Linear Motion on an Air Track

Physics 4AL, Spring 2022, May 1
Lab Section 7, Group 5

Lana Lim, Faraz Murshed, Aaron Zhao

Abstract

The purpose of this lab was to study constant acceleration air glider motion. We collected the position and time measurements of a glider moving on an air track. With this data, we recorded the object's movement from 2 different test cases: one where the glider's motion was measured on a leveled air track and another where the air track was elevated so that the glider's motion was affected by an angle of tilt. We used Arduino code to collect the values from an ultrasound sensor and Python to read in the raw data and plot data points. The experiment ran 3 trials for the glider sliding down the incline. The average acceleration of the glider from the 3 trials was ~.3 m/s^2. The measured angle of tilt was 2 degrees, and the average experimental angle of tilt reflected this value. The small angle for the incline corresponds to the small acceleration of the glider.

Introduction

Over the course of this lab, we became familiar with the Arduino ultrasound sensor setup for future labs and used it to study constant acceleration by recording the position and time data of a glider moving across an air track. Acceleration is defined as the rate of change in an object's speed over time. It was hypothesized that if a glider slides down an elevated air track, it will experience constant acceleration. This is because when an object is freely sliding down an inclined plane, it is only being affected by its weight. The object's acceleration along the direction of motion and perpendicular to the direction of motion is $g\sin\theta$ and $g\cos\theta$ respectively, where θ is the angle of the inclined plane. Gravity and the angle of tilt are constant, so acceleration is constant assuming there is no friction and air-resistance. Error propagation equations were also included in our calculations for acceleration and angle of tilt.

Methods

Equipment

- HC-SR04 Ultrasonic Sensor
- Arduino Uno
- Jumper wires
- Breadboard
- HC-06 Bluetooth module
- Battery holder
- Glider with plastic platform
- Air track
- Cardboard
- Laptop

Setup

For our set of experiments, an ultrasound sensor and HC-06 Bluetooth module were attached to an Arduino board to track the glider's movement. The circuit shown in Figure 1 was the setup for connecting the Bluetooth module to the Arduino board. This allows for wireless data communication between the Arduino and ultrasound sensor. A battery holder was connected to the

Arduino board for power. The final circuit connected the ultrasound sensor to the rest of the Arduino setup in Figure 2. It was then mounted on the glider's plastic platform and placed on an air track with a constant air supply in Figure 4.

We used an ultrasound sensor as our primary source for data collection. The sensor records the time it takes for a chirp to be omitted from it, bounce off of a reflecting surface (Figure 3), and return to its detector. It also measures the distance between the sensor and reflecting surface. The Arduino code then receives the data transmitted from the ultrasound sensor via Bluetooth and reads in the glider's time in milliseconds and position in centimeters.

Procedure

In the first phase of the experiment, we recorded the glider's movement across a leveled air track. This part of the lab was to determine the maximum reading from the ultrasound sensor and maximum distance that the glider can move away from the reflecting surface before the signal gets too noisy. This is because after a certain distance, the data collected from the ultrasound signals bouncing off of the reflecting surface will be inaccurate. In other words, the distance read by the Arduino will largely deviate from the actual distance measured between the reflecting surface and glider.

The next phase of the experiment recorded the glider's movement on an elevated air track with a specified angle of tilt. The air track's airflow was set to maximum and we moved the glider to its maximum distance recorded in the first phase. We captured the data of the glider descending from the tilted air track after release. This process was repeated 3 times for 3 separate data sets per team member.

Data analysis was accomplished using Python. With np.polyfit, we plotted the position and time of the glider on the tilted air track and used it to estimate its acceleration with uncertainty. We also extracted the expected angle of tilt from np.polyfit and compared it with the actual angle of tilt measured.

In the data analysis, we assumed that the glider experienced no friction when calculating its acceleration. Also, the raw datapoints from the glider's position and time were spliced so that we could isolate the specific instance when the glider started moving down the track.

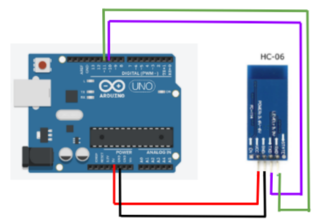

Figure 1. The Arduino board and Bluetooth module were assembled according to the diagram above. This component of the final circuit was to connect the Bluetooth module to the Arduino's analog signals.

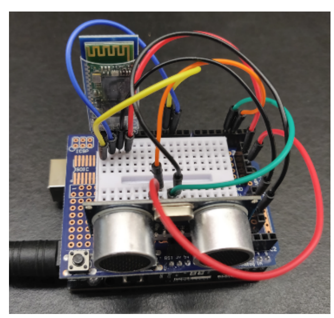

Figure 2. The final circuit is connected the Bluetooth module and ultrasound sensor to the Arduino board and breadboard.

Figure 3. The reflective surface setup was built as shown. It is made up of recycled cardboard and approximately 2ft by 2ft in dimension. It was sized appropriately to ensure that the signals bouncing off of the reflective surface would be read accurately by the ultrasound sensor.

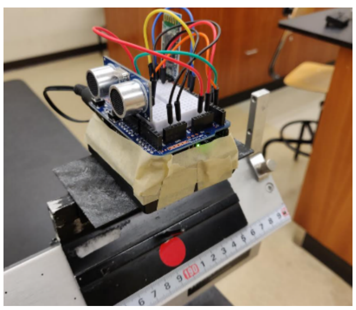

Figure 4. The Arduino setup and battery holder is mounted on the plastic platform of the air glider. The glider is placed on the air track and the ultrasound sensor is facing towards the reflective surface.

Results

The maximum reading from the ultrasound sensor before the data became noisy was .47 m. The maximum distance before the data became noisy was .50 m. The measured angle of tilt was 2 degrees.

