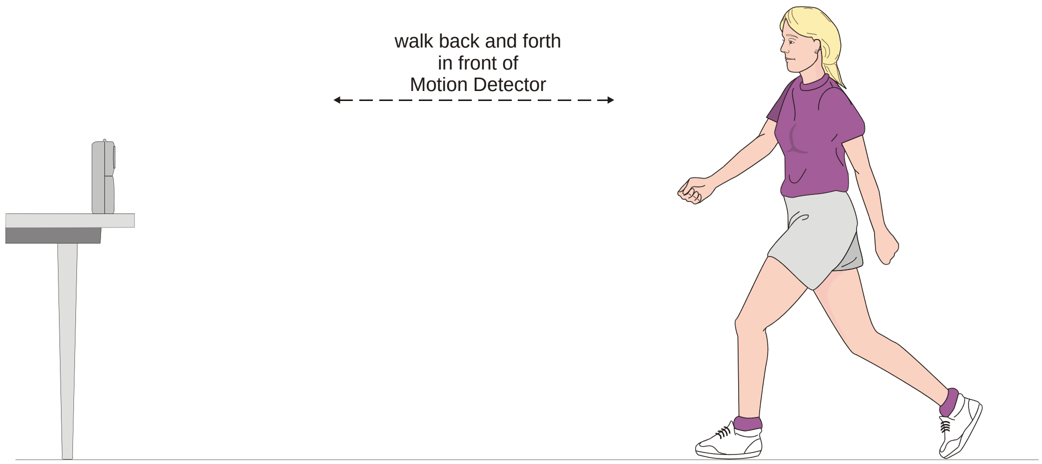
Kinematics



Objective: To understand the relationship between Distance, Velocity and Acceleration. To gain familiarity with collecting position data using a computer, motion sensor and lab interface. To be able to read and interpret a one-dimensional motion graph and to make predictions using Kinematics (equations of motion). To perform data analysis to non-repetitive measurements (find a pattern in the data).

Apparatus: Computer, motion sensor, LabPro lab interface, meter stick, flat reflective surface (folder or book), Pasco track, Pasco cart.

Introduction

Kinematics allows us to describe motion mathematically and make predictions of subsequent motion, such as an object's position or velocity at some future time. Such skills are vital in any field that deals with moving objects, and that includes just about all branches of science and engineering. For instance, in Forensic Science one can calculate how fast a car was moving by measuring the length of the skid marks at an accident site. In Civil Engineering, the length of an airport runway is determined with Kinematics from such values as the speed of the plane at takeoff, and the acceleration of the plane.

Galileo Galilei (1564-1642) performed experiments similar to those you will do today to discover the laws of Kinematics. Unlike him, who used crude instruments (such as using his pulse as a stopwatch), you will be using a much more sophisticated device that you are already familiar with – a motion sensor – to track the motion of an object.

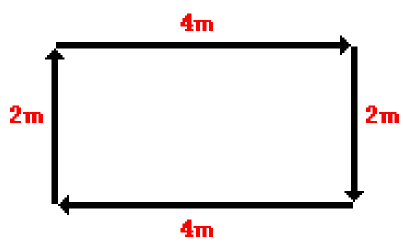
Theory

<u>Kinematics</u>

As you learned in lecture, Position, Velocity and Acceleration are related to each other as follows:

1. Position (x) is the the location of an object. In this experiment, this is the information that the motion sensor reports, as a function of time.

2. Distance vs. Displacement: Distance (always positive) is a *scalar* quantity that represents the length of travel. In one dimension, Displacement is the *change* in position $\Delta x = x_f - x_i$, and can be both positive or negative. The following shows the distinction between both:

	A student who starts at the upper left-hand corner of the rectangle on the left walks 4m East, 2m South, 4m West, then 2m North back to her starting location. Although her Displacement is 0m during her trip, her trip Distance is 12m.

3. Average velocity is the change in displacement divided by change in time. $v = \frac{\Delta x}{\Delta t}$. The slope between any two points in the x vs. t plot is the average velocity during those two points.

4. Average acceleration is the change in velocity divided by change in time $a = \frac{\Delta v}{\Delta t}$. The slope between any two points in the v vs. t plot is the average acceleration between those two points.

