Exam Preparation!

• Learn your ARM Assembly
  – Make sure you know how to write ARM assembly
  – Make sure you understand the EABI and how to write EABI compliant functions in assembly
  – Remember how to call functions from assembly
  – Remember how to use global variables in assembly

• Make sure you look at the practice exam

• Closed Book Exam
  – ARM and Thumb-2 Instruction Set Quick Ref allowed
  – Simple scientific calculator allowed
  – Notebook, cellphones, tablets NOT allowed
The Good, the Bad, and the Ugly

• Where can I get sensors (what this lecture is about...)
• More on motors (will have to do later)
• What to do about typical vs. min/max on datasheets
• OpAmp configurations for better sensing
  – You are not alone: “Op Amp Applications Handbook (Analog Devices Series)” by Walt Jung
These slides borrowed and adapted from Matt Smith, UM
Picking a Project Idea: Think **BIG** to Start

Thinking Big: Segway Example

**Problems**
- **Scale**: To Big...Accommodates adults!
- **Power**: Large Power Source and Actuators
- **Complex Control**
  - Gyro Stabilized
  - High Center of Gravity

**Solution**
- **Scale**: Scale Down 1’ High
- **Power**: Low Power, Hobby Servo Actuators
- **Simple Control**
  - “Tail” controls variable resistor
  - Low Center of Gravity

Simplified 373 Project
Types Of Projects: Music Air Guitar

Guitar Pick air action is modeled with 3 axis accelerometer.

Music created by sending MIDI codes to MIDI synthesizer.

Touch key matrix to emulate fret board of guitar. Fabricate with PC board.
Types Of Projects: Concept Auto Balancing Teeter Totter

Angle position controlled by propeller speed

Angle is maintained with feedback control.

Construction by Knex

Infrared distance sensor to measure height
Types Of Projects: Robotic Knight Ryder

• Featured gyros and accelerometers for inertial guidance (really).
• Spoiler was added to maintain traction and stability at high speeds! (probably cosmetic).

Graphics display indicating heading and position
Types Of Projects: Gaming

Space Invaders

Intense gaming in the 373 lab!

Classic game controllers: N64 and N8

Graphics display indicating the termination of Earth!

Player Two wins!
Earth Terminated
(Press any key)!
Types Of Projects: Measurement

Radar

- Servo provided angular sweep.
- IR and Ultrasonic Sensor for Ranging
- Reflections plotted as function of angle and distance

Advertisement
Types Of Projects: Research Wireless Power Monitoring

**Objectives**
- Contained in 1 cubic inch
- Wireless transmitting info to central monitor and control
- Low power
- Low cost (in quantity)

- Processor (LPC1114)
- Power Monitor Circuit (ADE7753)
- AC thru plug
- Radio (CC2520)
- Interconnect Points Fold to Connect Cube Sides

PCB Design!
Idea Starting Points

• Review Past 373 Projects
  – [http://www.eecs.umich.edu/courses/eecs373/Labs/Web/projects.html](http://www.eecs.umich.edu/courses/eecs373/Labs/Web/projects.html)
  – Search YouTube 373 projects
  – Provides Sense of Scale
  – Use Typical Devices
  – Range of Applications
  – Many of these projects were not portable because of kit restrictions!

• Review Cornell Projects Web Site
  – Feedback control oriented, but lots of applications
  – More devices to consider

• Research Oriented Projects
  – Prof Schmid will provide a list soon

• YOU!
  – Have a big cup of coffee and dream
  – Pick something you want to do!!
  – Think about all the embedded applications around you
    • Consider variants
    • Consider improvements
    • Research the application (know something about it!)
  – Discuss your ideas with potential partners and friends
  – Discuss your ideas with class staff
Forming Groups

• Group sizes: 2 – 4

• Larger Groups
  – Advantages: Do more complex projects
  – Disadvantages: Challenging group management, unknown relationships

• Smaller Groups
  – Advantages: Group dynamic is simpler, task management, known relationship, etc
  – Disadvantages: Possibly limits project complexity

• Start with existing Lab Partner or form new groups
Project Advising

• Prof Schmid
  – Next week
  – Probably Th and Fr, watch for announcement
  – During lab
  – Ask during office hours
Proposal

• Due: 3/6, Tu in Lecture
• Contents
  – List Group Members
  – Goal Statement: In general terms describe your application?
  – Functional Specification
    • List and Describe High Level Functions
    • High Level Functional Diagram
  – Preliminary Component List
• Proposal Reviews
  – Th and Fr the week proposal is due.
  – Look for announcement for review appointments.
Proposal Example

Goal Statement

For our project we intend to build a sound level meter. Sound level meters are used in applications ranging from environmental noise management to balancing sound systems in concert halls.

