1 Objectives

There are two main objectives of this lab session. The first is to orient you to the use of ultrasonic motion sensors and the Pasco DataStudio software. We will be using this equipment to explore kinematics and dynamics in future labs. The second objective is to give you the opportunity to develop your understanding of the principles of kinematics by exploring one-dimensional motion in a quantitative way.

Pedagogically, this lab is a bit of an experiment, with you as the guinea pig. Rather than have you conduct a preformulated exercise following specific instructions and filling out a worksheet, I’d like you to learn to use the equipment and then take a playful and exploratory approach to learning about some foundational concepts of kinematics. Consequently, the instructions are more in the form of suggestions rather than concrete steps to follow. So take a serious approach, making a good effort to expand your understanding, and have a little fun with it.

2 Prelab Exercise

Please work through the exercises below to help you prepare for lab. Turn in your work at the beginning of the lab session. Your TA will very much appreciate it if you keep your responses as brief as you possibly can. You may hand write your responses if you wish, but typed responses are always appreciated, and you could use this exercise as an opportunity to start getting familiar with the use of an equation editor.

1. The motion sensors we will use are based on the principle of sonic time of flight, similar to the “echolocation” phenomenon used by bats for navigation and searching for prey. The sensor itself is a combination loudspeaker and microphone. Operating as a loudspeaker, the sensor emits a brief ultrasonic sound pulse (called a chirp) and then immediately begins acting as a microphone “listening” for an echo. A clock in the device keeps track of the time elapsed since the sound pulse was emitted. The pulse travels away from the sensor, and when it encounters an object (technically called a target), it reflects and travels back to the sensor where it is detected. The clock measures the total time of flight of the sound pulse in traveling from the sensor to the object and back.

If the speed of sound in air has a known value $u$ (it’s about $u = 343 \text{ m/s}$), and the time of flight for a particular measurement is $\tau$, how does the DataStudio software compute the distance $x$ from the sensor to the target?
2. Under the control of the software, the sensor emits chirps at regular time intervals and keeps a record of the distance to the target for each chirp. More specifically, at each time \( t \), the sensor emits a chirp and records the distance \( x(t) \) for that moment. If you imagine a number line representing the \( x \)-axis extending from the sensor past the target, the value of \( x(t) \) is the position of the target at time \( t \). The table below is a brief sample of data from this system.

Draw a position-time graph for this data. Show your data points with small dots and connect the dots with short straight line segments. (Pencil is fine, but please consider using a ruler.) Think about how to scale and label your axes.

Table 1. Sample time and position data.

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100</td>
<td>0.28</td>
</tr>
<tr>
<td>0.200</td>
<td>0.29</td>
</tr>
<tr>
<td>0.300</td>
<td>0.32</td>
</tr>
<tr>
<td>0.400</td>
<td>0.37</td>
</tr>
<tr>
<td>0.500</td>
<td>0.42</td>
</tr>
<tr>
<td>0.600</td>
<td>0.47</td>
</tr>
<tr>
<td>0.700</td>
<td>0.52</td>
</tr>
<tr>
<td>0.800</td>
<td>0.56</td>
</tr>
<tr>
<td>0.900</td>
<td>0.59</td>
</tr>
<tr>
<td>1.000</td>
<td>0.61</td>
</tr>
</tbody>
</table>

3. Are you glad or not glad that the DataStudio software automatically plots your data as it is collected?

4. If you had this data in a computer file, could you create your graph using Excel? This is a yes-no-maybe type question. If the answer is “yes” you have permission to use Excel to complete the graphing exercise above. (You may, of course, substitute Matlab or any other spreadsheet or data analysis program you like for Excel.) Even if the answer is “maybe” or “no” you still have permission.

5. In the sample data above, what is the velocity of the target at time \( t = 0.5 \) s?

6. What was the time of flight for the chirp used to take the sample at \( t = 0.5 \) s?

7. In your commendable zeal for brevity, did you still manage to show your work for the previous two items?
3 Equipment

Be sure to bring note-taking supplies and a calculator to lab with you. If you bring a USB flashdrive you will be able to transfer data easily to your own computer.

