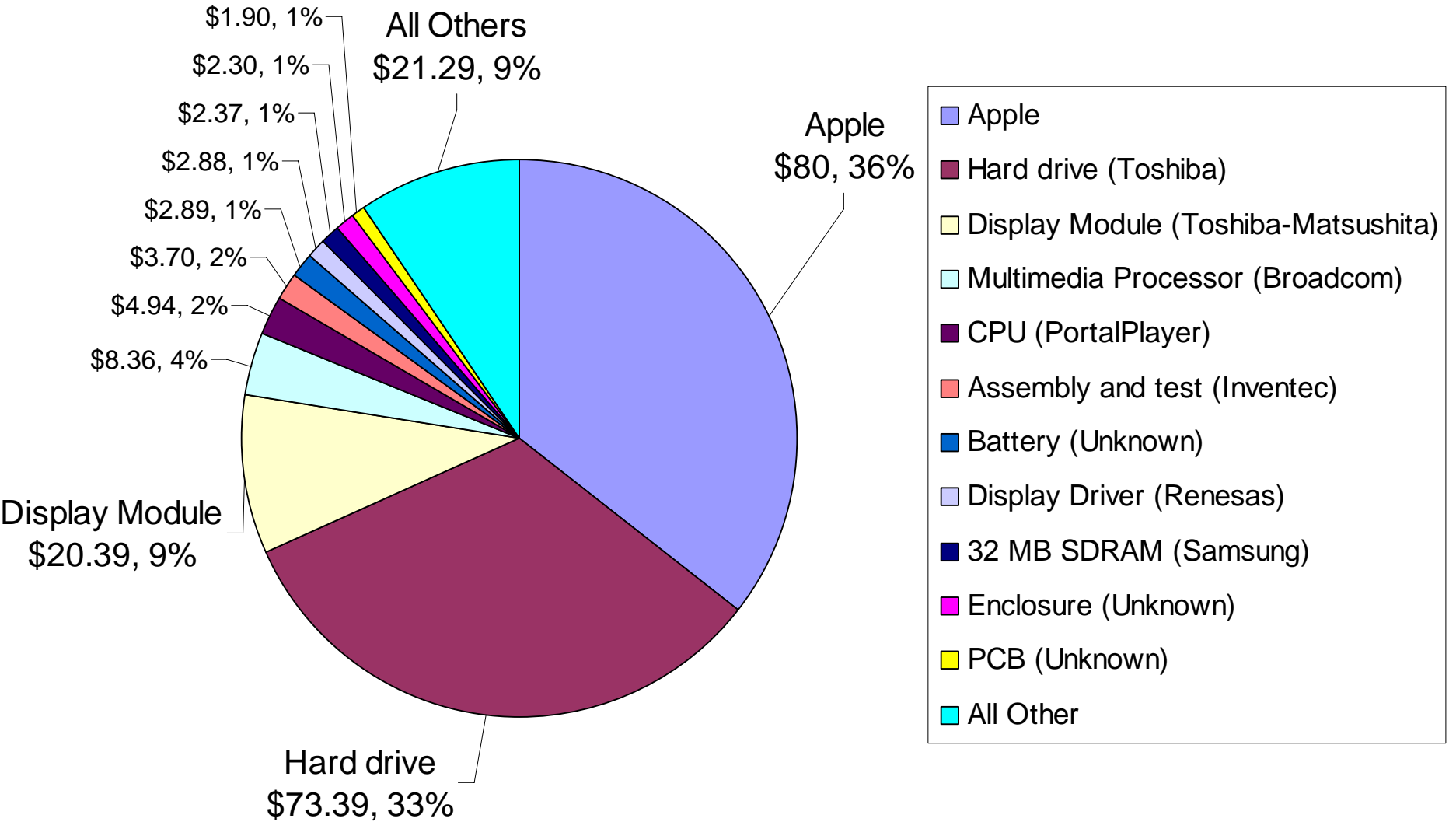
# iPod Breakdown

Images removed due to copyright restrictions.  
iPod circuitboards.