Our meter will approximate the Extech Model 407764. We will attempt emulate some the meter’s basic functionality, but without the same precision or reference accuracy.

The meter will have the following basic functions:
1. Sound level measurement with A and C frequency weighting
2. Time weighting from 1 – 100 seconds
3. Linear and logarithmic display of sounds level
4. Manual (4 ranges) and auto ranging
5. Data logging for 1 hour
6. PC interface to hyper terminal for ASCII file time series file storage of data log.
Functional Description

• Sound Measurement
  – Microphone: Commercial sound meters use expensive microphones. We will use a simple audio mic that will not have the same sensitivity, but can be frequency compensated.
  – Signal Conditioning: An audio amplifier will have to be provided to provide gain to the ADC.
  – Signal Conditioning: An anti-aliasing filter will have to be provided to for audio frequencies. We will use an active filter.

• Data Acquisition
  – The ACE will be setup to acquire data with 10 bit resolution and sample frequency of 40khz.

• Frequency Measurement
  – An FFT over the audio range will be performed using SmartFusion FFT core.

• Display
  – Display sound level digitally, simply analog meter graphic, measurement modes, etc.

• Key Pad
  – User input: measurement modes, display options, etc.
Functional Diagram

Audio Microphone, Amplifier, Anti-alias Filter

SmartFusion Kit
User Interface
ADC
FFT
Log Memory

Keypad

Serial Interface to Computer

Display
Component List

• Describe component
  – Simple audio microphone used for basic audio applications. Provides sufficient frequency response and sensitivity. Uni-directional for measurement application.

• Manufacture and Part Number
  – Audio-Technica ATR1100

• Vendor (distributor) and vendor part number
  – zZounds, part number is manufacturer’s number

• Vendor link
  – http://www.zzounds.com/item--AUTATR1100

• List Price: $9.95

• Image: Consider a providing a screen shot. This can be useful during reviews.
Component List

• Microphone
  – Description: Simple audio microphone used for basic audio applications. Provides sufficient frequency response and sensitivity. Uni-directional for measurement application.
  – Manufacture: Audio-Technica ATR1100
  – Supplier: zZounds, part number is manufacturer’s number
  – Supplier Link: http://www.zzounds.com/item--AUTATR1100
  – List Price: $9.95
  – Image:

• Miscellaneous Analog Components (lab supplies)
  – Audio Amplifier: 2, LM741 or equivalent
  – Bypass capacitors: 100uf
  – Audio Coupling Capacitors: 1 uf
  – Resistors: Assorted
  – Potentiometer: 10k
Component List

- **Display: Character Display with Key Pad interface and serial IO.**
  - Description: 20x 4 Character display with character define capability for simple graphics. UART or I2C interface. Keypad input with controller.
  - Manufacture: Max Orbital LK204-25
  - Supplier: Digikey part number 635-1024-ND link
  - List price: $69.95
  - Image
Component List

• Keypad
  – Description: 4x4 keypad membrane style (connects to display LK204-25)
  – Manufacturer: NKK switches FMBN16BE
  – Supplier: Digikey
  – Supplier Link http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&name=360-2297-ND
  – List Price: $25
  – Image
Component List

• Enclosure
  – Description: 7.3"x5.8"x3.0“ ABS
  – Manufacturer: JAMECO VALUEPRO 203-112F-1-R
  – Supplier: Jameco
  – Supplier Link http://www.jameco.com/webapp/wcs/stores/servlet/Product_10001_10001_141859_1?CID=PDF
  – List Price: $11.95
  – Image

• Batteries
  – Standard 9 volt battery (lab supplies or obtain)

• 9 volt battery connector with connector leads
  – Vendor: Jameco A104-R or equivalent
  – List Price $0.39
Component Issues

- Check to see if there is stock!
  - Most vendors list available stock
- Check if there are inherent shipping delays
  - Overseas
  - Indirect Shipping
  - Small private supplier (ebay)
- What is the budget?
  - Relative price and long term use will determine affordability
- Consider lower cost alternatives
  - Reduced performance (range, precision, smaller display, smaller actuator, etc)
  - No controller (I2C interface vs analog)
Suppliers

• Digikey: Major electronic supply house
• Jameco: Many components but significantly cheaper than many vendors.
• Sparkfun: Great electronics hobby source
• Acroname: Robot hobby oriented. Lots of components
• Pololu: Electronic hobby oriented. Lots of sensors.
• Servo City: Lots of servos and actuators
• Images Scientific: Unusual sensors http://www.imagesco.com/
• There are lots of alternate suppliers. Search the web!!
Alternate Kits: Cypress SoC