The lab will supply the following items:

- Computer with Pasco DataStudio and Microsoft Excel installed.
- Cart track. (1.2 meter.)
- Motion sensor. (PASPort PS-2103 Motion Sensor II, USBLink, and cables.)
- Torpedo level (may be shared among groups).
- Masking tape (May be shared among groups).
- Low friction cart. (PASCAR ME-6950.)
- Friction foot.
- Cart Fan (Pasco ME-9491.)
- Cart weights (2 each, 250 g).
- Shims.

3.1 Motion sensor

The motion sensor is shown in the figure. The gold disk behind the grille is the sensor itself. The housing mounts to the end of the cart track, but is easily removed by simply pulling on it. The device connects to the computer via a USB cable and the Pasco USBLink adapter.

The motion detector measures the distance to the nearest object directly in front of it, transfers the information to the computer by USB, and then the computer displays graphs of position as a function of time. The software can also derive the velocity from the position data and plot a graph of velocity as a function of time.

Here are a few points to help you use the motion sensor successfully:

- The motion sensor detects the closest object directly in front of it (including tables, chairs, people, your arm if you reach across the track, etc.)
• The motion sensor cannot measure anything closer than a certain distance (typically about 20 cm).

• The motion sensor has two settings: one for large objects at long distances (like people several feet away) and another for smaller objects at close distances (like the carts on the track). It’s important to use the appropriate setting. There is a switch on the top of the case to select mode. You can see it in the picture.

• There’s a green LED on the front of the sensor that lights when the sensor is active, specifically, whenever it is receiving echoes.

3.2 Computer and DataStudio Software

The lab computer is an ordinary Windows desktop PC. It runs Pasco DataStudio software, which is necessary to operate the motion sensors. You can start the software by simply double-clicking the icon on the desktop.

You should be able to use your time in lab to complete everything you need to do using DataStudio. Nevertheless, if you wish to work outside the lab, you may load DataStudio onto your own computer using Dartmouth’s site license. The latest version is available for download at http://www.pasco.com/support/downloads/datastudio-update.cfm. You may also borrow an installation CD from your TA. Either way, you will need a serial number and license key for the installation. This information is posted on Blackboard where you found this writeup. There is a manual for DataStudio posted on Blackboard.

Microsoft Excel is a very powerful tool for compiling, analyzing, and graphing data. If you have some familiarity with Excel, you may find it convenient and useful for working with your data. It’s available on the lab computers. To export your data for use in Excel, choose the export option and add the “.xls” file extension to the filename you choose.

If you have Excel (or similar) on your computer, you can work on your data out of lab without loading DataStudio on your computer. I strongly encourage you to use this lab assignment as an opportunity to learn to use Excel for analyzing data.

3.3 Track and Cart

The motion sensor attaches to one end of a track upon which small carts roll with very little friction. A cart on the track is shown in the figure below. Although these carts are not particularly delicate, they will not stand much abuse. Please handle them carefully to avoid dropping them or crashing them violently into the ends of the track.

You will also be provided with two weights which fit into the cart to increase its mass, as shown in the second figure.

One end of the track is supported by a single screwjack which allows you to level the track, which you can do with the provided bubble level. The screwjack turns easily by hand.
The track is fitted with a distance scale running along its length. Think before using this scale! Where is its zero? Where do you read cart position off the scale?

The third figure shows the cart fitted with a battery-powered fan that provides some self-propulsion.

4 Activities

4.1 Getting Started

Be sure to take notes throughout your work in the lab. It’s a bit of an art to know how detailed these notes should be. For instance, you don’t need to keep a record of everything you try while “playing around” with the equipment while trying to get it to work and getting comfortable with using it. On the other hand, if you formulate a specific question you are trying to answer, you should record the question and enough information about how you went about answering it so that later on you can reconstruct what you did and what you learned.

