Motion 1+2 Lab 1

Equipment: SWS, motion sensor mounted about 25 cm above lab bench, meter stick, air track+ 2 gliders, 2 wooden blocks.

Reading: Read the laminated Science Work Shop reference cards located on the table.

Air Tracks: In this experiment you will be using an air track. This is a long straight triangular like beam that has many small holes in it. A blower pumps air through the holes. A glider placed on top of the air track floats on a cushion of air with relatively little friction. The blower sits on the floor and has a switch on the top. The blowers are noisy and run hot. Run them only when you need them!

Please handle the gliders carefully. They are expensive, and if dropped or abused often do not work well. Do not move the gliders on the air track without the blower on, as this will wear both the glider and air track. If the motion sensor is used to detect the gliders, the gliders may have a piece of cardboard at one end to reflect the sonic pulses. Put the cardboard toward the motion sensor.

The Motion Sensor: The motion sensor depends on sound, and in particular on sound in air. Sound is a pressure wave that travels with a characteristic speed. For a given gas the speed of sound is proportional to the $\sqrt{T}$, where $T$ is the absolute temperature of the air. For air at 20 deg C the speed is 344 m/s. At a given position a pure tone will have sinusoidal pressure variation in time. At a given time a pure tone will have a sinusoidal pressure variation in space. Music and noise will have much more complicated temporal and spatial dependences.

The motion sensor periodically produces very short sound pulses, each pulse traveling at the speed of sound. If you were along side of the motion sensor most of the time you would not sense any pressure variations, but once a period a very short pressure pulse would pass you traveling away from the motion sensor, and before the next pulse is emitted from the motion sensor a reflected pulse, if there is one, would pass you traveling toward the motion sensor.

Like all wave phenomena, sound can be reflected (echos) and refracted (bent). The motion sensor not only sends out the pulses but also detects the reflections (echos).

The motion sensor emits short sound pulses. Each sound pulse travels away from the motion sensor at the speed of sound and spreads out in a narrow cone. The pulses are equally spaced in time, and the number of pulses emitted per unit time is called the trigger rate. The trigger rate gives the number of positions measured per second. The trigger rate can be varied from 5 to 120 Hz. The default trigger rate is 20 Hz, which means that 20 pulses are emitted per second. The pulses are ultrasonic (pressure variations that are too fast to be heard) but you can hear a click. The motion sensor also detects the reflected pulses and measures the time between the emission and reflection of a given pulse. The SWS digits display used can be programmed to give the round trip time of the pulses, distance from the motion sensor, velocity, and acceleration. What is measured is the round trip pulse time. The other quantities are calculated by SWS.

The motion sensor is a 2 plug digital sensor. The yellow plug carries the transmitted signal and is inserted into channel 1 of the interface. The black plug detects the echo and is inserted into channel 2. The maximum distance that can be measured depends on the trigger rate. The minimum distance measurable is stated in the calibration window to be 0.5 m but in fact is about 0.4 m. Some of the motion sensors have a switch which allows you to choose between a pulse emitted in a narrow or somewhat broader cone. Choose the
switch position that gives the best results.

1 Introduction

In Part 1 of this lab you will set up SWS for the motion sensor and digits display. The motion of a notebook that you move with your arms will be examined as will various aspects of the digits display. As this is the first lab using SWS the instructions will be more detailed than they will be in future labs. In this write up the instructions become less detailed further on. Please remember that the procedures used with respect to the motion sensor calibration window, digits display set up window, and input menu apply, with very little variation, to other sensors and displays.

In Part 2 of this lab a curve of position vs time and a curve of speed vs time will be presented on the computer screen. The position and speed will be that of a notebook that you move in front of the motion sensor. The motion sensor will record the position or the speed of the notebook as you move it, and the data will also be presented on the computer screen. Your task is to move the notebook so that your data follows the presented curves as closely as possible. IMPORTANT: Before doing the experiments, look at the curves and infer what motion you must impart to the notebook so that your data most closely matches the curves!

In Part 3 you will study the relationships between position ($x$), velocity ($v$), acceleration ($a$), and time ($t$). In general, $x$, $v$, and $a$ are vectors but we specialize to the one dimensional case where we may consider them as scalars. We also make the special assumption that $a$ is a constant (In general, $a$ may be a function of position and/or velocity and/or time).

2 Theory

The velocity $v$ is defined as $v = \frac{dx}{dt}$ and the acceleration as $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$. If this last definition is integrated twice for $a=\text{constant}$, the two integrations yield

$$x = x_0 + v_0 t + \frac{1}{2} a t^2, \text{ and}$$

$$v = v_0 + a t.$$

The constants $x_0$ and $v_0$ are the position and velocity when $t = 0$. The first equation is a parabola and the second a straight line. If these equations are graphed, by convention time is chosen as the horizontal axis and position and velocity as the vertical axes.

3 Part 1

3.1 Programming SWS

To program SWS for the motion sensor, in the right experiment set up window drag the digital (stereo) plug to channel 1. Click motion sensor in the dialog box that appears and then click the OK button. When the calibration window appears, calibrate the sensor by putting a notebook 1 m from the grill of the sensor and clicking the calibrate button. What is the speed of sound? Can you think of why it might vary from day to day?