In the limit where the time interval between two points goes to zero. $\Delta t \rightarrow 0$, the above quantities become instantaneous velocity and acceleration and can be written in derivative form: $v = \frac{dx}{dt}$; $a = \frac{dv}{dt}$

5. The area under the v vs. t plot is the total distance traveled. In calculus, we say that the distance traveled is equal to the definite integral between any two points in the plot.

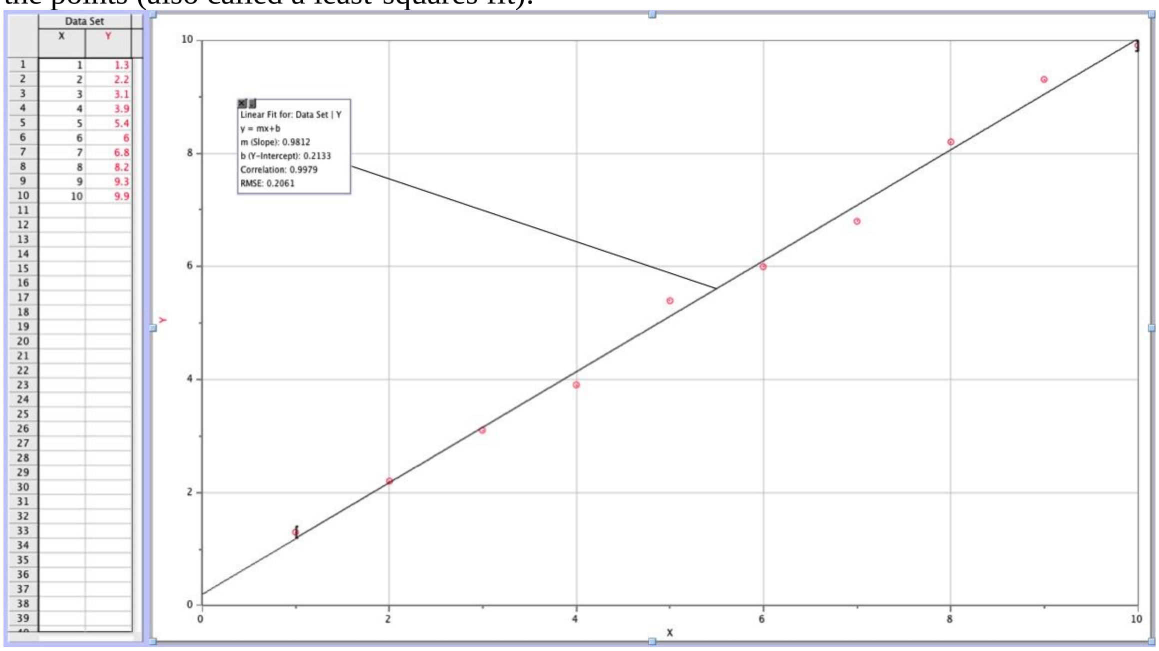
In the first experiment, you (or the cart on the track) will be the object in motion. You will try to duplicate, by moving yourself or a cart back and forth in front of a motion sensor, various plots of Distance, Velocity and Acceleration versus time. These graphs will be automatically plotted in the data-acquisition software, Logger Pro. In the second experiment, you will analyze the position of a cart on a track using the same motion sensor.

You may also recall from lecture the general equation of motion, when acceleration is constant (which can be gotten from doing a definite integral of. $a = \frac{dx^2}{dt^2}$, for you students of calculus): $x(t) = x_0 + v_0 t + \frac{1}{2}at^2$; a time-independent version of this is:

$v^2 = v_0^2 + 2a\Delta x$.

<u>Curve-Fitting</u>

This is the application of data analysis to quantities that change with time (as opposed to your reaction time, which should be clustered around an average value). Typically, one value (dependent variable, Y) is plotted against another (independent variable, X). Then a relationship between the two is determined by drawing a line as close to the points as possible; mathematically, the line is drawn such that the total distance between the line to the points (also called a least-squares fit):



In this lab you will use software (Logger Pro) which allows you to perform a curve-fit on your data with a variety of functions – linear, quadratic, polynomial, exponential, etc.

