Adding Multiple Static Pulleys to a Simple Pulley System

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Lab Section 7, Group 5

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Abstract

The purpose of this lab was to study the mechanics of a pulley system. This simple machine is comprised of a series of wheels and ropes that change the direction of an applied force to lift a weight to a given height. In this experiment, we assume that the addition of static pulleys, wheels that are clamped to a set position on the stand, do not affect the equations of motion for an object attached to the end of the rope if we were studying a simple pulley system. We made a pulley system out of 3 static pulleys stationary on a stand. Then, we gathered the acceleration and position data of an Arduino as it moved down the pulley when we attached a lighter mass to the other end of the rope. We were able to determine that motion, specifically acceleration, was not lost through the pulley system and that the pulley had no effect on net acceleration due to mass vs a system without a pulley.

Introduction

A simple pulley system is a device composed of a wheel on an axle over a rope. The rope can have masses attached to either end and is used to study Newton's first law of motion. The equations for motion of a simple pulley system can be derived from Newton's first law,

$$F_{net} = ma.$$

Let two blocks of mass m1 and m2 hang off a simple pulley as show (Figure 1). Suppose m1 > m2. Notice that the only external force acting upon the system is gravity, so the acceleration of the system can be calculated as

$$a = \frac{F_{net}}{m_{tot}}$$

$$a = \frac{m_1 g - m_2 g}{m_1 + m_2}$$

$$a = \frac{(m_1 - m_2)g}{m_1 + m_2}$$

This is without considering the forces that exist internal to the system like tension. We are also assuming that the interaction between the string and the pulley is frictionless and that the tension of the string is the same throughout the entire system. We hypothesized that if we were to add two additional static pulleys to the existing experimental design, the equations for motion would be the same. The way to calculate the acceleration of the system would be the same because the static pulleys act as directional changes of the string's path. They do not add any external force to the system and therefore do not affect its acceleration.

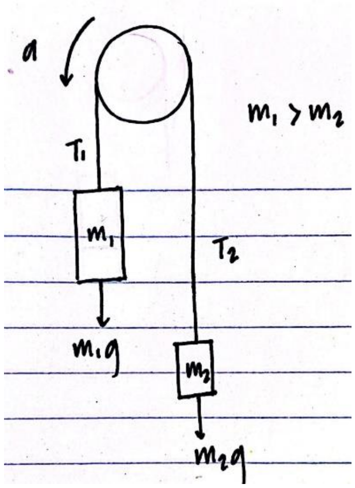

Figure 1. A simple pulley system. m1 is heavier than m2, so when m2 is released from a certain height, the acceleration of the system is dependent on the heavier mass m1. m1 would move downwards as m2 moves upwards.

Methods

Equipment

- HC-SR04 Ultrasonic Sensor
- Arduino Uno
- Jumper wires
- Breadboard
- HC-06 Bluetooth module
- MPU-6050 Accelerometer
- Battery holder
- Tape
- String
- Weigher
- Masses
- Ruler
- Laptop
- Python
- Stand
- Metal bar
- Metal clamps
- Pulley
- Reflecting surface

Setup

Attach a metal bar horizontally on the stand about .5m off the ground. Assemble the reflecting surface directly on the ground so that the ultrasound sensor attached to the Arduino setup can read in values correctly. Add a sponge below the reflecting surface to cushion the fall of the object after every trial, since the Arduino accelerates downwards until it impacts the ground. Add three static pulleys to the metal bar via metal clamps. Ensure that the pulleys are not crooked and are parallel to the metal bar. Next, set up the Arduino as one of the masses in a simple pulley system. Verify that the voltage of the batteries powering the Arduino are at the most optimal setting. Voltages greater than 1.37 V are recommended for accurate data collection. Then, connect the ultrasound sensor, HC-06 Bluetooth module, and accelerometer to the Arduino. The hardware will be responsible for tracking the Arduino's position and acceleration over time. Assemble the circuit like in Figure 2. Next, guide a string into the holes on the Arduino board like in Figure 3. Tape the battery holder and Arduino setup together to make one compact unit and weight it. When you hang the Arduino setup by the end of the spring, ensure that the ultrasound sensor is facing downwards and is resting flat in the air. Also, ensure that the ultrasound will reflect off the ground and clear any other part of the stand or objects that are directly beneath it. Create a second Arduino setup following the same procedure to act as a counterbalance for the Arduino we are using to gather data. Add additional masses to the working Arduino. We will take data points from the heavier Arduino setup.

