The Watt Balance

ECE445 Project Proposal

Justin Ansell (jansell2), Julian O'Hern (johern2), John Howard (johnlh3)

1. **Introduction**

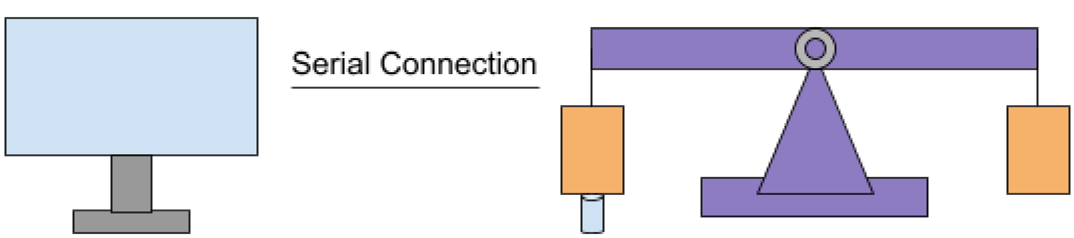
Problem:

Since 1879, the universal standard of a kilogram was derived from a physical mass made of a platinum-iridium alloy stored away in a vault. However, even with careful preservation in optimal conditions, over time the mass of the object drifted slightly, which is problematic for use as a constant standard. In 2019, as part of a sweeping change to the SI system, the kilogram was redefined to depend on Planck's constant rather than the mass of a physical object. Researchers at the National Institute of Standards and Technology (NIST) developed a device called a Watt Balance (or Kibble Balance) that uses induced magnetic fields to precisely determine the mass of a given object by measuring the rotational velocity and force generated by the balance. A group of graduate researchers in the ABE department of UIUC created a simple replica of this balance using LEGOs, but it is imprecise, often off by 20-30% or more on measurements. This is problematic for a device whose goal is to create very precise measurements.

Solution:

Our solution for this problem involves iterating on the design created by the UIUC graduate researchers and creating a more precise and easier to use Watt Balance. We plan to improve the sensing capabilities of the device and make mechanical improvements to help support those changes. By replacing the 3d printed fulcrum of the balance with a smooth axle and bearing, we can not only reduce friction in the balance, but also use a more accurate sensor on the axle than the ultrasonic sensor the previous design used. We plan to improve the sensing of the induced current in the coil using an ammeter rather than the arduino ports as it was previously measured to further increase the accuracy of the mass calculation. We also plan to update their current MATLAB-based software implementation to a more powerful language to allow for more efficient processing of the data.

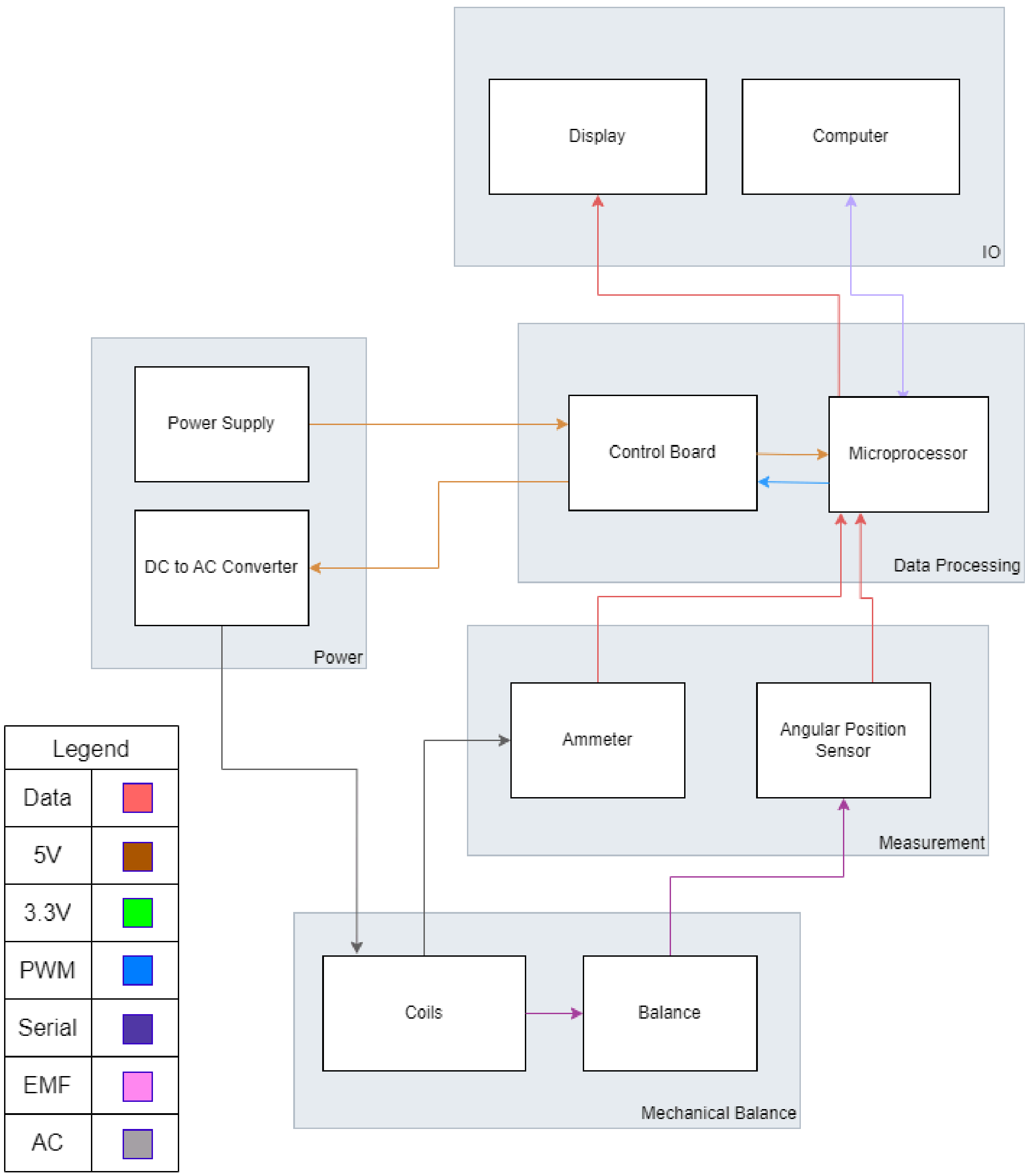
Visual Aid:



High-level requirements:

1. The device must be able to accurately measure the rotational velocity of the balance.
2. The device must be able to accurately measure the force generated by induction in the coil.
3. The device must be able to calculate the mass of the object and present it to the user in a clear and efficient manner.

2. **Design**
   - **Block Diagram:**



Device Subsystems:

Power Subsystem

Function: The power subsystem is the main source of power for all of the electronics, delivering DC power that is propagated throughout the entire device. The power subsystem also delivers a consistent and expected AC power to the coils to drive the balance force, and can be adjusted by the control board. This is important as precision in the input voltage is directly necessary to getting an accurate current reading from the ammeter.

Requirements:

Must Have	**Stretch Goal**
DC to AC converter to power coils	
Power to the Control Board	

Measurement Subsystem

Function: The measurement subsystems should both be able to measure the current induced in the coils, along with the movement and velocity of the balance as power is applied. The data from these measurements will be sent to the control board for both feedback and tuning purposes, and for calculating the mass of the object.

Requirements:

Must Have	**Stretch Goal**
Accurate sensing of angular position to within 5% error	Accurate sensing of angular position to within 1% error
Accurate sensing of current to within 5% error	Accurate sensing of current to within 1% error

Mechanical Subsystem

Function: The mechanical subsystem allows manipulation of the balance through the electromagnetic force generated by the coils. It also encapsulates the changes to the fulcrum of the balance to allow its angular position to be read by the angular position sensor

Requirements:

Must Have	**Stretch Goal**
Ability to move the balanced using the force from an induced magnetic field in the coil	
Minimal interference with other electronic components (shielding if necessary)	
Minimal friction in the fulcrum	

Data Processing Subsystem

Function: The data processing system should be able to take in input’s from the IO, sensors, and voltage readings, and correctly allow for adjusting parameters along with calculate and output measurements.

Requirements:

Must Have	**Stretch Goal**
Read in measurements from position and current sensors	
Convert position and current data into angular velocity and force data	
Calculate the mass of the object based off the angular velocity and force data	

IO Subsystem

Function: The IO subsystem will be the primary way for interacting with the control board, there will be some sort of display to give out reading from the sensors, and the mass, along with input methods to tune the inputs to the balance, such as voltage, and tune how the sensors are read.

Requirements:

Must Have	Stretch Goal
User interface to input and read data and parameters	
Communication of data and parameters between a computer and the microcontroller	Setting of parameters based off automatic calibration
Display to read out the mass of the object on the balance	

Tolerance Analysis:

One critical component of the device is the rotational position measurement. Looking at Hall effect sensors, which are our current frontrunners for a positional sensor, many seem to be accurate to about 0.3%. Converting the position to velocity is a derivative relationship, meaning that the error in the measurement should remain as 0.3%, which satisfies our target threshold for the velocity measurement. We also will be averaging the slope across many points to further increase the accuracy of the measurement.

3. **Ethics and Safety**

Our project does not have many major safety concerns. Some smaller concerns may be having fingers pinched between magnets, or risk of electrical shock from exposed coils. However, the voltages and currents involved will be relatively low, and the magnets will be fairly small, meaning that the safety risk involved is minimal. We don’t anticipate any ethical concerns arising from our project, as this is not intended to be a commercial product, and the Watt Balance is in the public domain.