- C1: Linear tech (LT4055) USB power controller / Li-ion battery charger
- C6: PortalPlayer (PP5002) CPU
- C8: Broadcom (BCM2722) multimedia processor
- C9,C10: Philips (TEA1211, PCF50605) DC-DC power supplies
- C11: Cypress Semi (CY8C21) 8-bit microprocessor

# Component Breakdown of a 30 GB iPod in 2005

Retail: \$299, Wholesale: \$224



# Class Components

- Lectures (M W 11:00-12:30, 3-442)
  - Include assignments
  - First half: formal lectures
  - Second half: guest lectures and weekly team presentations
- Lab (Tentatively: M 2-5)
  - PCB design
  - First half only
  - Computer lab: 3-462 – get account from ME Ugrad office (1-106)
  - Hardware / firmware lab: 5-007
- Project
  - Teams of 4
  - Work with doctors to develop new medical devices
  - Lab space: 5-007

# Course Staff

- Instructor: Hong Ma
- Course Administrative: Maureen Lynch
- Mechanical Guru: Prof. Alex H. Slocum, PhD
- Electrical Guru: Dr. Chris Salthouse, PhD
- Medical Guru: Dr. Rajiv Gupta, MD, PhD

# Reference Material

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Text book covers.

- Art of Electronics – Horowitz and Hill
- Op Amps for Everyone – R. Mancini at TI
- Active Filters Cookbook – D. Lancaster
- Capacitive Sensors – L. Baxter
- Internet

# Industry Magazines and Catalogs

Images removed due to copyright restrictions.  
Magazine and catalogue covers.

- Electronic Design, EDN, Design News
- Free subscription, lots of ads
- Develop “the eye of an inventor”
- Digikey catalog



# Lecture Topics

- Basic Electronics
  - Resistor, capacitor, inductor
  - Thevenin and Norton equivalent circuits
  - Impedance, Bode plot, basic filters
  - Real components, range of values, accuracy vs. cost
- Diodes
  - Basic principles
  - Signal diode, schottky, LEDs, photodiodes, Zeners, TVS
  - Simple diode circuits: peak detectors, rectifiers

# Lecture Topics (cont.)

- Transistors
  - BJT, MOSFET, JFET
  - Models, how to use them
  - Switches, H-bridges, amplifiers
- Power Supplies
  - Bypassing
  - Ground planes
  - Linear power supplies, Low-drop out regulator
  - Switching power supplies
- Op Amps I
  - Basic topologies
  - Feedback and stability
  - Errors and error propagation

# Lecture Topics (Cont.)

- Op Amps II
  - How to choose an op amp
  - How to read an op amp datasheets
  - Industry jargon: single-supply, rail-to-rail, audio, video
- Analog signal processing
  - Voltage references
  - Working with ADCs
  - Noise
  - Synchronous detection

Image removed due to copyright restrictions.  
Sample op amp data sheet.

# Lecture Topics (Cont.)

- Microprocessors I
  - Basic architecture
  - Clocks
  - hex/bin math
  - Programming in C
- Microprocessors II
  - Timers
  - Asynchronous communications
  - Wireless, error checking
- PC user interface design (optional)
  - Visual basic programming

Image removed due to copyright restrictions.  
Promotional image for MSP340 MCU.