Procedure

Our lab requires a HC-SR04 Ultrasonic sensor, HC-06 Bluetooth Module, and a MPU-6050 Accelerometer in the Arduino setup. This combination of hardware and software allows us to measure the Arduino's acceleration, position, and time in the pulley system. The initial phase of the experiment focuses on the data collected by the ultrasound sensor, while the next phase has a greater emphases on the accelerometer. . The accelerometer measures acceleration based on the mass-spring system that is inside of it. Some force is required to stretch and compress the spring, which causes the spring to push or pull the mass by some displacement. The acceleration from the force required to displace the mass is what's measured. The MPU-6050 Accelerometer is a more portable, compact version of a standard accelerometer that can be connected it to our Arduino board using the pins on its surface. The ultrasound sensor records the time it takes for a chirp to be omitted from it, bounce off of a reflecting surface, and return to its detector. It also measures the distance between the sensor and reflecting surface. In this case, the reflecting surface will be on the ground. The Bluetooth Module allows the Arduino code to wirelessly communicate with the accelerometer and ultrasound sensor. This reads in the important values of the spring-mass system in real time without the setup being connected to the laptop. When running the experiment, the Arduino code receives 5 columns of data in the serial monitor. The first value is the elapsed time in milliseconds and the second one is the distance between the sensor and ground in centimeters. The third, fourth, and fifth values are the accelerations of the setup in the x, y, and z directions respectively.

The first phase of the experiment was to collect the position and time of an Arduino moving downwards in a 3 static pulley system and analyze its behavior. The height of the lighter Arduino should increase as the height of the heavier Arduino decreases. This is because the heavier Arduino has a greater weight due to gravity and pulls the string down, bringing the mass in the other end upwards. We attached a battery to the heavier Arduino, which adds an additional 22g to it.

Once we have verified with the ultrasound data that the Arduino setup is following expected behavior, the second phase of the experiment was to collect the acceleration data of an Arduino moving downwards in a 3 static pulley system. We performed 3 different trials where the heavier Arduino had an additional 50g, 100g, and 150g attached to it.

Data Analysis

For every recorded trial, we received five columns of Arduino data and then stored it in a csv file. The hardware components used were the ultrasound sensor, the MEMS accelerometer, and the Bluetooth module. The fields we utilized were time (ms), displacement (cm), X-axis acceleration, Y-axis acceleration, and Z-axis acceleration. The time and displacement fields were then converted into seconds and meters respectively, so that we could perform more effective computations and analysis. This methodology was similar to the Lab 3A accelerometer process.

The first group of data we analyzed was the ultrasound data. The only relevant information bits here were time and displacement, so plotting and analyzing was relatively straightforward. The main goal in this aspect was to verify that the overall behavior was understandable, as the goal of our project was to make observations focusing on the acceleration, not displacement.

The next step was to calibrate the accelerometer. This was also done similarly to previous labs. We plotted two points corresponding to accelerations of 0 m/s^2 and -9.81 m/s^2. A Python function was created to acquire the slope and intercept. The resulting equation was plotted to verify that the calibration output was sensible.

For every trial, we calculated the acceleration from analog output using the computed slope and intercept, along with an addition of 9.81 to account for relative acceleration. Using these values, we computed the mean acceleration for each trial. We plotted this with the net mass difference (g), which represents the difference between the two weights. We compared the measured line with the line of the expected accelerations for each mass difference value. This was computed using the theoretical pulley system equations.

