Department of Physics

Graphing Motion

Lab Objectives

- Formatting using significant figures
- Reporting a measurement
- Linear fitting and statistics
- Interpreting graphs of motion

Lab Equipment

- Vernier Motion Detector
- Vernier Dynamics Cart
- Flat Cart Track

Experimental Background

The Time Measurement

There are many ways to keep track of time, such as by using a clock or a stopwatch. For many of our labs, we will want to make a time measurement. Instead of using a physical clock for most of these experiments, we will make use of the computer's internal clock to keep track of time.

The Position Measurement

The first device you get to know in this lab for making a position measurement is called the "motion detector", or "sonar ranger". The motion detector emits ultrasonic sound waves and listens for the echo. That is, it measures the *travel time* of a sound wave in air, which is the same principle that bats use for finding their prey. It is not really a position measurement, because time is measured. But since the velocity of sound in air is constant[1] as far as we are concerned, this time measurement can be calibrated to a distance measurement.

This insight into how your sensors work is most useful when you want to make unorthodox measurements or when something goes wrong. You might want to use the setup in a situation outside of the range of design specifications (for example, measure the distance in a helium atmosphere, or do the experiment outside at a

[1] The velocity of sound in air is not *really* constant. It depends on a variety of parameters like the air temperature, the air pressure, the molecular composition of the gas, etc. The speed of sound in air at standard temperature and pressure (STP) is 331 m/s.

temperature of -40°C: this is really, *really* cold) or if you are still here in our lab, the data that you record may not represent what you were trying to measure.

In all these cases, more often than not in the last scenario, it is important to know about your detector and how it works. You need to be able to interpret your data, and you have to be able to identify experimental artifacts. You are only able to understand an artifact if you know how the detector works.

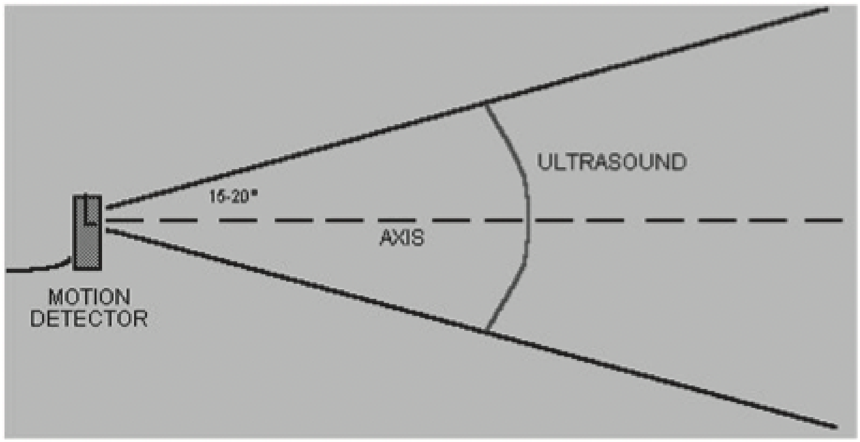


Figure 1: Diagram showing the ultrasound detection path.

Look at Figure 1: you see a sketch of the motion detector and an emerging cone of ultrasound waves. The opening angle of this cone is 15°-20°, measured against a straight line perpendicular to the active surface of the detector. That means that everything within this cone will be hit by ultrasound waves during the measurement. Objects close to the detector will produce the most recognizable echo, so you have to make sure to remove any unwanted obstacles from this cone when making a measurement. Some of these obstacles might include tables, chairs, backpacks and lab equipment on the tables, or your lab partner's head.

One last word of caution: the motion detector has a limited measurement range. You cannot measure a distance smaller than approximately 15 centimeters, nor a distance larger than 6 meters. If you try, the computer will give you a false reading.

Experimental Setup

Doing the experimental data-taking with computer assistance, you have a big advantage over past generations: the computer calculates and displays the velocity and acceleration automatically, and you don't have to do the calculations yourself. The drawback of this simplification is that you have to recognize errors that result from the automation. *The fact that "the computer does the experiment" does not mean that the results are correct!* You have to provide the interpretation of the graphs generated by a computer, and you have to explain and minimize errors generated by the apparatus.

Make sure your sonar ranger is attached to the computer interface and open up Logger Pro which should be on the desktop. You should see two empty graphs on the page, one for position vs time and another that is velocity vs time. We would like to have a third graph on this page, acceleration vs time. The easiest way to do this is to use the menu item `Insert > Graph`. This should position a small graph on top of the other graphs. You could manually resize all of the window items to fit, but an easier way is to use the menu item `Page > Auto Arrange`. This function should automatically fit all of the window items into the window for you.

