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Accelerations in the Real World

The portability of the data-collection equipment makes it ideal for studying accelerations that occur outside the physics laboratory. Some interesting situations are the automobile and amusement park rides, as well as high-speed elevators, motorcycles, and go-carts.

An accelerometer measures the acceleration in a specific direction. You will need to choose an appropriate time scale and the direction in which to hold the accelerometer to obtain meaningful information. Obtaining acceleration data from independent kinematics measurements can transform an informal study into an empirical evaluation of a mathematical model.

This experiment highlights several situations where you can collect real-world acceleration data. A general procedure is given that you will modify depending on which study is performed. After the general procedure, you will find several suggestions for acceleration investigations. You will need to plan an experiment around the motion to be studied, adjusting data-collection parameters as needed.

OBJECTIVES

* Measure acceleration in a real-world setting.
* Compare the acceleration measured to the value calculated from other data.

MATERIALS

Chromebook, computer, or mobile device

Graphical Analysis 4 app

Go Direct Acceleration or Go Direct Force and Acceleration

set up PROCEDURE

The following steps will guide you through configuring Graphical Analysis to collect acceleration data with an acceleration sensor. You will probably need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

1. Launch Graphical Analysis. Connect the Go Direct Force and Acceleration Sensor or the Go Direct Acceleration Sensor to your Chromebook, computer, or mobile device. Click or tap Sensor Channels, and select the appropriate channels for your experiment.
2. Set up the data-collection mode.
   1. Click or tap Mode to open Data-Collection Settings.
   2. Change Rate to 10 samples/s and End Collection to 20 s. You may want to use different values according to your experimental conditions. Click or tap Done.
3. Zero the acceleration sensor in the orientation you plan to collect data. For example, if the acceleration sensor is to be oriented horizontally during data collection, place the sensor on a horizontal surface while zeroing. Or, if you will be collecting data with the sensor oriented vertically, then place the sensor against a vertical surface.
   1. Orient your sensor as appropriate for your experiment. Note: If you are collecting data along multiple axes, you will zero the sensor multiple times. Orient the sensor for one of the axes you will use.
   2. Click or tap the appropriate Acceleration meter and choose Zero. When the process is complete, the acceleration values are close to zero.
   3. If collecting data for multiple axes, repeat this process for each axis along which you will collect data.
4. Click or tap Collect to start data collection when you are ready to collect data.
5. When data collection is complete, a graph of acceleration vs. time is displayed. Click or tap the graph to examine the data. Note: You can also adjust the Examine line by dragging the line.

AUTOMOBILES and MOTORCYCLES

Part I  Linear Acceleration on a Straight Road

The accelerometer can record the acceleration of a motor vehicle. A good motion to study is speeding up from rest, followed by slowing to a stop. Initially, set up data collection for a duration of 30 seconds, although you may find that this time should be shortened or extended. Zero the accelerometer with the relevant arrow held horizontally.

Secure the accelerometer in a horizontal direction with the relevant arrow of the accelerometer aligned with the direction of the motion. Start data collection just before starting the vehicle. Accelerate to a safe speed, and then slow to a stop. Keep the vehicle moving in a straight line and keep it on a level section of roadway for this experiment.

Ask the driver to maintain a constant acceleration while speeding up, as well as a constant acceleration when slowing down. Compare different vehicles; compare acceleration patterns with automatic and manual transmissions. For an independent acceleration measurement, collect velocity vs. time data during the trial, either by calling out times and recording the instantaneous velocities, or perhaps by collecting video of the speedometer. Compare the accelerations you obtain with the accelerations that are recorded by the interface.

Part II  Centripetal Acceleration in Corners

When a vehicle turns a corner, a centripetal acceleration is present. By securing the relevant axis of the accelerometer horizontally and perpendicular to the forward direction, you can record the accelerations in curvilinear motion. Initially set up data collection for a duration of 30 seconds, although you may find that this time should be shortened or extended. Set up a path that has several curves of measured radii as well as straight sections. A parking lot not used on weekends would be best. Practice until the driver can maneuver through the course while maintaining a steady speed. Orient the relevant arrow of the accelerometer in the horizontal direction so it is stable relative to the vehicle and perpendicular to the vehicle's motion (the relevant arrow should be pointing to the inside of curve). Accelerate to the planned speed and keep the vehicle moving at a constant speed. Start data collection just before entering the test section containing the curves.

