225L Position, Velocity and Acceleration

Introduction: By this time in your lecture class, you should have worked some problems with the equations for position and velocity as a function of time for one dimensional motion with constant acceleration. If you had high school physics, you would also have used these equations. In case you don't remember them, the equations are

$$v = v_0 + at \qquad (1.)$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2 \qquad (2.)$$

Here v is the velocity at time *t*, v_0 the initial velocity (velocity at $t = 0$), *a* the acceleration, *x* is the position at time *t*, x_0 the initial position (position at $t = 0$), and *t* is the time measured from when the object was at position x_0 with velocity v_0. Although the equations are very simple, they do involve six variables and can be confusing. There are three major aspects of the equations that demonstrate some fundamental and useful things that we want to make sure you fully understand. In addition, we want you to become familiar with graphs of position, velocity, and acceleration as functions of time, and what they can tell you about the motion of an object. A final goal will be to help you to become familiar with dealing with data that has noise in it due to the measurement technique used.

In this lab period we will use a low friction, wheeled cart on a grooved track about two meters long, in conjunction with a sonic ranger and computer software, to acquire data for the position, velocity, and acceleration as a function of time for a moving cart. The cart has a motorized fan mounted on it with a switch to provide thrust and thus acceleration. When the fan is turned on, it provides a constant thrust and thus a constant acceleration to the cart (the thrust will eventually decrease as the fan slows down due to the batteries discharging. Be sure to turn your fans off when not taking data to conserve the battery charge for the next lab. The lab is no fun when the fan batteries are low.).

Summary of the experiment: In today's lab, you will be making measurements with the cart and Logger Pro software for 3 important cases. 1. Constant velocity, 2. constant acceleration with zero initial velocity, and 3. constant acceleration with initial velocity opposite to the direction of acceleration. For case 3. you should take data for 2 different initial velocities and compare the measured maximum distance and the calculated maximum distance using your measured values for v_0 and *a* for each of the two cases. You will take screen shots of your data graphs for each case (a total of 4 screen shots) so that you can paste them into a Word document and print them to include in your lab report. (taking a screen shot is done by holding down the Alt key to the left of the space bar while pressing the Prt Scr key on the keyboard. This is the print screen key located on the top row and to the right on standard PC computer keyboards). This makes a bitmap copy of the active window that you are to paste and resize in the Word document used to print your report graphs from.

The graphs of position, velocity, and acceleration for each of the 3 cases with your comments and answers to questions and any data tables or results should be stapled, taped, and handwritten into your exam blue books as appropriate, and submitted as a single lab report for each lab station. The details of this exercise follow.

0.) Constant (zero) velocity. (cart stationary)

Put the cart on the track with the fan off and hold it stationary for a moment, then release it without imparting any motion. The cart should remain stationary. If it rolls in either direction, the track is not level. Please call your instructor to help you level the track.

1.) Coasting (zero acceleration, constant non-zero v)

Open the Logger Pro software file called: "acceleration.cmbl". The display should show three graphs, as in the example figure 1 below. Make sure the position, velocity, and acceleration scales on your graphs are the same as the vertical and horizontal scales in the example figure below, and insure that you select the manual scale option if you need to adjust them (the default is auto scale, which does not display the data with sufficient magnification and tends to change each data run).

First position the sonic ranger near the lab counter end of the track, (behind the stop so the cart does not collide with it) and aim it towards the target card on the cart (the fan should be pointed away from the ranger at all times. Position the cart on the far end of the track, click the green go button at the top of the computer screen to start the data acquisition, and slowly move the cart by hand while watching the screen to make sure that the software is working. The position should be changing as you move the cart towards and away from the sonic ranger. Practice a couple of times how long you wait after clicking the green go button to moving the cart so that you get nice graphs that look similar to figure 1 below. There is a brief pause after hitting the go button before the computer begins taking data, and you do not want to launch the cart until the first data shows up on the screen.

