Center for Embedded Networked Sensing

System Identification of an Inverted Pendulum Device

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Introduction

Device to be used in controls laboratory

- **Typical introductory controls lesson involves inverted pendulum**

  The ***concept***s learned from controlling an inverted pendulum system are seen as a great introduction to ***control theory***; however, the materials are so costly that student use is ***restricted***.

- **Standard controls course for all Electrical Engineering students**

  A wide variety of students enroll in EE 141, the course ***required*** of all EE students at UCLA. These students have diverse educational backgrounds; indeed, the only ***prerequisite*** for EE 141 is a systems and signals course.

System Identification necessary prior to use

- **Every device will have slight differences in its construction**
  - Helps the user to identify ***parameters*** he will need to control the device.
  - Provides a ***model*** for ***system behavior***.
- **Considered a standard "first step" in the use of any piece of hardware**

Problem Statement: Mathematical modeling of a device is only an approximation

Hardware variances affect behavior of any system

- No two devices are 100 percent identical; thus, small differences in behavior are common. These slight variances can be exploited during inter-device communication when device behavior deviates from what is expected. In the inverted pendulum control system, the unique makeup of pendulum and motor affect the movement of the inverted cart.
- Attempting to control the motor and pendulum with mathematically derived constants leads to imprecise system behavior.

Solution: System Identification facilitates more accurate control of a device

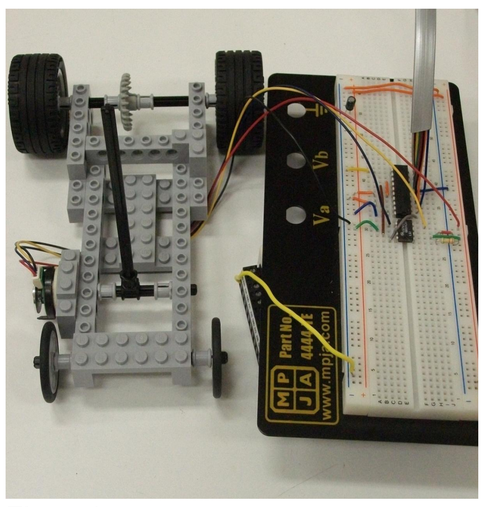

Figure 1

Figures 1 and 2 show the entire control system used in the Electrical Engineering 141 laboratory section . Students are required to assemble both the vehicle and the circuitry on their own.

The vehicle contains an encoder sensor, which reads data pertaining to pendulum and wheel movement. The circuit board is directly connected to a Data Acquisition device, which delivers voltage and interprets data from the encoder for the system identification software.

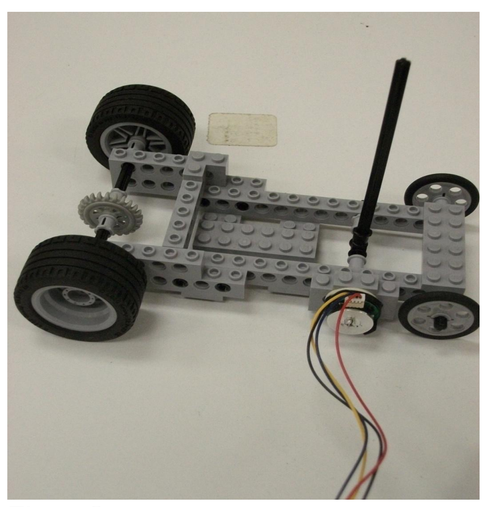

Figure 2

Pendulum Identification

- Pendulum movement is measured as a waveform.
  - Differences in the direction of the pendulum determine whether the amplitude is positive or negative.
- Variances in size and weight ultimately lead to a unique damping ratio for each pendulum: a measurement of the lessening of pendulum oscillation. Students will use this value later in the laboratory exercise.
- Students also need to know the natural frequency of the pendulum, or the frequency of the wave had the pendulum remained in motion forever.
- Real-time graphical data of the pendulum's position clearly indicates the pendulum's movement, which serves to reassure the student that the experiment is being conducted accurately; as shown in Figure 3.