Predictions

Using the graphs in Figure 2:

1. Describe the kind of motion that produced the position versus time graph.
2. Sketch the $v(t)$ and $a(t)$ graphs you would expect to get for this motion using the `Insert Shape > Scribble` command.
3. Try to recreate this motion in real life, collect the data with Logger Pro, and qualitatively compare your predicted graphs with the graphs calculated in Logger Pro.

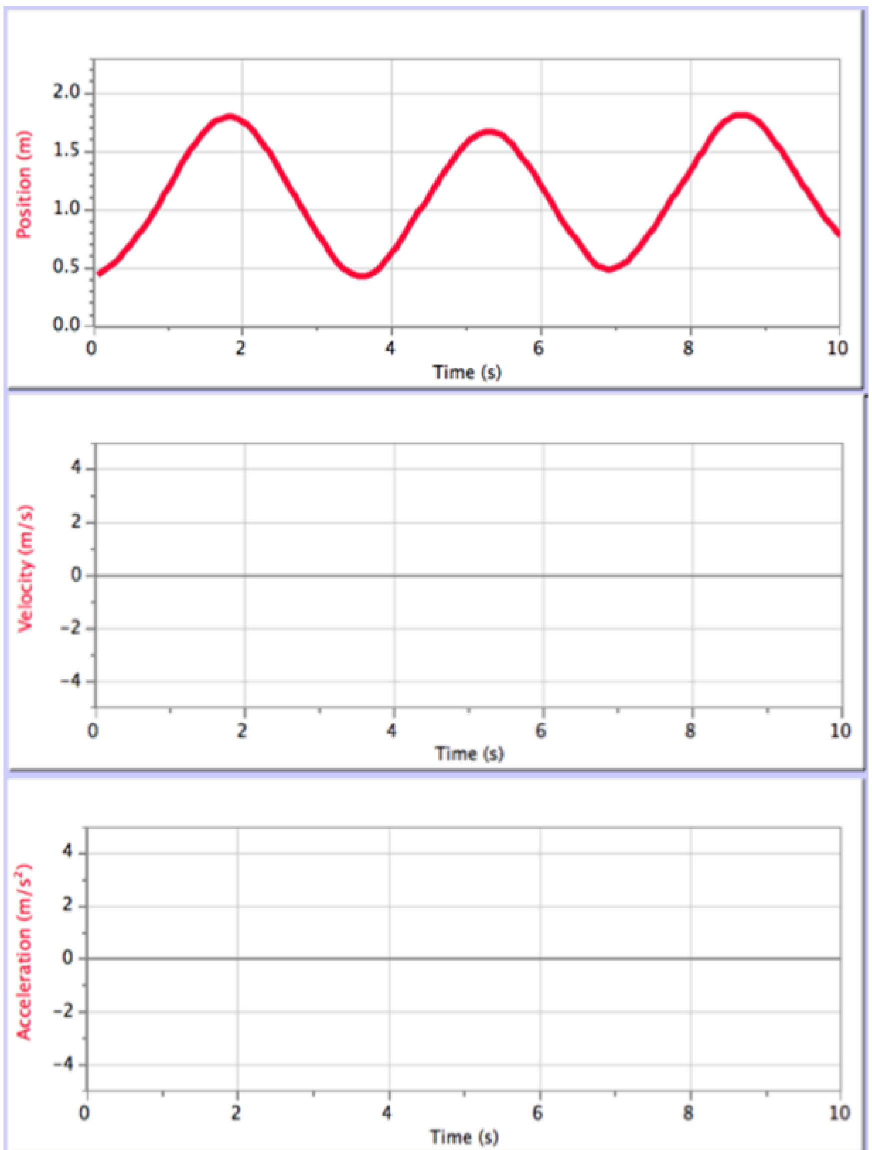


Figure 2: Graphs of the position, velocity, and acceleration of an object as functions of time.

Questions 4, 5 and 6 describe different types of motion, for each of the motions predict the following:

- Will the position, velocity, and acceleration be zero, positive, or negative, or will it be more complex?

- What will the graphs of $x(t)$, $v(t)$, and $a(t)$ look like? (i.e. a straight line slanted up or slanted down, a constant, curving up, curving down, etc.)