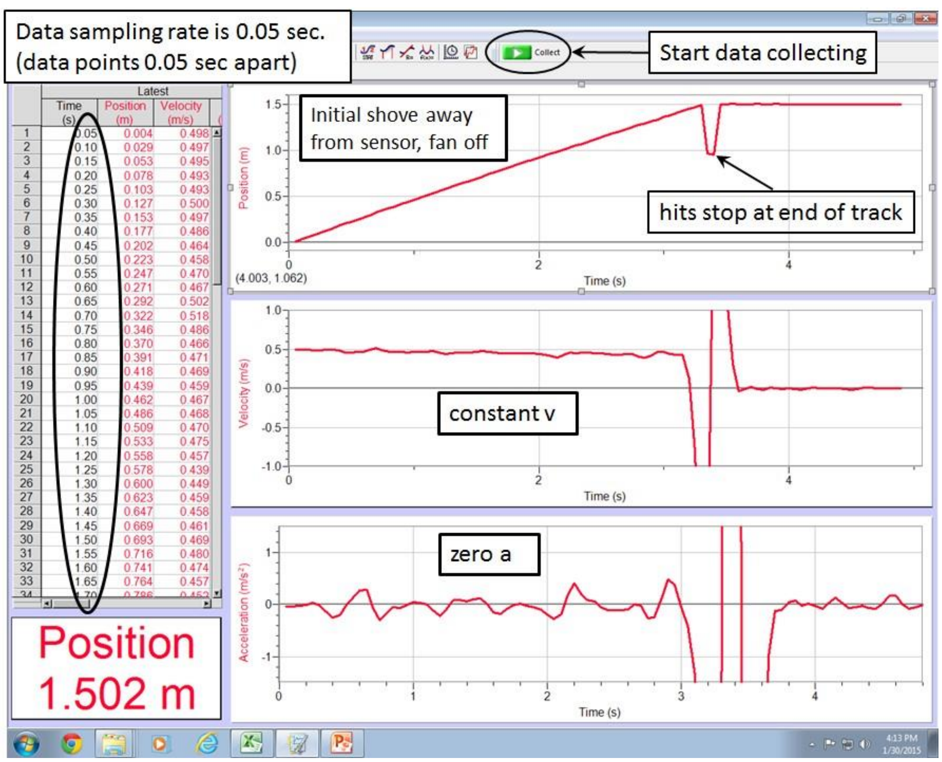

Figure 1 Screen shot of Logger Pro position, velocity, and acceleration graphs for the case of constant velocity. Note the vertical and horizontal scale ranges. Zero *a* corresponds to the average of the data values due to numerical error in computing the second derivative from the position vs. time data, and undersampling the data. The data become more and more noisy with increasing derivative order.

With the fan off and the cart on the sensor end of the track, give your cart an initial (gentle!) push and record the data until the cart hits the stop at the other end. When launching the cart away from the sensor, be sure to keep body parts from moving in the vicinity of the sensor, or you will get data with a lot of variation in the velocity. Practice releasing the cart with a gentle shove of two fingers behind the cart with your fingers kept low and out of the sensor beam until you get data that shows a smooth, linearly increasing position vs. time graph similar to figure 1. The data acquisition will automatically stop recording after about 5 seconds, do not hit the space bar before it is finished or you will lose your data for that run! Take a screen shot of the data and paste it in a Word document in order to save it. Be sure to save the Word document each time you paste in a screen shot so that you do not accidentally lose the previous data.

a.) Was the velocity of the cart constant? If so, what was its value and over how big a region was it constant? Explain how you can tell.
b.) If the velocity of the cart was not constant, describe some possible sources of error and their effect. (hint: wheel friction, wheel shape irregularities, track groove irregularities, etc.)
c.) Was the acceleration zero? Report its (average) value Discuss why the acceleration is not perfectly constant or zero.

2.) Constant acceleration with zero initial velocity (free fall from rest)
In this part of the lab experiment, position the cart near the end of the track farthest away from the sonic ranger, with the propeller in the back of the cart facing so that when the fan is turned on, the cart will accelerate towards the sonic ranger. With your hands and fingers clear of the fan propeller, and the fingers on one hand placed in front of the cart to prevent it from moving towards the sonic ranger, carefully use the other hand to turn on the fan. ***Be careful not to get your hands or fingers in the path of the propeller blade, it can hurt a lot!***

With the fan on, move your fingers in front of the cart out of the way so as to release the cart from rest and it accelerates towards the sonic ranger until it hits the stop at the end of the track. When you get data that shows a good curvature in the position vs. time graph, and a nearly linear decrease in the velocity vs. time graph, take a screen shot of the data and paste it into Word. Save the document.

a.) Was the acceleration of your cart “constant”? The up and down fluctuations in the acceleration are an artifact of taking a numerical second derivative of the position vs. time graph for a fairly small acceleration, and also under sampling the data. Take an approximate average value for the acceleration and report that number. (ideally, if there was sufficient time in the lab, one would take a segment of the *a* vs. *t* data which is horizontal on average, import that data in a spreadsheet and then take the mean and standard deviation.

