Lab 2. Motion in a Straight Line

Goals

- To understand how position, velocity, and acceleration are related.
- To understand how to interpret the signed (+,–) of velocity and acceleration.
- To understand how the acceleration of an object behaves when the direction of the object's motion reverses.

Introduction

What concepts are required to describe motion? Certainly position comes to mind, but is that enough? Hardly. We often wish to know how long it takes to move from one point to another. The concept of velocity allow us to describe position in terms of this time. For motion along a straight line during a very small time interval, velocity is defined as:

velocity = displacement/(time interval) — or symbolically, $v = \Delta x/\Delta t$)

Under some circumstances, knowing the position and velocity is enough to answer the questions we have, but sometimes we more is required. For instance, we may be initially at rest, then start moving. Our velocity changes in this situation, and knowing how quickly our velocity changes (our acceleration) is important. For very small time intervals, acceleration is defined as:

acceleration = (change in velocity)/(time interval) — or symbolically $a = \Delta v/\Delta t$)

One can continue this progression, but for most practical purposes we stop after reaching the concept of acceleration. Acceleration is proportional to force in NewtonÕs Second Law, which is our main tool for predicting motion. Our goal is to understand how acceleration, velocity, and position are related for the simple case of motion along a straight path. We will explore more complicated motions later.

Motion along a straight, horizontal track

Before continuing, make sure that the cart track is level. The track has a screw at one end (the nearest the edge of the table) that can be turned to raise and lower that end of the track until the track is level. Your teaching assistant will describe how to use a spirit level to make sure the track is properly leveled.

Observe and describe motion

Place the cart at the end of the track closest to the motion sensor and give it a gentle but quick push so it travels the length of the track in about one second. Observe the motion *after you are no longer touching the cart* and the cart is coasting along the track, but has not yet hit the bumper at the other end of the track. Describe the motion of the cart in words. From your observations predict the relationships between *position and time* and *velocity and time* by drawing graphs of position and velocity as functions of time. Using the same time scale for each graph, show the qualitative (no actual numerical values) behavior of the motion that you have just observed. Use a straightedge to where appropriate. **Include some words to explain the reasoning behind each of the graphs that you draw. You may wish to use arrows pointing to special features of your descriptions along with corresponding explanations of why you included those features.**

Now start the cart at the end of the track farthest from the motion sensor and give it a gentle but quick push *toward* the motion sensor. Draw graphs showing your descriptions of the position and velocity as functions of time using a consistent time scale for both graphs as above.

Suggestion: Draw the position and velocity graphs for motion toward the sensor and motion away from the sensor in one vertical column on a single sheet of engineering paper.

Acquire position, velocity and acceleration data

Consult the Computer Tools Supplement at the back of the lab manual for instructions for connecting the motion sensor to the black computer interface box at your lab station. Once the sensor is connected, set up the DataStudio software to display graphs of position, velocity, and acceleration as functions of time. General instructions for configuring DataStudio to record and display data are available at the beginning of the Computer Tools Supplement. **An important detail is to change the "sample rate" displayed in the "Setup" window from the default value of 10 Hz to 20 Hz.** The motion sensor measures positive values for positions in front of the sensor, with the sensor itself at the origin of the position coordinate. Due to limitations of the electronics, the motion sensor only measures distances greater than 0.40 m, or 40 cm. (Some of the newer motion sensors can detect objects as close as 0.25 m.) Make sure during all your experiments that the object of interest is never closer than this minimum value.

Position the cart on the end of the track toward the motion sensor, click on the "Start" button in DataStudio, then give the cart a quick push away from the motion sensor so it reaches the other end of the track in approximately one second. Rescaling the resulting graphs both horizontally and vertically to show only the region of interest during the "free" motion of the cart. Then print out the graphs in "landscape" format on a single piece of paper. Write a descriptive title across the top of your graph.

Use the DataStudio software to calculate the average velocity during the "free" motion of the cart by averaging a number of velocity values and finding the standard deviation of the values as an uncertainty estimate. This is done by selecting the velocity-time data you wish to average with the cursor and clicking on the "Σ" symbol at the top of the graph window; a drop-down menu of options is displayed. Check the standard deviation option, and leave the other checked options checked. Refer to the Uncertainty/Graphical Analysis supplement at the back of your lab manual for more information on the standard deviation, what it means and how it is defined and calculated.

