Low-Cost Mobile Lab Solutions for Individualized Mechatronic Education

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Agenda / Contents

• Introduction to Mechatronics
• Opportunity in low cost lab design
• Designing a solution:
  – Design Lab at Rensselaer
  – Fall 2013 Team accomplishments
  – Spring 2014 Team deliverables
• Preliminary Results
Mechatronics

• The synergistic integration of physical systems, electronics, controls, and computers through the design process, from the very start of the design process

• Multidisciplinary Systems Engineering - an understanding of the essential characteristics of each domain and how they contribute to the system performance
Dynamic System Investigation

• A key element is a balance between
  – Theory: Modeling and Analysis
  – Practice: Experimental Validation & Hardware Implementation
Traditional Lab Experience

Typical Challenges:

- Expensive equipment: workstation, DAQ, sensors and actuators
- Distributing and collecting material
- Maintenance and staffing
- Limited access – building/lab rooms
- Require student lab teams (2-5 students)
- Typically introduced later in the curriculum

Opportunity:

- Utilize the integration of low-cost prototyping hardware:
  - Arduino, RPi, sensors, drivers
- Utilize MATLAB and Simulink as the enabling technology:
  - Arduino libraries with automatic code generation
  - System level concepts can be easily realized and
  - Implementation on the hardware with 1-Click Programming

Create complete low-cost systems
System Design Goals

• Focus is on complete systems:
  – Low-cost: ~$100 – affordable so every student can perform multiple labs
  – Portable and self-contained – labs can be performed anytime, anywhere
  – Designed to compliment a student textbook with an inspiring hardware system

• Hardware suite capable of demonstrating multiple concepts from multiple classes and curriculum
All Hands-On Hardware Approach

• Provide:
  – A real, physical, means to connect theory to practice for every student
  – A useful prototyping platform for other coursework and projects
  – Inspiration: encourages tinkering

• Introduce early in curriculum to provide extended value throughout coursework
Engineering a Solution: The Design Lab at Rensselaer

Providing clinical “real-world” experiences for undergraduate students to integrate discipline-specific knowledge with practice on challenging multidisciplinary design projects.
Design Lab Resources

- Bright enthusiastic students!
- Professional support staff
  - Operations Manager
  - Project Engineers
  - CAD/CAM/CAE Manager
  - Purchasing Manager
  - Shop Manager & Technicians
- Multidisciplinary team of faculty
- Research university environment
- A showcase facility
  - 6000 sq ft conference area
  - 8000 sq ft shop area
  - Haas Technical Center
  - Web-based Collaboration system

Academically diverse / multi-disciplinary student teams with professional support!
## Typical Design Lab Project Areas

<table>
<thead>
<tr>
<th>Business Phase</th>
<th>Project Characteristics</th>
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<tbody>
<tr>
<td><strong>Research</strong></td>
<td>• Developing a tool/apparatus for supporting research activities</td>
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<td>• Design of experiments</td>
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<td><strong>Technology Transfer</strong></td>
<td>• Proof of theory prototype development</td>
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<td>• Evaluation of new technologies/materials/processes</td>
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<td><strong>Product Development</strong></td>
<td>• Product concept development and prototyping</td>
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<td>• Advanced development of new products</td>
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<td>• Redesign and enhancing a product</td>
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<td>• Analyzing and improving the sustainability of a product</td>
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<td><strong>Manufacturing &amp; QA</strong></td>
<td>• Manufacturing process redesign to improve productivity and achieve cost savings</td>
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<td></td>
<td>• Developing new tools for manufacturing processes</td>
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<td></td>
<td>• Quality assurance methods and test apparatus development</td>
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<td><strong>Marketing &amp; Sales</strong></td>
<td>• Studying new business opportunities by building &amp; using prototypes</td>
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<td>• Create a demo system for sales and trade show supports</td>
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<td>• Develop tools to support/Enhance sales</td>
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<tr>
<td><strong>Customer Supports &amp; Maintenance</strong></td>
<td>• Designing and building tools and methods for simplifying field service (maintenance) operations</td>
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<td><strong>Business Operations</strong></td>
<td>• Business process re-engineering</td>
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<td></td>
<td>• Developing tools/processes for improving business processes</td>
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Design Lab Project Teams: Real-Time Systems Using MATLAB

- Examine Engineering lab curriculum at Rensselaer from Freshmen to Senior to identify opportunities

- Fall 2013: Development of basic software components
  - Kelly Burghart, Anton Cataldi, Andrew Haslam, Chris Heinbokel, James Kalfas, Matthew Kosman, Benjamin Lane, Michael Medica, Pratik Patel

- Spring 2014: Complete system design
Simulink Support Package for Arduino

• Existing Simulink support package provides all basic hardware functions

• Extend this functionality to support common sensors and actuators
Fall 2013 Software Library

Device Specific Libraries:
- MinSegShield M1V4
- MinSegShield M2V3
- MinSegShield M2V3
- MinSegMega
- MinSegMega