Procedure:

Again, as with all your work this semester, your lab report will consist of a created Google Docs document shared amongst the lab partners, your TA and your LA. Note that you can do your plotting and curve-fitting in Google Sheets and include a link to that document on your Google Docs lab report.

Motion Sensor (40pts)

Note that you have your choice here of using your body as the object, or the cart (on the track) as your object.

1. Open "PRACTICE.xmbl", which is a Logger Pro file in the same folder as this write-up (Desktop-->Course Folders-->205-->Kinematics).

2. Position the motion sensor near the side of the table – as close as possible to the edge, but far enough such that it still lands on the table in the event it tips over. Make sure that the sensor switch is set to the Wide setting. Point it in such a direction that you, the object it will be tracking, have a 4 meter "corridor" of space in which you will neither bump into adjacent tables or people nor encroach onto other lab groups' "corridors". Discuss the placement of your "corridors" with adjacent groups. *Alternatively, you can also choose to use the cart (rather than your body) as the object in motion – in this case, keep the motion sensor positioned on the track and pointed toward the cart; the sensor switch should be set to the Narrow setting*.

***SKIP TO STEP 7 IF YOU ALREADY PERFORMED THE "Intro. to Experiment" LAB LAST WEEK.**

3. Play *around with the apparatus and software.* Still in Motion PRACTICE.XMBL, Press the Collect button in Logger Pro to collect data. You will hear rapid clicking, which is the sound of the pulses coming out of the motion sensor. Have your partner move back and forth in front of the motion sensor in a random fashion (**or move the cart back and forth in a random fashion in front of the motion sensor)**.

4. After the 10 second collection period, examine your graphs. In the menu bar, go to Analyze-->Examine. Now activate any of the three graphs by clicking on it, then moving the cursor around to trace the plot – you should see the coordinates displayed on the top left hand corner of the graph, and they will change as you move around the plot. **If you are not getting any data, make sure your motion sensor is plugged into the DIG/SONIC1 input on the LabPro (translucent aqua blue covered flat box).**

5. Turn off the Examine feature, and again go to Analyze-->Tangent. Move your cursor around one of the plots again – this time it will draw a line tangent to whatever point on the plot your cursor is on and display the slope. Turn off the Tangent feature.

6. Use the meter stick and a piece of chalk to mark off two points on the floor one meter apart (or just note two points one meter apart on the track). Make sure they lie in a straight line along your motion sensor beam line, within your "corridor". Press Collect again, and have your partner move from one marked point to another, spending a few

seconds in each location (or move the cart accordingly). Confirm from your graphs that the points are indeed one meter apart. If they are not, notify your instructor. **If your motion sensor has a wide/narrow beam adjustment, you can switch to the narrow beam if you are getting too much interference or back to the wide beam if the sensor is not tracking you; experiment with what works best.**

7. You should now be ready to try the distance and velocity matches. Open the first match file (Motion A -Walk.XMBL or Motion A – Cart.XMBL). Examine the blue trace with your partner and note the starting values. Discuss your walking (or cart rolling) plan to duplicate the blue trace, keeping in mind the relationships between Distance, Velocity and Acceleration. **Remember that the beam may bounce off any object along its "cone", so keep track of the objects it may be seeing. You may also find that holding a flat, rigid object (folder or binder, for example) in front of you may improve the beam's "tracking" of your position.** Practice a few times, run through the distance match and take a screenshot (or take a clear photo of your monitor/screen with your smartphone) of the each of the group's best plots for matches A, B, C & D (total of 4 per group) and include in your lab report. (10 pts per match x 4 = 40pts total)

> To take a screenshot on a Mac, use the key combination Command (⌘) -Shift-3 on the Mac; you can then log in to your email account using Safari, attach it by navigating to where the screenshot was stored and selecting it. If this doesn't work for you, you can use your smartphone to photograph the lab Mac's monitor and include that into your Google Docs lab report. *Downloading the Google Docs app to your phone makes it easy to insert phone photos into your report.*

Cart on Track (35pts)

1. Take your motion sensor from the side of the lab table. Place it on the Pasco track, about 20cm from the end that does not have the guard. Make sure the head of the sensor is pointing horizontally (the angle reads zero on the side of the sensor). See to it that the track is horizontal by rolling the cart along it and checking that it's not more likely to roll in one direction more than the other – in that case "level" the track by turning the screws on the rubber feet either clockwise or counterclockwise so that it is.

