

CSCI5143 Proposal

Mason Hawver and Kuba Kedzior

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Introduction

Our project's goal is to build a cart-pole system and develop algorithms to estimate and control its state. A cart-pole system consists of a cart that moves along a track, driven by a motor via a belt, and a pendulum attached to the cart, which can rotate freely through 360 degrees. A cart pole system is depicted in Figure 1.

The objective is to control the motion of the cart in such a way that the pendulum swings up from a downward position to an upright position and remains balanced as seen in Figure 1. This requires designing accurate state estimation that can process noisy sensor data on the cart's position and the pendulum's angular position and fuse it with the motor's torque commands that drive the system. In addition, robust control algorithms must be developed to use the estimated state to compute and apply motor torques, driving the system toward the desired upright position for the pendulum.

To achieve this, we plan to integrate:

- Time of Flight (ToF) sensors for precise distance measurement,
- Motor encoders to track angular positions,
- Brushed DC motor for accurate control,
- Microcontroller(s) with pulse width modulation (PWM) for motor feedback
- External device capable of floating-point operations for computational heavy-lifting,
- RTOS for managing real-time tasks and communication.

Why is this a reasonable final project?

This project is a reasonable final project for CSCI 5143 because it directly applies the skills we have learned in class, while also pushing us to explore more advanced topics in embedded systems. Throughout the project, we will utilize core concepts such as digital and analog I/O, using motor encoders for digital input and controlling the motor's torque through analog output. We will also implement wired communication between the microcontroller managing the sensors and the one controlling the motor, and establish communication with an external device to handle floating-point operations.

In addition to applying these fundamental skills, the project will challenge us to implement more advanced techniques. We will leverage optimal estimation methods like the Kalman filter and control algorithms such as linear quadratic regulation (LQR) to ensure precise state estimation and control in the presence of noisy sensor data. Moreover, by integrating field-oriented control with pulse width modulation (PWM), we can accurately control the motor torque, which is critical to balancing the pendulum. The use of an RTOS to

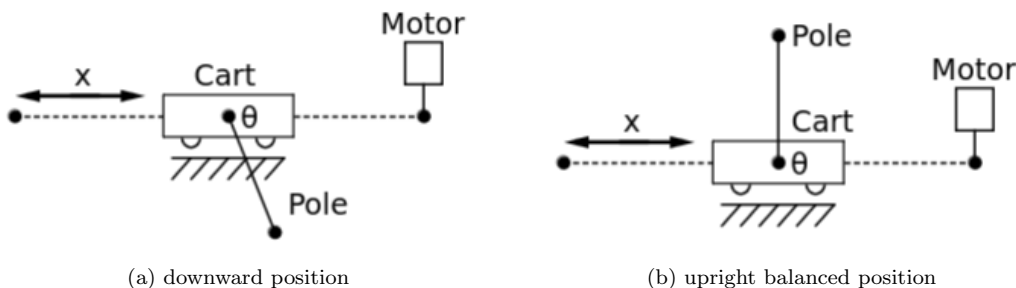


Figure 1: Diagram of the Cart Pole System

manage real-time tasks and communication will further test our ability to handle real-world timing constraints. Thus, this project will not only reinforce our foundational knowledge but also expand our expertise into more complex areas of embedded system design and control.

Technical Challenges

- **Building the Physical System:** The first technical challenge we will face is constructing the physical system. As computer science majors, we have limited experience with CAD, soldering, and building something that isn't source code.
- **Precise Motor Control:** The next challenge will be achieving precise motor control using a field-oriented controller. The analog output required for this task will be significantly more complex than the analog out we worked with in class, requiring a substantial amount of new learning.
- **Optimal Estimation and Control Algorithms:** Developing both optimal estimation and control algorithms for this system will also be a challenge. While we have some experience in these areas, it has been limited to homework assignments and simulated systems—not a real-world system that introduces non-Gaussian noise and nonlinearities.

After we successfully navigate these challenges, the remaining technical aspects of the project will fall into place.