For an independent acceleration measurement from kinematics, you will need to know both the radii of the turns and the speed of the vehicle.

ELEVATORS

Investigate a high-speed elevator in a building with six stories or more. Zero the accelerometer with the relevant arrow held vertically. Initially set up data collection for a duration of 90 seconds. You will want to adjust this time depending on the transit time of your elevator.

Enter the elevator and place the accelerometer against the elevator wall or floor with the relevant arrow pointing upward. Do not hold it in your extended hand because the motion of your arm will change the acceleration measurement.

Program the elevator to stop at two floors on the way up, then program it to stop at two floors on the way back down. Start data collection when the doors close on the elevator.

Optional: If you can determine the height of a single story, you can collect data on floor-number vs. time to obtain velocities while the elevator is ascending or descending. You can use a video recording to measure this. Compare the velocity you obtain this way with the area under the acceleration vs. time graph.

AMUSEMENT PARKS

Many amusement parks feature a Physics Day where students take instruments on the rides and perform calculations. Sensor-based data collection can extend data collection so that the ride characteristics can be studied in more detail than is possible with traditional methods. Several categories of study are suggested below.

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For any ride it is essential that you plan your data collection carefully. It is best to concentrate on a single portion of a ride, such as a particular loop or corner of a roller coaster. Decide which part of the ride you want to study, and estimate the length of time you will need to collect data. You may want to measure the time interval while watching others on the ride. The time between samples can then be calculated by dividing the desired time interval by the number of points you want to collect.

Along with planning the data-collection parameters, you must plan the orientation of the accelerometer during the ride. Which axis of the acceleration do you want to record? Hold or fasten the accelerometer so the arrow is parallel to this axis. The direction of the arrow will correspond to positive acceleration.

When describing the directions of accelerations on an amusement park ride, it is convenient to have a common vocabulary. The diagram defines the terms vertical, lateral and longitudinal. These designations are from the frame of reference of the rider.

Note: Depending on the ride, you may need to begin data collection before the ride begins. Extend the suggested data collection duration accordingly. A duration of 60–80 seconds is usually needed to record a complete ride. A decision on which axis to record should be made before getting on the ride.

Part I  Dips

Most roller coasters feature a dip following the first major climb, as well as several others during the course of the ride. If you know the speed of the train at the top of the hill and the vertical distance to the bottom, expected speed of the train at the bottom can be calculated using conservation of energy. Knowing the radius of the curve at the bottom, the expected acceleration due to circular motion can be calculated using kinematics.

The acceleration during such a dip can be measured as the train descends into the dip, and the maximum acceleration can be determined by tracing along the graph.

To record a single dip, first zero the accelerometer with the relevant arrow upward. On the ride, secure the accelerometer vertically with the arrow upward relative to the rider. Set the data-collection duration to 15 seconds. Start data collection just before the car starts over the edge of the first drop. Compare the readings obtained at the front of the train as compared to those at the center or at the back of the train. Explain any differences.

Part II  Vertical Loops

Many modern roller coasters feature vertical loops. To record acceleration data during loops, first zero the accelerometer with the relevant arrow upward. On the ride, secure the accelerometer with the arrow upward relative to the rider. Set the data collection time to approximately 15 seconds and start data collection just before the car enters the loop.

Part III  Corners

Many roller coasters have the cars riding on rails, and so the corners can be nearly horizontal. If the axis of the accelerometer is secured so that it is level and perpendicular to the direction of the motion, the lateral acceleration will be recorded. Zero the accelerometer while the relevant axis is horizontal.

Set the data-collection duration for 15–30 seconds, as determined by your study of the ride in advance. Start data collection just before the train enters the horizontal curve.

Part IV  Barrels

Some rides at amusement parks and carnivals feature a barrel in which the riders appear to be held to the inside surface by an outward force. In fact, there is no outward force. Instead, the inward normal force from the wall keeps the riders moving in a circular path. To take data in a barrel ride, first zero the accelerometer with the relevant arrow held horizontally. Secure the accelerometer such that the relevant arrow is pointing inward radially toward the center of the circular motion.

Part V  Starts and Stops

Many rides feature large accelerations. If the direction is forward or back, the reference is to longitudinal acceleration, while if it is up or down, it is vertical.

Rapid starts and stops are usually short lived. A data-collection duration of 10–15 seconds is usually enough to capture the entire acceleration, allowing you to start data collection just before the ride begins. If you wish to record the stopping of the car, again a short duration is needed; possibly as short as 10 seconds. Study the ride in advance to choose an appropriate data collection time.

