CHAPTER 1

Introduction

1.1 Purpose

The intent of this thesis is as follows:

1. Establish Control Problem
   1.1. Select a well-established control problem as a focal point. [*Inverted Pendulum: Two-wheeled Robot*]
2. Establish Plant
   2.1. Select and derive equations for a physical dynamics model associated with the control problem. [*Yamamoto [1]*]
   2.2. Select real-world hardware which parallels the selected physical dynamics model. [*MinSeg M2V5*]
   2.3. Characterize the selected hardware to populate the physical dynamics equations.
3. Establish Controller
   3.1. Select and derive controller design(s) to address the selected control problem. [*Optimal Controller*]
   3.2. Select introductory gains to populate the selected controller design equations.
4. Establish Test Platform (*for Simulation and Actuation*)
   4.1. Select an integrated development environment (IDE). [*Mathworks Software Suite*]
   4.2. Develop a robust test software platform on the selected IDE which is able to:
      - Model established plant in simulation.
      - Model established controller in simulation **and** in real-time.
      - Program selected real-world hardware prior to operation.
      - Communicate with selected real-world hardware during/after operation.
5. Execute Testing
   5.1. Determine idealized controller equation parameters via simulation testing/post-processing.
   5.2. Determine actualized controller equation parameters via real-time testing/post-processing.

1.2 Statement of the Problem

The two-wheeled robot is a well-established control problem. The robot is topheavy and must continually work to balance itself. The robot is able to move freely on a two-dimensional plane; however, any movements performed by the robot create additional disturbances against its ability to balance itself.

Numerous command regulator approaches (*PID, pole-placement, optimal*) have been developed to control such a device; however, no one approach has been determined as a clear choice. Additional functionalities other than command regulators which significantly improve performance may also be implemented in a controller.

This study therefore intends to comparatively study multiple control approaches involving optimal-control-focused command regulators and to study the effects of additional functionalities which may be beneficial in general control cases. As a prerequisite to this work, a test platform must be developed for which to design the controllers. This study intends to design the test platform such that:

- Studies could be performed in simulation *(using a hardware-equivalent model)*.
- Studies could be performed on actual hardware.
- Similar work involving alternate control methods could easily be incorporated on both.

The intent of the latter is to significantly diminish several barriers to entry to perform a control study relating to hardware *(initial implementation, interfacing/communication, and theoretical/simulation modeling)*. This would ideally encourage future studies as well as draw them to a common platform, which would allow for effective comparisons between those studies.

1.3 Methodology

The methodology of this thesis is as follows:

1. Select a well-established control problem as a focal point. [*Inverted Pendulum: Two-wheeled Robot*]
   - Select compatible hardware and software. [HW: *MinSeg (Two-Wheeled Robot)*; SW: *Mathworks Matlab & Simulink*]
   - Implement basic hardware-software interfaces.
     - Process signals input to hardware drivers.
     - Process raw signals output from hardware sensors.

     [*Datatype conversion*; *Unit conversion*; *Derivation/Integration*; *Filtration*]
2. Develop a modular test platform.
   - Establish infrastructure.
     - Develop a unified, modular Simulink model which is capable of representing any desired system configuration. [*Variant subsystems used.*]
     - Create a Matlab script hierarchy which is able to:
       - Configure the Simulink model to any desired system configuration.
       - Configure the Simulink model to any desired build/run state.
       - Organize the relatively large number of parameters involved in such a system.
       - Minimize the effort required for the user to incorporate additional system configurations.
       - Minimize the effort required for the user to transition between any system configurations.
   - Establish robust methods of signal routing.
     - Implement bus structures.
     - Implement serial communication between hardware and development computer.
       - Minimimize sampling interval within the limits of the board hardware.
       - Process transmitted signals prior to sending and reconstruct after receiving.

- Calibrate hardware sensors.
  - Mitigate gyroscope bias.
- Develop theoretical plant model.
  - Research (non-linear) physical equations.
  - Linearize the physical equations.
    - Develop a state-space model.
  - Acquire linear plant model parameters.
  - Implement linear plant model into unified test platform.

3. Design and develop and controller for the test platform.
   - Implement dynamic reference tracking to mitigate bias on the body angular velocity ϕ sensors.
   - Determine control gains using LQR.

1.4 Bibliography

[1] Y. Yamamoto. (May 1, 2009). “Nxtway-gs (self-balancing two-wheeled robot) controller design,” [Online]. Available: `https://www.mathworks.com/matlabcentral/fileexchange/19147-nxtway-gs--self-balancing-two-wheeled-robot--controller-design` (visited on 07/03/2017).