Motions:

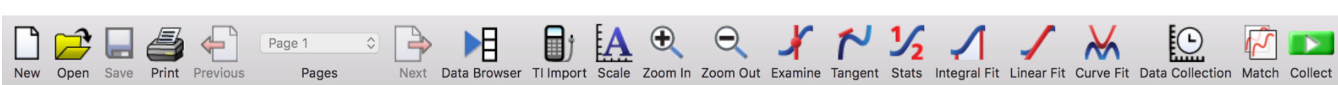
4. Moving towards the motion detector at a constant velocity.
5. Moving away from the motion detector with continuously increasing velocity.
6. Moving toward, then away from, the motion detector (looking only at the turning point).

The Experiment

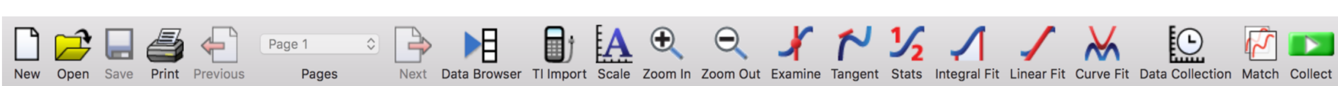
You will try each of the motions above with the cart on the track and perform a few data analysis steps on each motion. There is a lot of information below so we highly recommend that you read the rest of the lab before you continue.

- Does your data match your prediction *qualitatively* (The general shape of the graphs, sign of the slopes, etc.)? If you are happy with the match between what you expected and what you got, you can proceed to the quantitative analysis. If not, ask your lab instructor to discuss your results with you before you continue. You should not change your prediction. No points will be taken away for an incorrect prediction, only for not having one.
- For the first motion, make a measurement of the velocity for the **relevant portion** of the experiment using the slope of the *position* versus time graph. Find the average value of velocity in the same time interval in the velocity plot displayed by the computer.
- For the second and third motions, make a measurement of the acceleration for the **relevant portion** of the experiment using the slope of the *velocity* versus time graph. Find the average value of acceleration in the same time interval in the acceleration plot displayed by the computer.

You can find the *slope* of a part of a measurement by dragging a rectangle around the region of interest and selecting the linear fit tool from the toolbar. Uncertainties for the parameter values can be seen by right clicking on the linear fit box and selecting "Linear Fit Options" and checking the box marked "Show Uncertainties".



You can find the *average value* of a measurement over any time period by dragging a rectangle around the region of interest and selecting the statistics tool from the toolbar.



Note: if your screen does not show the words "Linear Fit" or "Stats" under the icon, go to the menu item `Loggerpro > Customize Toolbar` and chose "Icon & Text" from the "Show Menu".

Insert your graphs, including your linear fits and statistics into your worksheet (you can right click to copy the graph, then paste it into your sheet), for each motion into your answer sheet using the guidelines for Figures and Captions below. You should have a total of nine figures from this part of the exercise.

The Figures and Captions

There are a few very important aspects to creating a proper figure and caption. If you follow these rules, not only will you get points on your physics lab grades, you will impress your instructors and peers in the future.

The Caption

- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Figure 1", "Figure 2", etc.
- The caption should allow the figure to be standalone; that is to say, by reading the caption and looking at the figure, it should be clear what the figure is about and why it was included without reading the whole paper.
- The caption should contain complete sentences and be as brief as possible while still conveying your information clearly (this is not always easy).

The Figure

- Make sure that the resolution is high enough to not be pixelated at its final size.
- Check that any text is readable at the final size (Using a smaller graph in Logger Pro will cause the text to be larger in relation to the graph when inserted into another program)
- For graphs, ensure that the axes are labeled (including units) and that there is a legend if you have multiple data sets on the same graphs.
- Re-scale every plot to reveal as much information as possible. Figures 3 and 4 show velocity versus time data. The two plots are the same data, but Figure 6 reveals much more information. Be sure your graphs look more like Figure 4, with detail easy to see rather than like Figure Figures 3.