Some parks feature rides that have vertical rises and falls. Recording data on such a ride consists of choosing an appropriate time and holding the relevant arrow of the accelerometer in a vertical direction throughout the ride. Zero the accelerometer while the arrow is vertical.

Part VI  Scrambler

Some parks have rides known as scramblers. In the scrambler, the rider’s seat rotates about a pivot point with a small radius while that point is being carried around in a larger radius by the overall ride. The axis of the accelerometer directed to the side of the rider will record the lateral acceleration throughout the ride. The axis of the accelerometer that is pointed forward or backward relative to the rider will record the longitudinal acceleration. For these rides, zero the accelerometer twice, while the relevant arrow is held horizontally. Some scramblers may even have vertical accelerations, in which case use all three axes of the accelerometer.

Analysis

Automobiles and Motorcycles

1. For the motion along a straight line, is the acceleration of a motorized vehicle constant? If not, why do you suspect the rate is larger during part of the run than another part? How does the acceleration while speeding up compare to the acceleration while stopping? Why do you suppose this pattern is true? Characterize the ability of your driver to accelerate the vehicle at a constant rate.
2. For the cornering motions, how do the calculated accelerations from kinematics equations compare to the accelerations measured with the interface? How do the measured accelerations compare to the acceleration due to gravity, or g?

Elevators

1. How large is the acceleration when the elevator begins to move? How large is the acceleration when the elevator has been underway for a few seconds? How large is the acceleration when the elevator is slowing to a stop? What does the sign of the acceleration indicate?
2. Use the integral tool to analyze a graph of acceleration vs. time. How does the area under the acceleration graph while speeding up compare to the area under the graph while it is slowing down? Why should these two areas be equal magnitude but of opposite signs?
3. Can you determine which direction the elevator is moving (upwards or downwards) by the size or direction of the accelerations? Explain your answer.
4. If you collect data while holding the accelerometer in your hand (arm in front of your body), how does the resulting acceleration compare to that recorded while the accelerometer is held rigidly against the elevator itself?

Amusement Parks

Part II  Vertical Loops

1. How does the acceleration at the bottom of the loop compare to the value at the top of the loop? How does the value at the top compare to the acceleration due to gravity? What does the reading you get at the top mean? Is the loop circular in shape? If not, why not?

Part III  Corners

1. By measuring the speed of the ride, and estimating the radius of curvature, you can calculate an independent value for the centripetal acceleration using kinematics. Compare this value with the measured value. What aspect of the ride could lead to the two accelerations being different?

Part IV  Barrels

1. Because this type of ride is rotating at a constant angular velocity, the physics is that of uniform circular motion. The acceleration is radially inward and should be equal to 4π2R/T2. Calculate an acceleration from measurements of the radius R and the period T for comparison to the acceleration measured while on the ride. The changes in this value while the ride is starting up and also while slowing down can be studied using the interface.

Part V  Starts and Stops

1. Which is larger, the starting or the stopping acceleration? Why might one be larger than the other? Is the vertical acceleration experienced during the ride ever that of free fall?

Part VI  Scrambler

1. How close are the radial accelerations of the scrambler to that of the acceleration of an object in free fall?

EXTENSIONS

1. For any of the applications discussed in this activity, you can use all three axes of the Go Direct Force and Acceleration Sensor or the Go Direct Acceleration Sensor. The vector sum of the three acceleration components can be calculated to give the acceleration magnitude.
2. Collect acceleration data while snow skiing or snowboarding. Make several turns while recording the lateral acceleration. A procedure similar to the one described above could be employed to study the turning accelerations as the rider makes sharp and gradual turns.
3. Have a skier, skateboarder, or a bicyclist go over a vertical jump and record the acceleration in the vertical direction during the jump. Video analysis measurements could be used to compare to the interface measurements.
4. Have a rider on a skateboard, ice skates, or roller blades execute a series of turns while collecting acceleration data. Video analysis measurements could be used to compare to the interface measurements.
5. Other carnival and amusement park rides can be studied using techniques similar to the ones described in this experiment. Most have a preferred direction of acceleration that can be ascertained by studying the motion of the ride.
6. Use the altitude channel of a Go Direct Acceleration to measure changes in elevation during the motion of an elevator or roller coaster ride.