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.

Mathematical equation:

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

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

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>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 are 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](http://research.vuse.vanderbilt.edu/MEDLab/haptic_paddle.html)

References


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