The position and time read by the ultrasound sensor was imported in a Collab notebook and converted to the correct units, meters and seconds respectively. Datasets we collected were not exhibiting ideal, quadratic behavior expected from an object moving down the incline, so we isolated the specific array indexes right before the glider was released and after it reached the end of the air track. The isolated portions of the plot are shown in Figures 5, 6, and 7 with a best of fit line using np.polyfit in Python. The covariance matrix from np.polyfit helped us find the associated error for the acceleration and angle of tilt.

From the three trials, the glider's acceleration was about ~.3 m/s^2. Calculated uncertainty was at the hundredths place for acceleration, so we can assume that friction did not play a significant role on the air track. The calculated angle of tilt from the data we collected deviated more from the measured angle. It is important to note that the uncertainties for the angle of tilt carries over to the uncertainties for acceleration. This is because an object's acceleration when moving down an incline is affected by the angle of tilt, θ. The acceleration parallel to the direction of motion and perpendicular to the direction of motion is $g\sin\theta$ and $g\cos\theta$ respectively.

	Acceleration (m/s^2)
Trial 1	0.371 +- 0.032
Trial 2	0.313 +- 0.040
Trial 3	0.370 +- 0.029

Table 1. Acceleration with uncertainties for the three trials.

	Angle of tilt (degrees)
Measured	2
Trial 1	2.167 +- 0.208
Trial 2	1.830 +- 0.147
Trial 3	2.140 +- 0.029

Table 2. Angle of tilt with uncertainties for the three trials.

The three plots have a clear downwards trend over time as the glider moved down the track at an angle. The glider accelerates downwards due to the acceleration from gravity. The small angle of tilt found in Table 2 corresponds to the small acceleration determined from the data in Table 1, seen in the slight curve of Figures 5, 6, and 7.

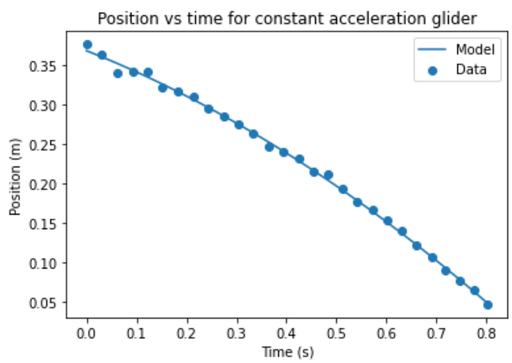

Figure 5. Plot of position vs time for trial 1.

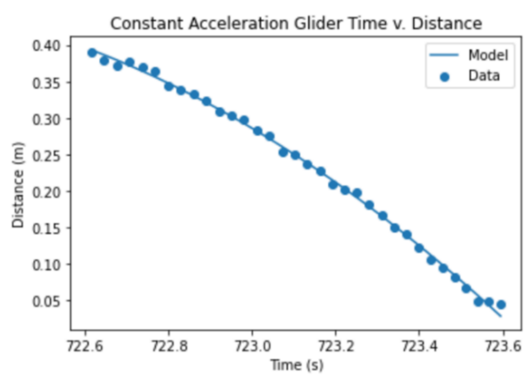

Figure 6. Plot of position vs time for trial 2.

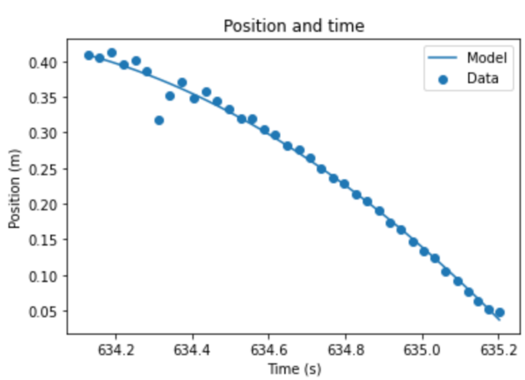

Figure 7. Plot of position vs time for trial 3.

Conclusion

The original goal of this experiment was to familiarize ourselves with the Bluetooth Arduino ultrasound sensor setup and to study constant acceleration from an air glider descending from an incline.

The first part of the experiment was to determine the limitations of the ultrasound sensor. The maximum reading of distance from the sensor and the measured distance differed very slightly by .03 m. As demonstrated by the starting point of our plots, the glider's position never exceeded its upper bound of ~.5 m. From this portion of the lab, we were able to learn and apply our knowledge about sensor limitations.

The second part involved studying the actual motion of the glider on the air track. After obtaining our 3 separate plots and best fit lines, we were able to acquire the listed accelerations, and then extract 3 separate angle of tilt values from there. All the trials resulted in values close to the actual measure value of 2 degrees. Thus, our experimental results followed expectations very closely.

Potential errors in the experimental setup may have been the root of uncertainties calculated for the object's acceleration and angle of tilt. One potential error could result from the actual release of the glider. We let go of the glider using our hands, which may not be the most accurate method for releasing, as it is possible that a small force could be applied in the direction of the glider's movement. This could explain minor differences in calculated acceleration. If there was an available apparatus to trap and release the glider, this aspect of the experiment would become more controlled.

Other examples of possible human error include the actual mounting of the Arduino and the stability of the air track. The Arduino's security was dependent on how it was taped. If this taping was not optimal, then there could be increased noise during the glider's motion. A more uniform mechanism could be used in the future that would hold the Arduino in place. The track screws were also toggled during experimentation to find the point of highest stability, but there is still a chance this was not completely optimal. Consequently, there are several errors or suboptimal conditions that may have been present during this experiment. Given that our collected data was close in value to expected data, none of these described conditions were that costly. Fixing these possible issues could still provide slight improvements if reattempted.