- CY8CKIT-014 PSoC® 5 FirstTouch™ Starter Kit
- Programmable system-on-chip design methodology and architecture.
- 32-bit ARM Cortex-M3 CPU core
- On board sensors
  - Accelerometer
  - Thermistor
  - Proximity Sensing
  - CapSense® touch-sensing interface,
  - 12-pin wireless module header
  - 28 general purpose I/O pins (GPIOs)

- Several available

- http://www.cypress.com/?rID=43674
Alternate Kits: LPCXpresso

- NXP's low-cost ARM based development platform
- Small foot print
- Break away development kit
## Alternate Kits: LPCXpresso

Many kits varying in ARM processor and peripherals.  
See http://ics.nxp.com/lpcxpresso/

<table>
<thead>
<tr>
<th>DAC</th>
<th>LPC1768</th>
<th>LPC1769</th>
<th>LPC1772</th>
<th>LPC1774</th>
<th>LPC1776</th>
<th>LPC1777</th>
<th>LPC1778</th>
<th>LPC1785</th>
<th>LPC1786</th>
<th>LPC1787</th>
<th>LPC1788</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARM Cortex-M3 microcontroller with 512KB flash, 64KB SRAM, 10/100 ethernet, USB 2.0 Host/Device/OTG, 2 CAN, I2S, 12-bit ADC, 10-bit DAC</td>
<td>ARM Cortex-M3 microcontroller with 512KB flash, 64KB SRAM, 10/100 ethernet, USB 2.0 Host/Device/OTG, 2 CAN, I2S, 12-bit ADC, 10-bit DAC; 120MHz operation</td>
<td>ARM Cortex-M3 microcontroller with 64KB flash, 24KB SRAM, 2KB EEPROM, external memory controller, USB 2.0 Device, 2 CAN, 12-bit ADC, 10-bit DAC, I2S</td>
<td>ARM Cortex-M3 microcontroller with 128KB flash, 40KB SRAM, 2KB EEPROM, external memory controller, USB 2.0 Device, 2 CAN, 12-bit ADC, 10-bit DAC, I2S</td>
<td>ARM Cortex-M3 microcontroller with 256KB flash, 80KB SRAM, 4KB EEPROM, external memory controller, 10/100 ethernet, USB 2.0 Host/Device/OTG, 2 CAN, 12-bit ADC, 10-bit DAC, SD/MMC, I2S</td>
<td>ARM Cortex-M3 microcontroller with 512KB flash, 96KB SRAM, 4KB EEPROM, external memory controller, USB 2.0 Host/Device/OTG, 2 CAN, 12-bit ADC, 10-bit DAC, I2S</td>
<td>ARM Cortex-M3 microcontroller with 512KB flash, 96KB SRAM, 4KB EEPROM, external memory controller, 10/100 ethernet, USB 2.0 Host/Device/OTG, 2 CAN, 12-bit ADC, 10-bit DAC, SD/MMC, I2S</td>
<td>ARM Cortex-M3 microcontroller with 256KB flash, 80KB SRAM, 4KB EEPROM, external memory controller, LCD controller up to true color XGA, USB 2.0 Host/Device/OTG, 2 CAN, 12-bit ADC, 10-bit DAC, I2S</td>
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</tr>
</tbody>
</table>
Alternate Kits: Others

• Should be ARM based
  – E.g. Atmel SAM3U-EK or SAM3S-EK
  – E.g. TI Beagle Board

• Must be approved by staff
Device Survey

- User Input
- Actuators
- Sensors
- Displays
User Input: Keypad

• 4x4 key pad
• Supplier: ucontroller
• Interface: UART serial interface
  – http://www.ucontroller.com
• Or, connects directly into some serially interface displays
User Input: Touch Screen

- Provides XY position
- Supplier: Sparkfun LCD-08977
- Interface: 2, Digital GPIO and 2, ADC channels
User Input: Resistive Touch

- Provides position along sensor (like iPOD)
- Supplier: Sparkfun SEN-09074
- Interface: ADC (sensor is variable resistor)
- Available in rotary and linear forms
User Input: Flex Sensors

• Change resistance as function of flex
• Interface: ADC
• Vendor: Spark fun or Images Scientific Instruments
User Input: Game Controllers