# Lecture Topics (Cont.)

- Sensors and interface circuits (2 Lectures)
  - Capacitive
  - Impedance
  - Optical
  - Strain
  - Acoustic
  - Encoders
  - Magnetic
  - Inertial

# Other Topics

- Low power techniques
- Finding / getting parts
- PCB layout techniques
- Soldering
- Electronics manufacturing and economics

# Guest Lectures

- Robopsy – Nevan Hanumara and Conor Walsh
- Dr. Chris Salthouse

# Term Project

- Teams of 4
- Weekly team meeting with staff
- Doctors available for weekly meeting
- First half: background research and bench-level experiments
- Second half: design, build, and test final device
- Weekly presentations in the second half
- Final report in the format of a journal article (e.g. IEEE Biomedical Devices)
- Final presentations Dec. 10

# Term Project (Cont.)

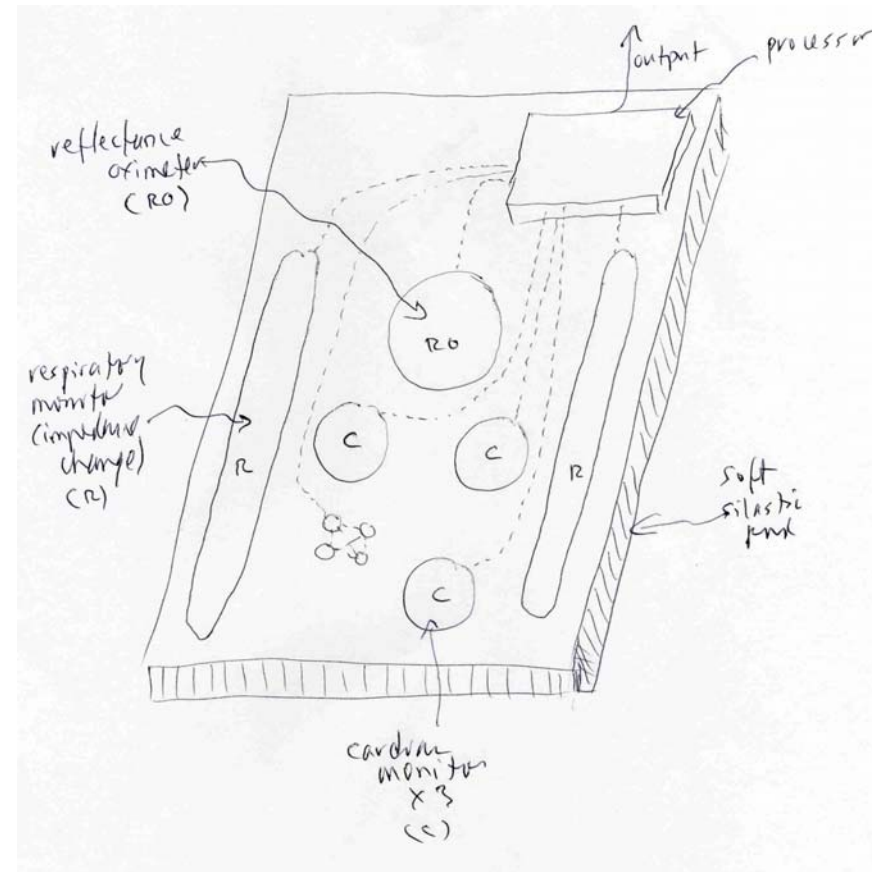
- Each team will have a budget of \$3000
  - Mechanical and Electronic components
  - PCB fabrication
  - Rapid prototyping
- Each team will present at the CIMIT Forum in Feb. 2008
- Intellectual property is jointly owned by the inventors and the hospital
  - Hospital is responsible for patenting



# Projects: 1. Smart Pad

- Emergency medicine today: a tangled mess of stickers and cables

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Photograph of a child in a hospital bed connected to various machines via many wires.