The average cart velocity can also be computed from the slope of the position versus time graph. Use the DataStudio software to find the slope of the position-time graph and the uncertainty of the slope during the “free" motion of the cart. First use the cursor to mark the region of interest on the position-time graph and then click on “fit" at the top of the graph window to choose the type of fit to make to your data. If the displayed precision of the position measurements is less than one standard deviation, you should increase the displayed precision. Your teaching assistant can explain the procedure.

Repeat the experiment for the case of motion *toward* the motion sensor, starting from the end of the track away from the motion sensor. Print out the resulting graphs after making the adjustments described above, and compute the average velocities using the same two methods.

Compare questions and data

Address the following questions in a summary paragraph before you move on to the next experiment:

1. How do the general shapes of your descriptions and experimental position-time, velocity-time, and acceleration-time graphs compare? Were your expectations borne out by the experiment? Explain why or why not.
2. Does the sign of the acceleration on the experimental acceleration-time graph make sense? Use the definition of acceleration to help answer this.
3. Are the averages determined by the two methods above consistent? Use the uncertainties derived from your data to make the comparison.

Complete your work with the horizontal track before moving on to the sloping track!

Motion along a sloping track

Raise the end of the track toward the motion sensor 8–10 cm above the tabletop by placing the wooden block on edge under it. Make sure the spring-loaded plunger on one end of the cart is facing downhill to cushion the impact at the bottom of the ramp.

Motion of cart moving down the ramp

Observe and describe motion

Observe the motion as the car is released from rest at the top of the ramp. Focus on the one-way trip down the ramp: ignore the bounces at the bottom end of the track. Describe the motion of the cart in words. On a single sheet of engineering paper draw graphs of what you expect the position, velocity, and acceleration functions to be for the cart from the point of release until the instant before the cart hits the bumper at the bottom of the ramp. Use the position of the motion sensor as the origin of the position-time graph.

Acquire position, velocity, and acceleration data

Use the DataStudio software to record the position-time, velocity-time, and acceleration-time graphs for the above motion. Print and label the graphs as described above.

Use the DataStudio software to calculate the average acceleration during the "free" motion of the cart (after your release or push) by two methods: by averaging a number of acceleration values and by taking the slope of the velocity-time graph. For each measurement, record the uncertainty estimate given by DataStudio. This will be the standard deviation of the acceleration values in the first case and the standard error of the slope in the second.

Compare descriptions and data

Address the following questions in a summary paragraph before you move on to the next experiment:

1. How do the general shapes of your descriptions and experimental position-time, velocity-time, and acceleration-time graphs compare? Were your expectations borne out by the experiment? Explain why or why not.

2. Does the sign of the acceleration on the experimental acceleration-time graph make sense? Use the definition of acceleration to help answer this.

3. Are the averages determined by the two methods above consistent? Use the uncertainties derived from your data to make the comparison.

Motion of cart moving up the ramp

Position the cart at the bottom of the ramp and give it a quick push up the ramp so that it does not bump into the end stop at the top of the ramp. Make sure that the distance between the cart and the motion sensor is always greater than the minimum for your motion sensor. Focus on the one- way trip up the ramp until the cart comes to rest. Draw graphs showing your descriptions of position, velocity, and acceleration as functions of time on another sheet of paper. Then acquire position, velocity, and acceleration data during this motion using the motion sensor. Address the three questions above in a summary paragraph before you move on to the next experiment.

Motion of cart moving up and down the ramp

Again, position the cart at the bottom of the ramp and give it a quick push up the ramp so that it does not bump into the end stop at the top of the ramp. This time focus on the two-way trip up and down the ramp until the cart hits the bumper at the bottom of the ramp. Draw graphs describing the position, velocity, and acceleration as functions of time on another sheet of paper. Then acquire position, velocity, and acceleration data during this motion using the motion sensor and address the three questions above.

Finally, describe the measured acceleration as the cart slows down, stops momentarily, and speeds up again at the top of the track. Consider especially the time when the velocity is momentarily zero.

Summary

Write a brief conclusion comparing your position, velocity, and acceleration measurements with your responses to the corresponding cases in the Motional Tutorial. Since you will be turning in the Motional Tutorial at the end of lab, you may want to write this conclusion before you leave lab. Tutorials turned after the end of lab will receive at most 50% credit.

Before you leave the lab please: Lower the end of the track toward the end of the table so that it rests on the table. Quit DataStudio and straighten up your lab station.