• Classic Nintendo 8 and 64
• Lab Stock
• Serial Interface
  – Custom serial interface with GPIO
  – N8 simple synchronous serial
  – N64 full duplex asynch serial
User Input: Joysticks

• Used for pointing
• Sparkfun provides many varieties
• Interface: variable resistance, ADC
User Input: Other key pads

- Multi-general purpose keypad
- Sparkfun
- Require scanning matrix with many GPIO
- May require extra logic to handle matrix scanning
User Input: Motion Sensing

• Accelerometers
• Sparkfun ADXL335
• Analog Voltage Interface (ADC)
• 3 axis +/-3G
User Input: Contact
From Sparfun

• Simple Push Buttons **COM-00097**
  – Interface: Digital IO

• Vibration **SEN-09197**
  – Interface: Provides voltage (piezo)

• Reflectance Sensor **ROB-09454**
  – Interface: Digital IO

• Pressure **SEN-09375**
  – Changes resistance with pressure
Actuators: DC Motors

• Basic DC motors
  – Hard to control and generally have poor torque at low speeds.
  – Ok, for high rotation speeds
  – Control with H-bridge and PWM

• Gear Motors
  – Use gear box for low speed control, but not very responsive.
  – Control with H-bridge and PWM
Actuators: Motor Control

- H bridges are common devices to buffer and reverse the direction of a DC motor.
- Common component is the SN754410NE

754410NE provides switching and buffering

Switch matrix can reverse voltage across load (motor)

Load voltage and control voltage are independently supplied
Actuators: Servos

- Angle adjust to +/- 90 degrees from center
- Available in continuous rotation models
- Interface: PWM via GPIO (easy)
- $10 - $40

![Diagram of Servo Motor]

**Graph:**
- Angle +/-90 degrees
- Pulse Width (0.8 – 1.5ms typically)
Actuators: Stepper Motors

• Good angle control with continuous rotation
• Complex interface compared to servo
• Possible to use controller with current buffer
• $25 - $50
Actuators: Linear

- Motor/gear box type
- Available in different torques, response and travel
- Voltage Control (PWM)
- Linear Feedback (potentiometer)
- ~$100
- http://www.firgelli.com
- http://www.trossenrobotics.com
Actuators: Linear

• Gear racks with motors
• Supplier: Servo City

• Or, lead screws with motors
Actuators: Linear

- Solenoids
- Short Travel
- Fast
- Power hungry! 0.5amp at 12volts
- Requires buffering and isolation
- Used for pneumatic and fluid valve
Robotic Chassis

• “Roomba” style
• Great Maneuverability
• DC motor control with H Bridge
• Lots of room for components
• Powered by standard RC batteries
Displays: Character

• NEWHAVEN DISPLAY NHD-0216K3Z-FS(RGB)-FBW
• Serial interface: I2C, SPI or RS232
• 2 lines x 16 characters
• No bit map graphics
• $24
• Supplier: Jameco
Displays: Character

- Matrix Orbital LK204-25
- 4x20 character display (no bit map graphics)
- 4 sets of eight custom characters
- Serial Interface: UART and I2C
- Keypad interface
- $70
- Supplier: Digikey
- Supplier: Jameco
Displays: Graphic

- Matrix Orbital GLK24064-25
- 240 x 64 pixel graphics display
- text display using built-in or user-supplied fonts
- adjustable contrast
- backlighting
- keypad interface
- RS-232 (UART) or I2C communications
Displays: Graphics Display with Embedded Controller

- 4D Systems uLCD 32pt-GFX-DS
- 3.2 inch with touchscreen
- Embedded graphics controller
- Serial Interface
- Sparkfun $85
- Graphics developed with high level application software.
Displays

• See Sparkfun for many other displays
• Consider your application and
  1. Serial Interface for easy interface
  2. Size
  3. Character vs Graphic
  4. Power consumption
  5. Cost
Sensors: Environmental

- **Temperature: Thermistor**
  - Resistance varies with temperature
  - Sparkfun SEN-00250, $2

- **Temperature: LM34DS analog**
  - +10 mv/degree F
  - Jameco, $2.25

- **Temperature: TI TMP102**
  - SPI type interface
  - Sparkfun, $6
  - 12-bit, 0.0625°C resolution
  - Accuracy: 0.5°C (-25°C to +85°C)
Sensors: Environmental

- Humidity
- Atmospheric Pressure
- Day Light
- Various Gases
  - Alcohol
  - CO2
  - LPG
  - Methane
- See Sparkfun or search web
Sensors: Motion