2. Again open PRACTICE.XMBL and start the data collection. Play around with the cart/track by pushing it back and forth along the track a few times and observing the graphs. If the graphs have abrupt jumps in them, check to see that the motion sensor is pointed correctly and the beam width set properly, or that there is nothing in the way between

3. Remove the cart from the track. Make sure the track feet are about 1/4 and 3/4 of the way along the track. Now incline the **motion sensor end** of the the track (so that the cart will always be travelling *away* from the sensor and will never crash into it) by putting a few blocks under the set of legs on that end. **Note that there is no reason to remove the legs whatsoever.** Again collect data by releasing the cart from high on the track, catching

it low on the track and prepare to comment *qualitatively* about the Position, Velocity and Acceleration of the cart between the points of release and catching. You will do curve-fitting in the next step, so **save your data in the Documents folder or do not quit Logger Pro.**

4. Collect data – press the Collect button and release the cart from high up the track until it almost reaches the other end of the track (catch it before it falls off or hits the sensor). Look at your graph and:

a) note the points when you released the cart and when you caught it on the other side. (5 pts)

b) How do you know that these points indeed correspond to these two events? (5 pts)

c) What can you (Positive? Negative? Zero? Increasing? Decreasing?) say about the Position, Velocity and Acceleration of the cart *between* these two points? (5 pts)

Curve-fitting

5. Still in Logger Pro, go to the Menu Bar-->Analyze-->Curve Fit. You'll see a list of fitting functions in the General Equation window; choose one of these (Linear or Quadratic, for instance), click on Try Fit, and see how closely the curve fits your data points. Remember that you should only select the range of data points of interest, which may not be all the points; select on the graph on the left the region of interest – for instance, it makes no sense to fit the time in which you are just holding the cart before it rolls down the incline! **Include a screenshot or photo of your fit curve in your lab report.**

6. Once you are satisfied with a function (*and it makes sense physically – you wouldn't expect an exponential* $y = Ae^{bt}$ *function to fit the distance a falling object falls with time; this should look more like* $y = \frac{1}{2}gt^2$):

a) write in your lab report which function you used and explain why it made sense. (5 pts)

Take note of the fit coefficients and write them in your report – these are the coefficients that provide the closest match of the fit equation to your graph. In the case of the highly useful constant-acceleration time-dependent kinematic equation, the fit coefficients from Logger Pro would appear as: $x(t) = At^2 + Bt + C$.

b) How do these each of these coefficients (A, B, C) theoretically relate to quantities Position ***x***, Velocity ***v*** and Acceleration ***a***? (10 pts).

c) From the fit equation, what are the values of the *theoretical* Initial Position, Initial Velocity and Acceleration of the cart along the x-axis (which is *along the track*)? Note that your values, derived from the coefficients, may not correspond to your plot and accompanying data, since that will likely not start at t=0 due to your having removed the data before you released the cart and after you caught the cart. Show all your work in your report, including the graph itself. (5 pts).

Questions (25pts)

1. Which graph was the most difficult to match, and why? (5 pts) Explain why it is extremely difficult to match the pre-drawn graph *exactly*. (5 pts)

2. When the cart was going down the track, you measured its **total** acceleration, since you aimed the motion sensor in a direction along the track. What if you instead placed the motion sensor on the table near the bottom of the track (sensor set to Wide, to still track the cart during its descent), **and oriented its swivel head horizontally** (pointing along the surface of the table) - would you now be measuring a higher or lower value, and why? *Think of the components of the velocity in the horizontal and vertical directions.* (5 pts)

3. If you released with this acceleration along an infinitely long inclined track, and if you assumed that both your initial position and initial velocity were **zero**, how far would it have traveled in 10 seconds? (5 pts) 100 seconds? (5 pts)