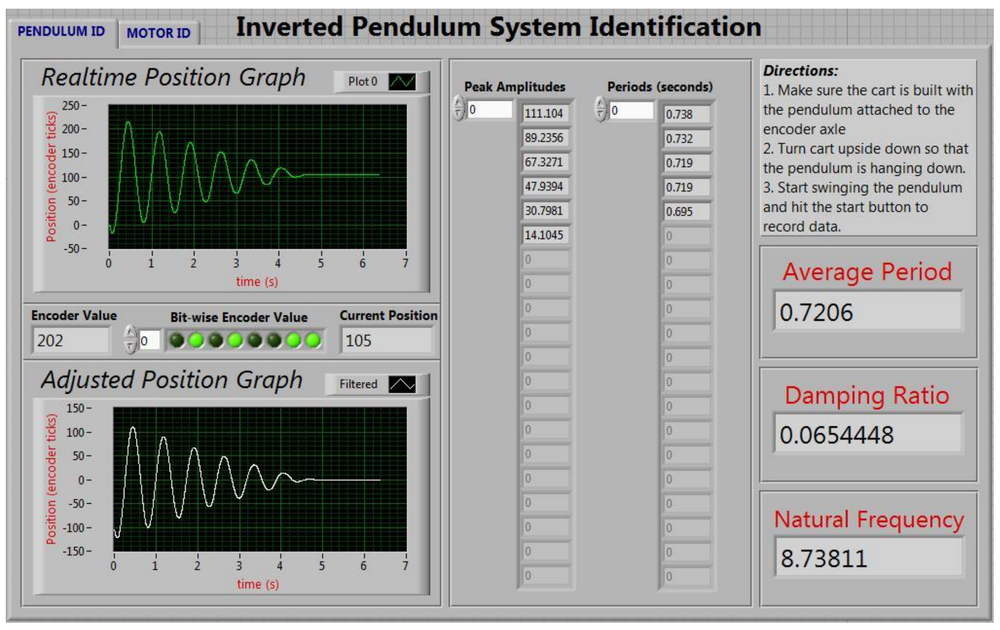

Figure 3: The interface used in performing pendulum system identification

Motor Identification

- Cart movement is measured as a function of motor rotation as it relates to voltage applied to circuit.
- Variances in voltage resistance and wheel construction could undermine system control.
- Software determines the correlation between voltage and movement by passing a wavelength representing the movement through a Pulse Width Modulation circuit, which yields a resultant velocity.
  - Samples taken at different voltages are plotted against measured velocity, the slope of which represents the relationship between raw voltage input and vehicle movement.

Figure 4 includes a slider which allows user to specify desired voltage, the only piece of information the user is required to provide.

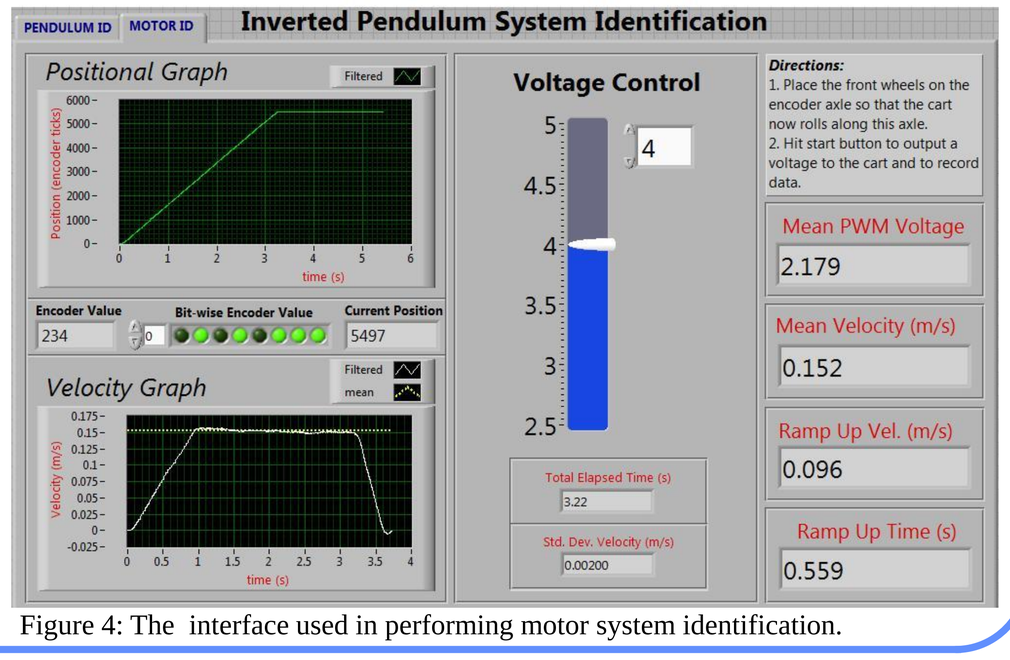

Figure 4: The interface used in performing motor system identification.