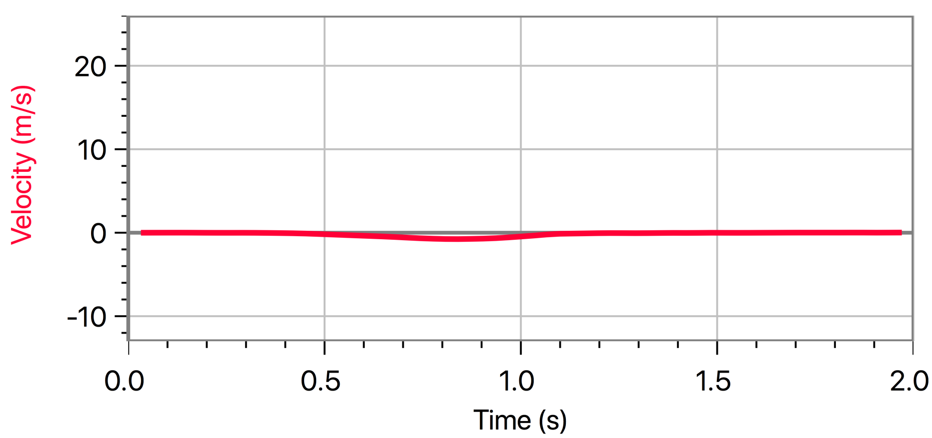
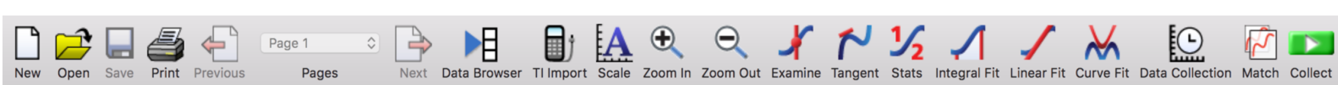


Figure 3: Above is an incorrectly scaled velocity vs time graph. Note that the velocity dip is not well defined and there is a lot of wasted space. At least the axes are labeled and units are included!

In Logger Pro, you can do a rough rescale by clicking the AUTOSCALE icon on the menu bar.



If you don't like what AUTOSCALE does to the axes, you can also re-scale the plots by double-clicking on the left vertical axis and changing the values in the dialog box. The purpose of re-scaling is to make your graph display the aspects of motion that you are most interested in.

Based on the data that you took today, answer the following questions:

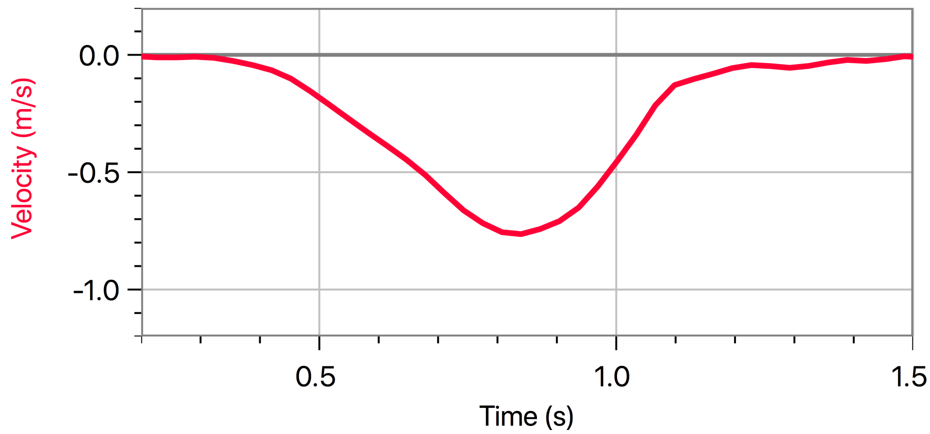


Figure 4: This is a correctly scaled velocity vs time graph. We can see that the minimum value for the velocity is between -0.5 and -1 m/s and occurs between 0.5 and 0.1 seconds.

For each of your graphs (a total of nine), answer the following questions for each motion in the caption along with your basic description of the figure.

- How do your position, velocity and acceleration graphs compare with your prediction? If you predicted ZERO for velocity or acceleration, was it exactly zero at all times? If you predicted non-zero velocity or acceleration, was the sign what you predicted?
- Compare the numerical values for the velocity and acceleration obtained by more than one method from your graphs, and comment on whether those differences are significant. Be as quantitative as you can (i.e., include uncertainties).

Experimental Method

For today's experiment, write down with bullet points the three most important steps for your data collection, including why you think the particular step is important. Use complete sentences (one per bullet point) not just a copy and paste of the instructions above.

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Graph and Data Checklist: You should have nine graphs with the appropriate title, labels, a complete caption and answered all of the questions highlighted by the gray boxes.