A “Hands-On” Approach to Teaching System Dynamics
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Course Description
- **System Dynamics** - Core Junior Level Mechanical Engineering Course where students learn to model dynamic systems in several domains.

![System Dynamics Diagram]

\[ \ddot{x} + \frac{b}{m} \dot{x} + \frac{k}{m} x = f(t) \]

Teaching Challenges
- Concepts are difficult to grasp when they lack interaction with a real physical system.
- Limited lab time and resources make thorough illustration challenging because each concept is best demonstrated by a different physical system.

Approach: The Haptic Paddle
- The haptic paddle [1] is an inexpensive force-feedback robot that students analyze, calibrate, program, and physically interact with in a series of lab assignments.
- Enables students to analyze a real dynamic system while also interacting with several virtual systems.

Hardware and Software
**HARDWARE:**
- Acrylic Components ($15)
- Arduino Microcontroller + Ardumoto Shield ($55)
- DC Motor (~$5)
- MagnetoResistive Angle Sensor ($6)

**SOFTWARE:**
- MATLAB SIMULINK
- ARDUINO

![Haptic Paddle Diagram]

Laboratories
- **Lab 1:**
  - Build models to simulate stiffness, damping, and a DC motor.
  - Conduct a motor spin down test.

- **Lab 2:**
  - Measure the inertia of the paddle handle.
  - Determine the torque constant and Coulomb friction in the motor.

- **Lab 3:**
  - Calibrate the angle sensor.
  - Model the paddle as a second order system and compare theoretical and experimental observations.

- **Lab 4:**
  - Investigate Feedback Control.

- **Lab 5:**
  - Explore Modes of Vibration.
  - Interact with Virtual Systems.

Assessment Results
- 25 question multiple choice quiz (5 questions per lab)
  - Administered at the beginning of the semester
- 5 question lab quiz administered to a specific student section at one of the times below:
  - Beginning of Lab
  - After a Pre-Lab Lecture
  - After Lab
  - After completing the Lab Report

**ANALYSIS: Wilcoxon Signed-Rank Test**

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<th>Lab</th>
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<th>After Lab Score</th>
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Pre–Test and After Lab scores (out of 5) from 2008 (top) and 2010 (bottom). Red denotes significance at \( \alpha=0.05 \); Green denotes significance at \( \alpha=0.1 \).

- Analyses of each portion of the learning experience is underway to assess when students are learning the most.

Dissemination
- Collaborating with a local physics teacher to use the paddle in a high school physics lab.
- Used in several K-12 outreach demonstrations.
- All lab materials and instructions are available online:
  http://research.vuse.vanderbilt.edu/MEDLab/haptic_paddle.html

References

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