Data Read/Write:
- LCDWrite
  - Write to LCD
- SD_Write
  - Write SD
- SD_Read
  - Read SD

Motor Drivers:
- Motor Driver PWM4, D5 LOW is zero speed (Mega Shield)
- Motor Driver PWM9, D11 LOW is zero speed (Mega Shield)

Accelerometer Gyroscope Magnetometer:
- MPU6050 Driver SFunction1
- HMC5883L, MPU6050 Driver SFunction
- HMC5883L Driver SFunction

Simple Serial Communication With Plotting:
- int16
  - Serial Send int16 Port0
- Single
  - Serial Send single Port0
- uint8
  - Serial Send uint8 Port0

Plot Data 'int16'
Plot Data 'single'
Plot Data 'uint8'

Ultrasonic Sensor:
- HC-SR04 Sonar SFunction1

Encoders:
- Dual Encoder Reading (Shields)

Rensselaer Arduino Support Package (RASPlib)
Spring 2014 Approach

• Identification of key physics concepts

• Identify low cost hardware components

• Creation of supporting Software libraries

• Develop introduction labs and curriculum

• Create Arduino Shields contain the entire experiment: “System-on-Shield”
Spring 2014

• Rensselaer Curriculum Investigation:

Physics I & II
Circuits/Intro to Electronics
Litec
Coco/Hardware Design
Fields & Waves
Signals & Systems
ModCon
Mechatronics
Dynamics/IEA
MSL/Strengths/MatSci/EMD
Thermals & Fluids
Digital Signal Processing
Chemistry/O-Chem
Biology

Physics I & II
Litec
Coco
ModCon
Mechatronics
Digital Signal Processing

• Reaches the most students - total enrollment of 786 students at RPI in S2014
• Introduces numerous core concepts used in later classes
Key Deliverables

• Downloadable Software Library
  – Starting point for “hackers” (aka engineering students) and users alike

• Hardware selection
  – Shield design schematic and/or board layout

Availability:
• Project completion for June 1, 2014
• Current library and examples can be found at http://homepages.rpi.edu/~hurstj2/
An Example: The MinSeg

• A miniature balancing robot designed for a mobile, distributed lab experience for the Mechatronics course

• Desktop DC Motor lab that easily converts to an inspirational balancing robot or line following car

Images from MinSeg.Com
The MinSeg

Hardware
• DC motor, axle, wheels and encoder
• 4 channel motor driver
• 3 axis gyroscope, 3 axis accelerometer
• 3 axis magnetometer
• Potentiometer
• 9v AA battery supply
• Arduino MEGA 2560 R3
• Bluetooth Header

Software
• Library & Examples with all supporting building blocks
External Mode

- In Simulink users can easily view data and modify parameters, in real time, for quick development, verification and debugging purposes:
Video: Demo Code External Mode

- Samples/Drives all sensors and actuators using library blocks
- External mode to view data or modify parameters
- Code executes at approximately 30Hz
System Level Design

- underlying code details are not visible:

DC Motor Control:

Motor HW Subsystem:
Video: DC Motor Control

• Simple DC Motor Control on Mega
• External mode to view data or modify parameters
• Code executes at approximately 30Hz
Deployment

- After algorithm verification the code is deployed to the stand-alone target (aka, the Arduino) with a single click!
Video: DC Motor Control

• Simple DC Motor Control deployed on Uno
• Potentiometer to modify controller gain
• Data sent serially
• Code executes every 3 milliseconds
Video: MinSeg Balancing

- LQR controller deployed on MinSeg
- Potentiometer to modify controller gain
- Data sent serially through Bluetooth
- Code executes every 5 milliseconds
Results

- All hands-on
- Theory to practice
Curriculum Development

• Finalizing 10 hardware based core labs as a foundation for future labs
  – Lab 1 - Introduction to Simulink and Arduino - Blinking LED
  – Lab 2 - Analog In, PWM Out, Quadrature Encoder
  – Lab 3 - Gyroscope - Reading and Calibrating
  – Lab 4 - Magnetometer - Making a Compass
  – Lab 5 - Serial Communication With Bluetooth
  – Lab 6 - DC Motor Step Response
  – Lab 7 - Basic DC Motor Position Control
  – Lab 8 - DC Motor Modeling and Parameter ID
  – Lab 9 - Determining Angle with Gyro and Accelerometer with a Complimentary Filter
  – Lab 10 - Ultrasonic Sensor
Summary / Conclusion

• Simulink Target Support and low cost hardware availability make it an exciting time for innovative low cost lab development!

• Focus is development of complete low-cost hardware, software, and curriculum that
  – Every student can use (all hands-on)
  – Easily connect Theory to Practice
  – Allow focus on Concepts (not code)
  – Is inspirational and encourages tinkering
With Thanks To

• MathWorks
  http://www.mathworks.com/

• The Design Lab at Rensselaer
  http://rpi.edu/academics/engineering/mdl/

• Kevin Craig
  http://www.marquette.edu/engineering/mechanical/facstaff_craig.shtml