Some people insist that lab notes should be in ink in a bound notebook. Others take notes on plain paper and then later compile them into some convenient form. Laptops and tablets are also finding their ways into the lab, despite a lack of efficient facilities for making sketches and organizing data tables. I believe note-taking style is very much a personal matter, but that a common feature of all successful experimenters is that they end up with something neat and organized. The goal is to be able to reconstruct what you did and what happened. Your TA may share some personal insights on this issue.

First, familiarize yourself with the equipment.

- Make sure the motion sensor is attached to the end of the track and connected to the USBLink, and that the USBLink is connected to the computer. If it isn’t already turned on, turn on the computer.
- Find the mode switch on the motion sensor. It should be in the “cart” position.
- Inspect the track. What does the scale measure? Make sure the track is level.
• Put a cart on the track and see how it moves. It should be very smooth and nearly frictionless. If you just release it, does it stay where you put it?

• Start DataStudio and have a look around. You can begin by loading the file MotionIntro_A1-1.ds. This file configures the system to collect position data at a rate of 20 samples per second. Play with it. Make some position-time graphs by starting data collection and moving the cart. Do the graphs you see make sense? Rather than the cart, try using your hand as a target. Do the graphs make sense to you?

• Please don’t modify MotionIntro_A1-1.ds, but feel free to create your own experiments at different sample rates. (Don’t waste a lot of time here; there’s much else to do.)

• Remove the motion sensor from the track, set the mode for large objects (the “person” position), and point the sensor at different objects in the room. Can you measure the distance to these objects? What happens if you move the sensor rather than the target?

Determine the zero offset and evaluate the accuracy of the equipment.

• Reconfigure your apparatus for measuring cart position on the track. The motion sensor indicates a distance (in meters) that in some sense measures the position of the cart. You could think of the distance scale on the track (the yellow tape) as being the number line of the x-axis of a one-dimensional coordinate system. But the cart is a macroscopic body, not a single point. When you think of the “position of the cart,” you must think of the position of some particular point on the cart. You could choose whatever point you want, but maybe the conceptually simplest thing would be to take the center of the cart. You could mark that point with a piece of masking tape, or simply take note of some landmark on the cart.

Now compare the position of the cart as measured by the position scale (the yellow tape). You should be able to convince yourself that there is a constant difference between the position and the sensor reading. How much is it? This difference is known as the sensor zero offset. (How’s your note-taking going?)

The upshot of this little exercise is to emphasize that the sensor does not measure position; it measures distance from the sensor to the nearest surface in front of it. You must compute position from this information, and that computation depends on both your choice of a position reference point on the cart, and on the position of the zero of your x-axis. The sensor-measured distance value and the position value differ by a constant once you make these choices.

• Make sure you know how to save your data. Consider examining your data using Notepad, and learning how to export to Excel. If you have a run with an outcome you wish to preserve for you notes or you wish to examine carefully, you may print it to the printer in the lab.
4.2 Position-Time Graphs

This next section is supposed to help you think critically about the use and interpretation of position-time graphs. Start out by seeing if you can think up a particular graph (say a straight-line increase, followed by a level segment), and then reproduce that shape by moving the cart. Challenge yourself. How do you get different slopes? Up slopes and down slopes? Steep and shallow? Curving upward and curving downward? How steep a slope can you make? Can you produce a motion profile that’s a mathematical step function? How does each graph feature correspond to the motion of the cart?

What happens if you just set the cart on the track so that it is stationary, and carefully release it? What graph do you get if you give the cart a little push before releasing? Can you apply your theoretical knowledge to predict the outcome of this experiment? (Careful about that zero offset thing.) Do you get what you expect? Can you explain any anomalous results? Does adding one or both weights to the cart change the outcome? (Please be careful about crashing the cart into the ends of the track.)

What happens if you repeat the previous experiment with the track tilted a bit? You can tilt the track by shimming it up a centimeter or so at one end with the small wooden shims provided. Try it tilted in both directions and with different masses. (We may not have yet covered the theory required to understand this experiment in detail, but in the spirit of playful exploration, try it anyway.)

