Name: Alan Kilian

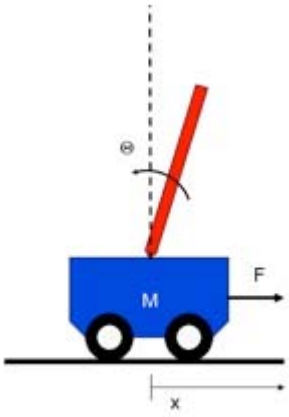
Title: Attracting Customers: Design and Construction of an Inverted Pendulum Mechanical System with a Closed-loop Control System for use at an industry trade show.

Description: This project will produce an Inverted Pendulum Mechanical System with a Closed-loop Control System.

An Inverted Pendulum Mechanical System consists of two mechanical parts:

- A cart which can move back and forth on a rail. This cart can be thought of as a toy train on a straight section of train track. The train can move in only one dimension. It can move forward or backwards but cannot move left, right, up or down since it must remain on the track at all times.
- A vertical pole mounted on the top of the cart. This pole is mounted in such a way that it can rotate about the lowest point where it is attached to the cart. The axis of rotation is perpendicular to the motion axis of the cart. This means that the pole can rotate either forward or backwards relative to the cart, but cannot rotate to the left or right.

  A drawing of this mechanical system (Downloaded from the National Instruments corporation at http://www.ni.com/white-paper/10703/en/) is as follows:



In this image, the cart is the Blue object and the pole is the Red object. The lowest point on the pole is where the pole and cart are attached through a mechanical device that allows the pole to rotate.

A Closed-loop Control System consists of four items:

- An electrical device to measure the angle of the pendulum. This device tells the control system if the pendulum is tilted forward or backward and measures the amount of the tilt from “a little” to “a lot”.
- An electrical device to measure the position of the cart along the track. It reports the position of the cart in inches (for example) from one end of the track. The cart may be 2 inches from one end of the track or it might me 12 inches from one end of the track.
- An electrical device that can cause the cart to move forward and backwards. This could be an electrical motor on the cart that causes the wheels of the cart to turn thus moving the cart forward or backward.
- A computer system that uses the measurements of pendulum angle and cart position and determines the correct direction and distance to move the cart in order to cause the pendulum to reduce its tilt and become vertical and in balance.

The goal of the Closed-loop Control System is to cause the cart to move to the left and right so that the pole remains balanced above the cart without falling over to the left or right and to attempt to keep the cart positioned in the center of its track.

This project will result in a working Inverted Pendulum Mechanical System with a Closed-loop Control System as documented in photographs and videos as well as a 5-7 page paper explaining the theoretical principles and practices used in the design and construction of the Inverted Pendulum Mechanical System with a Closed-loop Control System.

Background and Rationale:

This project is based on past learning as part of my job at the Logic PD Corporation.

The Logic PD Corporation works with other companies to help build products such as home thermostats, portable medical devices and robots. As a Principal Embedded Systems Engineer at the Logic PD Corporation, I work with Logic PD customers to design electrical circuits and software systems to meet the needs of their products. In order to meet new customers and generate sales,

Logic PD attends several industry conferences each year. These conferences include a large area for companies to setup a table and demonstrate their products to potential customers. These conference “Expos” can be very crowded with several hundred companies all attempting to get the attention of conference attendees’. Getting the attention of conference attendees can be difficult in this noisy crowded environment. In order to help attract attention to the Logic PD booth, the Vice President of the Sales group asked me if I could gather together some engineers and create a mechanical system that would be visible to conference attendees and would move in such a way to get the attention of these attendees as well as to demonstrate some of the capabilities offered by Logic PD.

After discussing several possibilities with other engineers, we agreed that having an Inverted Pendulum Mechanical System with a Closed-loop Control System demonstration running in our booth would attract their attention. In addition, allowing attendees to download an application to their smartphone to control the Inverted Pendulum Mechanical System with a Closed-loop Control System would be a great addition to the Logic PD booth.

My task was to build the Inverted Pendulum Mechanical System with a Closed-loop Control System hardware, software and website. Another developer at Logic PD developed the smartphone application.

This project is informed by learning in my Depth Criteria and my Extended Studies in Mathematics, Physics and Mechanics. The knowledge gained in the courses of Engineering Fortran, Operating Systems and Data Communications and Distributed Processing allowed me to write the software algorithms required to accomplish the goals of the project. The courses I took in Mechanical Engineering: Systems Dynamics and Control and Analog and Digital Control, as well as my Project #1 Develop a tuning guide for PID control systems allowed me to select, write and test appropriate motion controlling algorithms so that I was able to cause the Inverted Pendulum Mechanical System to move in a way necessary to accomplish the goals of the project.

Objectives:

1. To understand the mechanical principles and processes of an inverted pendulum with a closed-loop control system.
2. To calculate theoretical estimates for the electronic components of motor power, motor speed, encoder resolution, encoder rates and processing power required to properly balance an inverted pendulum.
3. To select mechanical system components suitable for implementing an Inverted Pendulum Mechanical System with a Closed-loop Control System.
4. To select electronic components suitable for implementing an Inverted Pendulum Mechanical System with a Closed-loop Control System.
5. To construct an Inverted Pendulum Mechanical System.
6. To write software to implement a Closed-Loop Control System.
7. To test and tune a working mechanical Inverted Pendulum with a Closed-Loop Control System.

Methods: Research possible mechanical systems that will allow the machine to perform the required motions. Select a mechanical design, acquire or build the required parts, assemble and test the mechanical system. Develop a theoretical estimate of the required motor and sensor characteristics, select and build a system to meet the requirements. Tune the control system for the completed mechanical system.

Results: The project will result is a working Inverted Pendulum Mechanical System with a Closed-loop Control System. Videos will be used to document the development of a

prior machine and the operation of the final machine. A 5-7 page report on the development of these machines will also be produced.

Schedule:

3/08 Selected a mechanical design, acquired parts, built system, wrote software and tuned system.	200-300 Hours
2/12 Selected a second mechanical design, acquired parts, built system, wrote software and tuned system.	150-250 Hours
2/14 Wrote project final report.	40 Hours

Evaluator: Dr. William Durfee Department of Mechanical Engineering, University of Minnesota. Minneapolis, MN

Evaluation:

- How well did the student demonstrate his understanding of the principles and processes of an Inverted Pendulum Mechanical System with a Closed-loop Control System?
- How well did the student calculate theoretical estimates for the electronic components of motor power, motor speed, encoder resolution, encoder rates and processing power required to properly balance an inverted pendulum?
- How well suited were the mechanical system components selected by the student for use in an Inverted Pendulum Mechanical System with a Closed-loop Control System?
- How well suited were the electronic components selected by the student for use in an Inverted Pendulum Mechanical System with a Closed-loop Control System?
- Please comment on the quality of the student's construction of an Inverted Pendulum Mechanical System.
- Please comment on the quality of the software written by the student to implement a Closed-loop Control System.
- Please comment on the quality of the testing and tuning the student performed which impacted the performance of the Inverted Pendulum System with a Closed-loop Control System's ability to perform the required task.

Bibliography:

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