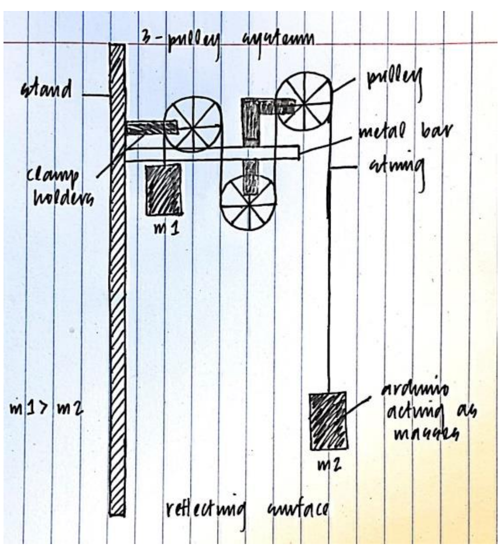

Figure 3. Initial design of the experimental setup. A 3 static pulley system.

Figure 4. Experimental setup in lab. 2 Arduinos act as masses and additional mass is added to one of them to make it heavier. The imbalance of weight between the two ends of the string causes the system to accelerate downwards as the heavier mass moves downwards.

Results

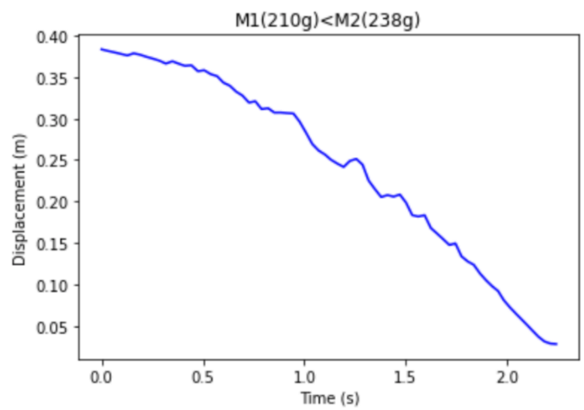

Figure 2. Displacement over time from perspective of M2 when it is heavier.

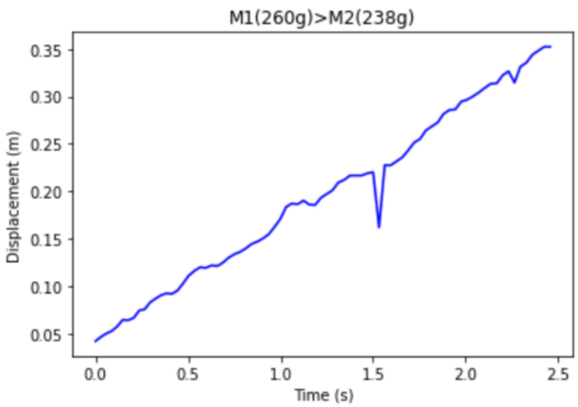

Figure 3. Displacement over time from perspective of M2 when it is lighter.

Figure 2 and Figure 3 are both graphs from the perspective of mass M2 over a time span of approximately 2.5s. In the former, M2 is 28g heavier than M1, and in the latter, M2 is 22g lighter than M1. When heavier, we would expect the mass to fall downwards, so it is understandable that there is a decline of about 0.35m. In the lighter case, we would expect the mass to move upwards. There is an incline of about 0.3m, which is almost equivalent in magnitude to the decline case. This is reasonable given the mass differences in both cases.

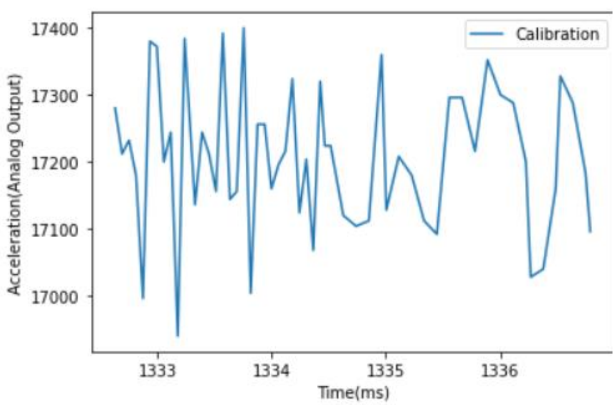

Figure 4. X-axis calibration plot for equilibrium state relating time and accelerometer output

Figure 4 shows an example of the calibration plots used to calibrate the data. By using the mean of the accelerometer data as the calibration point relating to 9.8 m/s^2 acceleration, we are able to convert the raw accelerometer data into acceleration in meters per second squarted that is usable for analysis.