The fan clips directly to the cart and is operated by the toggle switch. Play with it. (But try to be somewhat directed. Try to predict what will happen. Or observe how the fan-cart behaves and try to predict what the position-time graph will look like.) I’m not looking for any specific outcomes, here. We’ll be revisiting the fan-cart next week with a little more theory at our disposal.

Before you finish with this section, be sure to devise at least one method of producing a constant velocity motion of the cart. You may not be able to reproduce a particular value of velocity from one trial to the next, but you should be able to come up with a technique for producing a constant-velocity motion throughout a particular trial. How do you know by looking at the position-time graph that velocity is constant? How would you analyze the data to determine the velocity of a particular trial?

4.3 Velocity-Time Graphs

Given a table of position-time data for the motion of an object, how would you create a column for velocity? If you know your way around Excel you should be able to devise a formula that you could use to create a velocity column in your table. No, it won’t be exact. I can think of at least three ways to create this column, each giving slightly different results. Can you?

The file MotionIntro_A2-1.ds sets up DataStudio to collect velocity samples at 20 samples per second. Load this file and play with it a little. Notice how difficult it is to produce a smooth
curve when moving the cart by hand.

When you try to move the cart at constant velocity, do you get the curve you expect (plus or minus some roughness)? Can you make the velocity value go negative? What does that mean? When you were working with the position measuring setup could you make the position value go negative? (Are you sure about that?)

Be sure to replicate your constant-velocity experiment from the previous section. Do the velocity-time data confirm your assertion that velocity is, indeed, constant in these runs?

Also be sure to replicate your tilted-track experiments. Again, we don’t have a full complement of theory to bring to bear on this experiment, but try it anyway. Does the shape of the velocity-time curve make sense to you? Can you make a qualitative analysis of why it has the shape it has?

5 Homework

For your lab homework, please prepare a brief report that presents a discussion of how you produced constant velocity motion and presents the analysis described below. Please type your presentation, including any equations. Typing equations means using an equation editor, not using computer-style expressions like \( y = v_0 + \frac{1}{2}at^2 \). That equation should look like

\[
y = v_0 + \frac{1}{2}at^2.\]

(If you really can’t get an equation editor going at this point, write your equations into your text by hand. No prejudice.) I’m after neatness and cogency, not a particular format.

From your constant-velocity, position-time experiments, choose two trials, one with positive velocity and one with negative velocity. Describe how you produced these two runs and present tables of data for two seconds in the middle of each. Demonstrate that these data conform (within experimental error) to the theoretical kinematic equation of motion for the position of a particle moving at constant velocity. Include an estimate of the uncertainty in the velocity you measured.

In performing your analysis, you will want to graph your data and fit a straight line to it. (Right?) If you can learn to use the analytical tools in DataStudio, feel free to use them. If you analyze your data in Excel and want to use analysis tools in Excel, that’s very commendable. If you just want to fit a straight line by hand, you may certainly take that approach as well. In any case, you should include the actual graph of your data with the fitted line drawn in. You may use the printer in the lab to print graphs directly from DataStudio for inclusion in your report. Make sure your axes are labeled.

Your TA will read your report looking for evidence that you understand the interpretation of position-time graphs, that you know how to interpret the parts of the kinematic equation of motion for position at constant velocity, and that you can relate a position-time graph to that equation. Your report should not be long; make it just long enough to explain the
essential ideas:

- How did you produce constant velocity motion?
- How did you know you were successful in producing constant velocity motion?
- What equation describes this motion?
- What do the parameters (the constants) represent in your experiment?
- Show your data in tabular form.
- Show graphs of the two cases requested and analyze the graphs to evaluate the values of the parameters in the equation of motion for constant velocity.
- How accurate do you think your measurements are?

Be sure to indicate your name, the names of your lab partners, and the time of your lab section at the top right of your first page. Don’t use a separate title page. You should collaborate with your lab partners to make sure you all understand the physics, but in the end, prepare your own report. Be sure to cite any and all sources of assistance as described in the syllabus.