b.) Describe the position vs. time graph. Is it what you would expect for this situation? Right down the equation that describes it using the value for the acceleration found in part a.) above. (Hint: this equation is exactly the same as the equation for position vs. time for free fall of an object starting from rest)

3.) Constant acceleration with initial velocity opposite to the direction of acceleration (toss the ball in the air)

For this last part of the experiment, start the cart at the end of the track nearest the sonic ranger with the fan thrust pointing towards the sonic ranger. Turn on the fan and use two fingers to give the cart an initial velocity that is opposite to the direction of the fan thrust. Give the cart an initial velocity that is sufficient for the cart to move almost half way down the track before stopping, turning around and returning back to its original position. This will likely require some practice runs to get used to the amount of force required to launch the car down the track *The point where the cart velocity is zero and turns around is called a turning point of the motion, and is an important concept in mechanics*. This is the same kind of position vs. time motion that happens when you toss a ball vertically upwards in the air, it reaches its maximum height, which is a turning point, reverses velocity, and then returns to its initial position when you catch the ball at the same height it was released from.

Once you get the technique of imparting an initial velocity to the cart, take screenshots of data recorded for two different initial velocities and corresponding maximum distances from the sensor. The two different values of v_0 should be such that one of the values results in the cart turning around slightly less than half way down the track, and the other value of v_0 should be sufficient so that the car makes it nearly to the end of the track before turning around (3/4 of the way down minimum). Make sure that the position vs. time data are smooth and do not have artifacts due to the way you launched the carts. Make screenshots of your data for each of the two different initial velocities and paste them into Word.

a.) Was the acceleration constant for the two different v_0 values? Determine the region where it was constant and report the average values of the acceleration. Compare these values to the acceleration you found in part 2. What do you expect the relationship between the three values to be? Do your results agree with what you expect?

b.) From the velocity vs. time graphs, locate the position of the turning point (i.e. the corresponding time). Find the position of the cart at this value of the time and record it for both of your v_0 values. Also record the v_0 values. From the v_0 and a values, determine a formula for the expected position of the distance away from the release point where the cart turns around. (Hint: this is the same formula used to calculate the maximum height of a ball tossed in the air, and you substitute the carts acceleration for the acceleration of gravity, and the horizontal position of the cart for the vertical position of the ball.) Using the values for v_0 and a that you determined in 3.) and your formula, calculate the position of the turning point of the cart for the two different initial velocities. Compare these values with the measured values. Make a little table with the various values of v_0, a, x_{tp}(expt.), x_{tp}(calc.), where x_{tp} is the turning point distance from where the cart was initially released. Are the values in approximate agreement?

c.) Lastly, note that your graph of position vs. time is a parabola (at least it should be if you took the data correctly), thus one dimensional motion with constant acceleration is sometimes called parabolic motion, even though it is only one dimensional.

Additional Questions for your report:
(answer as many as you can if there is any additional time available, otherwise ignore these questions)

1.) Why were the velocity and acceleration graphs not smooth when they were supposed to be?

2.) Why was the acceleration fluctuating up and down so much more than the velocity when it was supposed to be constant?

3.) Describe what effects the data sampling rate of 0.05 seconds has on the accuracy of the position, velocity, and acceleration.

4.) Include in the write-up a brief discussion of the simple finite difference approximation for the first and second derivatives.

5.) The position sensor is a sonic ranger and measures distance $x(t)$ from the round trip time of flight of a sequence of very short acoustic pulses that are reflected from the target on the moving cart. What do you think happens when there are additional reflections from other nearby objects that are moving or stationary? Can you do a simple experiment to test your hypothesis?

Report:
When you are done with items 1.) → 3.), properly format and resize your screen shot graphs in the Word document along with any typed results and comments you may have (computer typing is not necessary, especially if it takes you longer than handwritten comments). Take the file to the instructor and have them print it. Tape or staple your computer graphs and hand written comments or answers to questions in your blue book. This may require a little bit of manual cutting of the graphs to fit the blue book pages. Both lab partner names and experiment title should be on the cover page of the blue book, along with the date. Be sure to write a summary of the results for the experiment at the end.

Appendix:

Effects of small periodic variations in position vs. time.

Finite difference, numerical approximation to derivatives and errors due to sampling rate.

KW 2/2/15