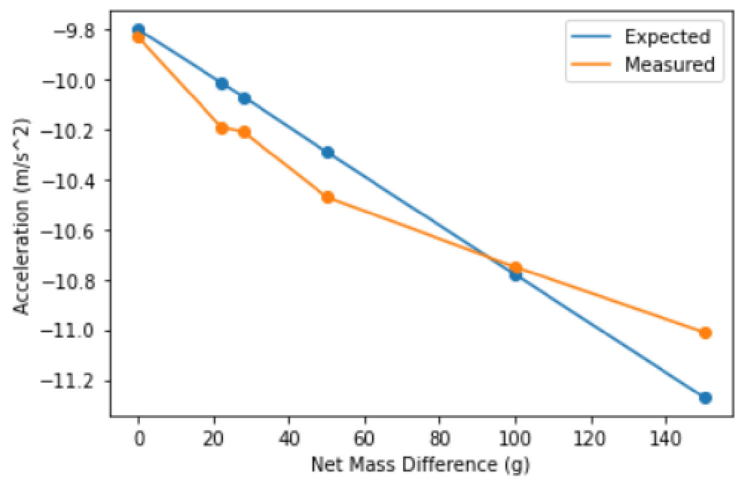

Figure 5. Graph of Expected Acceleration vs Measured Acceleration

Mass Difference (g)	0g (equilibrium)	22g (one 50g weight, one battery)	28g (one batter)	50g	1
Expected Acceleration (m/s^2	-9.8	-10.012	-10.07	-10.29	-
Measured Acceleration (m/s^2)	-9.83	-10.19	-10.21	-10.47	-

Figure 6. Table of Expected Acceleration and Measured Acceleration

Figures 5 and 6 display the results of our experiment, with expected data vs measured data. Expected acceleration values were the values calculated not including the mass of the Arduino, which is 210 grams and resolved in the calibration. The masses listed are the net mass differences, since there were two Arduino masses attached to both sides of the pulley. As seen in the graph, the accelerations measured were roughly similar to the expected acceleration, with slight deviations throughout. From the data we can verify that acceleration is conserved in the pulley system, and that the presence of the pulley has no effect on the acceleration of the masses.

Conclusion

Acceleration measured from the Arduino setup followed expected behavior with the constraints given. While we assumed that the interaction between the pulley and the string would be frictionless, the most probably cause of the deviation between the calculated and measured values is this. There is static friction that keeps the rope from slipping over the surface and makes the pulley rotate when the rope is pulled. Friction also exists between the pulley and axle. This results in a torque opposing the movement, causing the wheel to rotate when enough force is applied. Another critique in the experimental setup would be how the pulleys were placed. The bulkiness of the clamps forced the pulley to be spaced out accordingly, but when the string is placed over all of the pulleys, it produced a wide angle that would slightly rub on the metal bar. This is a frictional component not internal to the system, so this may have affected our results negatively. Also, the integrity of the Arduino setup may have played a factor. After each trial, the impact it experienced by landing on the reflecting surface caused technical issues. The impact would loosen up wires or dislodge the hardware from the Arduino’s breadboard, so we would have to fix the setup every single time we wanted to run another trial. The Arduino experiencing such motion also makes it have a slight angle with respect to the ground, so its ultrasound sensor is not entirely facing downwards towards the reflecting surface. This can cause inaccurate readings for the ultrasound sensor which gathers the objects position and time data. For future prospects, reducing friction by substituting the setup with low-friction pulleys and assembling them in a way to achieve a smaller angle of the string may produce more accurate results. However, the main purpose of this lab was achieved to produce the following conclusion: adding multiple static pulleys to a simple pulley system would have the same equations for motion if we were only studying a simple pulley system.