- 3 Axis Accelerometers
- MMA7260Q
  - Adjustable gains ±1.5, 2, 4, and 6g
  - Analog voltage output
  - Sparkfun $20
- BMA180
  - ±1g, 1.5g, 2g, 3g, 4g, 8g and 16g
  - SPI and I2C models
  - Sparkfun $30
Sensors: Motion

• Gyros: measure angular rate, degrees/sec

• Types
  – 1-3 axis
  – Sensitivity 30 – 300 degrees/sec
  – Analog and I2C interfaces
Sensors: Distance (Proximity)

- Infrared Proximity Sensor
- Target must be reflective, but may be small
- Optimized for various sensing distances 3-150 cm
- Analog interface (cm/volt)
- Sparkfun, Acroname

![Image of sensors]

15-150 cm 3-40 cm

Must work in linear ~ linear region or compensate.
Sensors: Distance (Proximity)

- Ultrasonic Range Finder
- Linear and accurate 0 – 255 inches
- Interface: RS232 serial, analog or PWM
- Target size and range depends on specific models
- See selection guide

Different beam width trade off target and clutter sensitivity.
Sensors: Vibration and Sound

- Omni-Directional Electret Condenser Microphone Cartridges
  - inexpensive
  - easy to use
  - good frequency response
Sensors: Vibration and Sound

- Piezo Vibration Sensor
- Produce voltage in response to flex change
- Available in various sensitivities
- Low Frequency response

Mass, stiffness and mounting orientation varies for different apps.
Sensors: Force

- Pressure (ohms proportional pressure)
- Come in variety of geometries
Sensors: Force

- Flex (resistance proportional to bend)
- Used in original Nintendo power glove
Sensors: Force

- Air pressure
- Provide 5 volt supply
- Voltage proportional to pressure
- Jameco
- Variety of sensors

<table>
<thead>
<tr>
<th>Measurable pressure range (kPa)</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~24.5</td>
<td>XFPN-03KPGV</td>
</tr>
<tr>
<td>0~100</td>
<td>XFPN-100KPGV</td>
</tr>
<tr>
<td>0~25</td>
<td>XFPN-025KPG</td>
</tr>
<tr>
<td>0~50</td>
<td>XFPN-050KPG</td>
</tr>
<tr>
<td>0~100</td>
<td>XFPN-100KPG</td>
</tr>
<tr>
<td>0~200</td>
<td>XFPN-200KPG</td>
</tr>
</tbody>
</table>
Sensors: Force

• IESP-12 force sensor
• resistance proportional force applied to the button
• Up to 4 Kg of force High resistance (>500K)
• Low resistance (~500 Ohms) at max loaa
• http://www.solarbotics.com/products/35170/
Sensors: Force

- Stretch
- Resistance proportional to stretch
- Available in bulk
- http://www.imagesco.com
Sensors: General

• Consider your application
  – What range of sensing do I need?
  – What sensitivity?
  – What response?
  – What kind of repeatability?

• Characterize the sensor with standard lab equipment first.

• I.E. for a resistive style force sensor
  – Attach to ohm meter and apply various forces

• I.E. for an accelerometer
  – Provide power
  – Attach to oscilloscope on slow trace and observe response to different orientations in gravity
Project Schedule

- **Week 2/27**
  - 2/28 Project Overview
  - Finish Lab 5

- **Week 3/5**
  - Work on project ideas
  - Tu 3/6 Proposal Due
  - Finish Lab 6
  - Proposal reviews (probably Th and Fr afternoon, look for announcement)

- **Week 3/12**
  - Spring Break
  - Potentially start working with stock components (ie characterization of a sensor)
  - If you want to get started with a special order component, let me know early (during advising or in lab sometime)

- **Week 3/19**
  - Work on projects
  - Receive special order components
  - At a minimum, you should have stock components and should be starting.
  - Project support hours begin

- **Week 3/26**
  - Work on projects

- **Week 4/2**
  - Work on projects

- **Week 4/9**
  - Work on projects

- **Week 4/16**
  - Finish up projects, make video
  - Friday: provide Prof Schmid with link to YouTube video!

- **Week 4/23 and 4/30 - Take-home Final**
  - 4/24 - last day of class. Video presentation from every group.
Last, but Not Least
Safety Restrictions

• Safety methods must be implemented and approved for the following items:
  – **High Speed Spinning Devices**: containment
  – **Water, Pop, Food**: containment, non-toxic fabrication
  – **Projectiles**: containment, soft materials, low velocity
  – **Heat**: isolated, insulated and non-combustible levels
  – **High voltage**: consult staff for isolation methods
  – **Lasers**: shielding or containment
  – **Not Sure**: ask us
Questions?