Expected Learning Outcomes

From this project, we expect to learn several key skills and concepts that extend beyond the coursework covered in CSCI 5143. Specifically:

- **Hardware Integration:** We will gain hands-on experience with integrating hardware components, such as ToF sensors, motor encoders, and brushed DC motors, into a cohesive system.
- **Advanced Motor Control:** By implementing a field-oriented control system with PWM, we will deepen our understanding of precise motor torque control, a more complex form of analog output than we have worked with in class.
- **Optimal Estimation and Control:** We will further develop our knowledge of state estimation techniques (e.g., Kalman filters) and control algorithms (e.g., LQR), applying them to a real-world, noisy, and nonlinear system for the first time.
- **Real-Time Systems:** Managing multiple real-time tasks using an RTOS, including sensor input processing, motor control, and communication between devices, will reinforce our understanding of real-time constraints in embedded systems.
- **Communication Protocols:** We will learn to establish and manage wired communication between microcontrollers and an external device, pushing our knowledge of data exchange in real-time systems.

These skills will collectively enhance our ability to design, build, and control real-world embedded systems.

Team

- **Kuba:** Previous experience with embedded systems electrical engineering projects for the university rocket team. Proficient understanding of 3d printing and laser cutting for manufacturing.
- **Mason:** A summer internship working on embedded systems for software-defined radios. Classes on optimal estimation and control. In addition, extensive experience with C, C++, and Python.

Description	Manufacturer and Model	Power	Pin-Out	Vendor	Link	#
DC Motor	AEXIT F181219AE00601	12V DC	Solder	Amazon	link	1
DC Power Supply	GALYGG B06XRBYN4Z	120V AC	Solder	Amazon	link	2
Rotational Encoders	BQLZR N04452	5V DC	Solder	Amazon	link	1
Time of Flight Sensors	DORHEA B08SK7XTNX	3.3V DC	Pin Out	Amazon	link	1
Belt	ESAKOYA B0CK21WWGV	N/A	N/A	Amazon	link	1

Table 1: Parts list

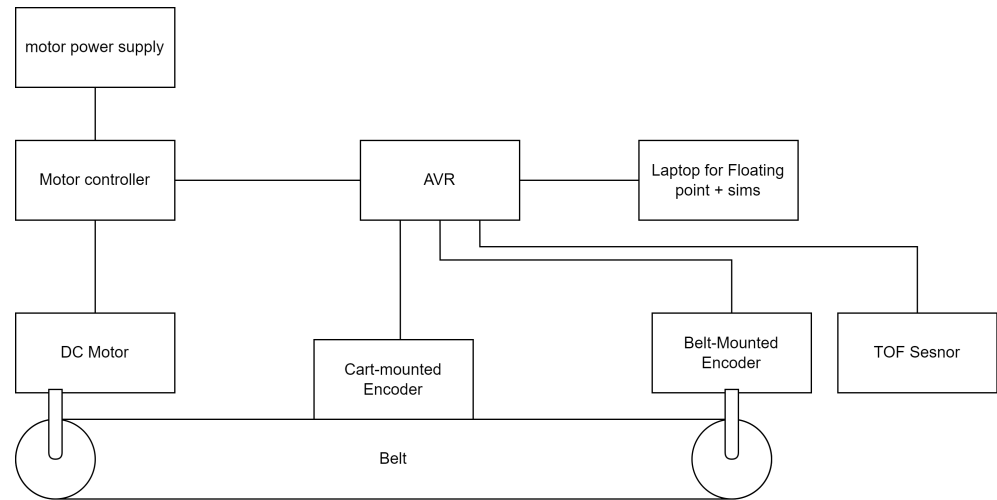


Figure 2: Wiring and Components Diagram

Hardware

The hardware needed for our project is outlined in Table 1. We will use a DC motor to drive the system. We already have a DC motor driver, but we will need a DC motor power supply to power the motor through the driver. Additionally, we will use rotational encoders and time-of-flight sensors (distance measuring units) to provide feedback to the motors, which the AVR will control through PWM output to the DC motor driver. We will also use a belt along with a V-Slot, which we have acquired, to create the track for the cart to move along. The motor mounts and cart will be 3D printed at Anderson Labs. Finally, the pendulum will be a paint stirrer that we have already acquired. A diagram of the dependence between our components is illustrated in Figure 2.