# Project 2: Osmoregulation

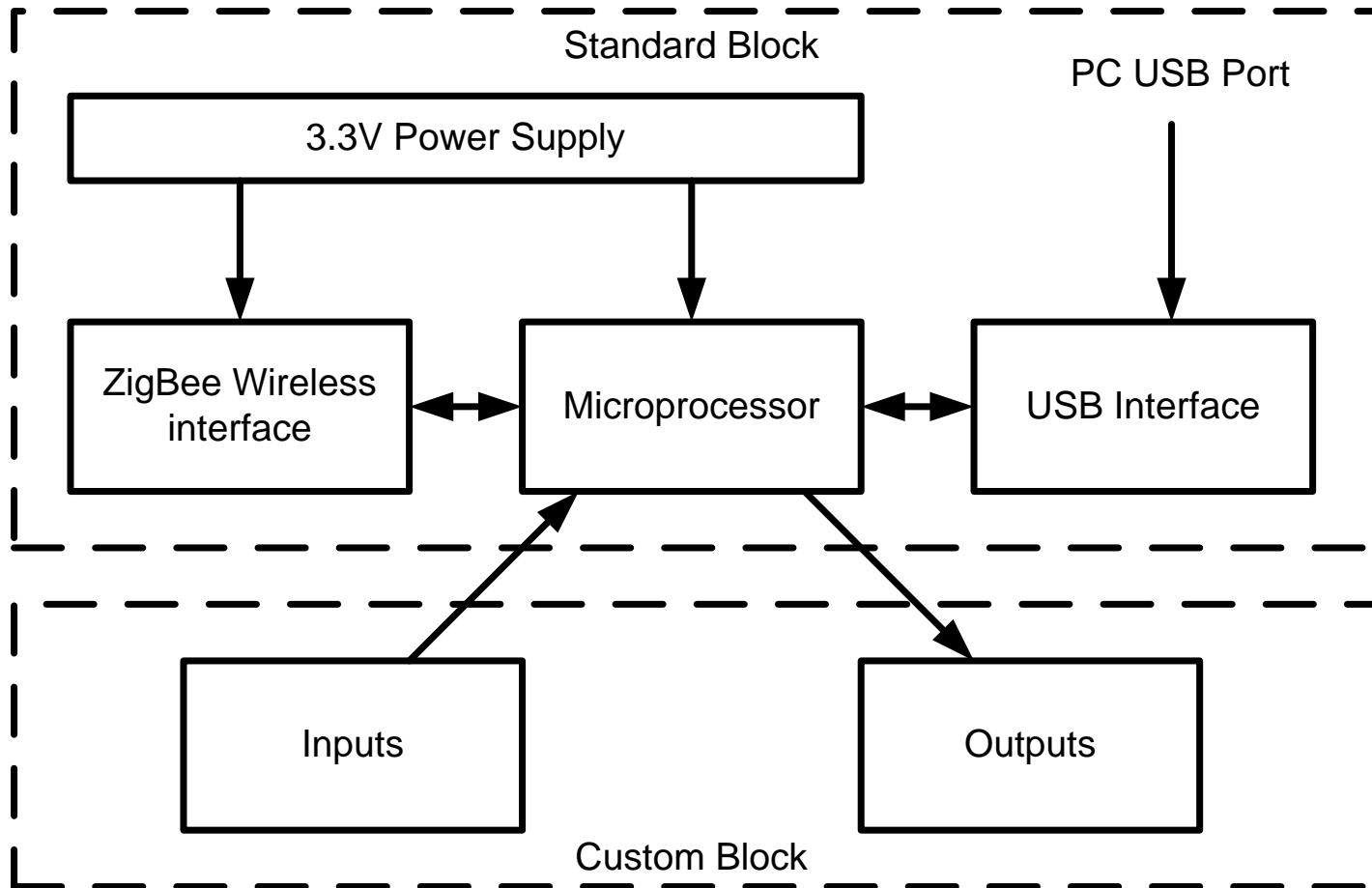
- Patients with loss of osmoregulation due to diabetes or inappropriate thirst mechanism require devices for measuring blood osmolarity
- Athletes and workers in distressed situation (soldiers and emergency workers) require a non-invasive way of determining their hydration state

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# Lab Goals:

- Learn the process of making a PCB based on a conceptual design
- Design and fabricate (with help) a multipurpose data acquisition system with wireless and USB connectivity
  - Useful for your project
  - PCB is yours to keep after the class
- Develop soldering and debugging skills
- Learn to program the MSP430 microprocessor

# Multipurpose Data Acquisition System



# Lab Demo

# Microprocessor: MSP430F2274

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- Simple to program
- Modern architecture
- 10 bit, 200 ksps ADC
- JTAG interface
- Low power consumption
- Up to 16 MHz crystal
- Selectable clock sources
- 16-bit timer
- 32kB programmable flash memory
- Communications: UART, I2C, SPI
- Low pin count, easy to solder package
- Free development software

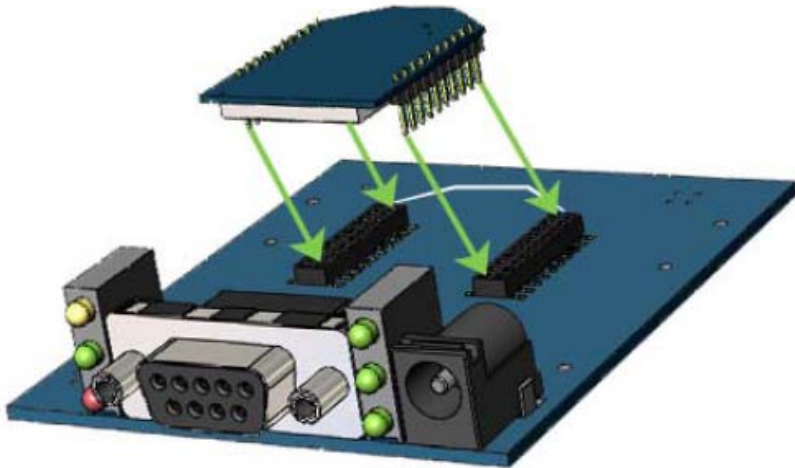
# USB Transceiver: FT232R

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- Serial-USB interface
- Single chip solution
- Up to 3 Mbps
- Software drivers interpret USB port as a COM port
- Can be powered directly from the USB port
- Interfaces with 1.8V to 5V logic

# Radio Module: XBee

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XBee and XBee Pro are interchangeable.



- 2.4 GHz radios
- ZigBee (802.15.4)
- Easy to use
- Prefabed module
- Indoor range 100'
- Line-of-sight range 300'
- Up to 115.2 kbps
- Tx current ~ 50mA
- Rx current ~ 50mA
- Highly robust



# Lab Schedule

| Task  | Week |
|---|------|
| 1. Come up with custom circuit                                  | 1    |
| 2. Learn PCB artist, create libraries, make a schematic diagram | 1-2  |
| 3. Layout PCB, send to manufacturer                             | 3    |
| 4. Solder and debug PCB   | 5    |
| 5. Microprocessor programming                                   | 6-7  |
| 6. PC user interface design (optional)                          | 8    |

# Lab Part 1

- Come up with your own input and output circuits for the DAQ PCB
  - Keep it simple, okay to use reference design
  - Components cost <\$15, available on Digikey
  - Design must be approved by staff
  - 5 minute design reviews with staff

## Example Lab

- 3-axis accelerometer (ADI: ADXL330)
- 4 LED's
- 2 auxiliary analog input channels

# Lab Part 2

- Learn to use PCB Artist
- Create library components in PCB Artist
- Create schematic
- Create bill of materials (BOM)

## PCB Artist Demo

# Schedule for Next Two Weeks

- Doctors to present on 9/10 during lecture time
- Enrollment decisions 9/12
- Student form teams by end of the week
- Lab 1 and 2 due 9/17

**Questions?**



# Enrollment

- Limited to 12 students
- After doctor presentations on 9/10, please email me with the following information:
  - Why you want to take this class?
  - What have you done before in electrical, mechanical, and signal processing design?
  - Rank the projects that you would like to do in order. Ties are okay.