In the calibration window the default trigger rate of 20 Hz is shown along with the maximum measurable distance of 8.00 m. Change the trigger rate to 120 Hz. What is now
the maximum measurable distance? Can you think of why the maximum distance depends on the trigger rate? Return the trigger rate to 20 Hz and click OK.

Note that a motion sensor icon is now below channels 1 and 2. Open a digits display by dragging the digits display icon onto the motion sensor icon. Click Position.,x(m) in the dialog box and then click the display button to produce the digits display. (The m in parentheses means the units are meters.) Note that Position(m) appear in the title bar and that icons for channel 1 and the motion sensor are on the input menu button.

Click on top of the digits display window and try the following.

• Move the digits display window by dragging the title bar.

• See if you can enlarge the digits display window by dragging an edge or a corner. You can’t, nor can you for the meter display. For all other displays you can and this is very useful for enlarging the displays.

• Click the input menu button on the digits display window. Note the arrow next to Digital 1 that indicates a submenu. Move the pointer onto Digital 1 to display the submenu. On the submenu there is a check next to Position.,x(m) which is the current input to the digits display. Move the pointer onto the submenu and click Velocity. Look at the title bar on the digits display window. Repeat the above for other items on the submenu but when through leave Position(m) on the title bar.

• Double click the display area of the digits display window to open the set up window. (Use this same procedure with other types of displays.) Without changing anything, note that the display can be programmed to give the current, maximum, or minimum value of the position, and that the number of digits to the right and left of the decimal point can be changed. Finally, put your bench number after Position(m) in the name text box and click OK. This is just practice, as the digits and meter display cannot be printed out. You will want to put your bench number on displays that can be printed out.

3.2 Measuring Position

Activate the left experiment set up window. Move the motion sensor so that it is on one side of the lab bench and about 25 cm above the bench. Then sit across the lab bench from this sensor. Place a meter stick on the bench with one end in the plane of the sensor grill, and hold a notebook in your hands. Have your partner click the REC button in the left experiment set up window and examine the digits display and meter stick while you move the notebook in the acoustic beam of the sensor. Click the STOP button when finished. Run # 1 appears in the data box. The digits display shows the last value measured.

Do you think the number of digits to the right of the decimal point is sufficient? If not, increase the number to a reasonable value (open the display set up window) and justify that value. Take another run and see how close you can get the notebook to the sensor and get reliable values.

Try deleting Run # 1 by clicking on it and pressing the delete key. You can delete more than one run at a time by dragging the pointer across more than one Run #. Don’t let too many runs accumulate.
3.3 Checking on SWS

It is a good idea to see if equipment one is using is doing what it is supposed to do. For example, if I were an MD and about to declare someone brain dead, I might well put the electrodes on my own head to be sure the machine was OK. Here we will check up on SWS. What the motion sensor actually measures is the round trip pulse time. SWS then calculates the distance. Is it doing this calculation correctly?

Set up a stationary stable reflector about 0.6 m in front of the motion sensor. Open two digits displays, one giving position and the other the round trip pulse time. Measure the position and the round trip pulse time to 3 significant figures. Use the speed of sound and the round trip pulse time to calculate the position. Compare your calculated value to the SWS calculated value as given in one of the digits displays. How do these values compare to what you get with a meter stick?

3.4 Measuring Velocity

Change the input of the digits display to velocity and take another run, seeing what happens as you move your notebook in various ways. What does a minus sign mean in the display? What does no sign mean?

3.5 Measuring Max and Min velocity

Carry out an experiment to see how fast you can move your notebook toward and away from the sensor. Hint: open the digits display set up window and examine it. Do you think the default trigger rate of 20 Hz is OK for this experiment? You can change it if you want. To do so, delete all data and double click on the motion sensor icon in the right experiment set up window. Remember that if you increase the trigger rate the maximum distance that the motion sensor will detect is reduced.

4 Part 2

4.1 The Library Experiments

SWS has a library of experiments. Two of these are included in this lab. These experiment are PO1 (short for PO1_MOT1.SWS) and PO2 (short for PO2_MOT2.SWS).

4.2 Library Experiment P01

Click File, Open, and Don’t Save. A window titled “Open a Science Workshop Document” will appear. If the file marked Library is closed open it by double clicking the icon, and then open the file marked Physics. Double click PO1 to open the Motion 1 library experiment. The 3 windows on the screen are the left experiment set up window, the graph display window, and the experiment notes window. Read the experiment notes window if you wish, but the procedures outlined below are somewhat different. Close the experiment notes window to get it out of the way. Activate the graph window and enlarge it by dragging the lower right hand corner to the lower right hand corner of the screen.

Determine the slope of the graph line as follows. Click the smart cursor button and move the smart cursor onto the graph with the mouse. Observe that the coordinates of the cursor appears in the margins of the graph. Determine the coordinates of the two break points.
in the graph and calculate the slope. You may do better by not moving the center of the cross hairs directly onto the break points. Try moving the smart cursor first to the left or right of a break point and then determine the vertical coordinate of the breakpoint with the horizontal line of the cursor. Determine a horizontal coordinate by moving the cursor above or below the breakpoint. Click to remove the smart cursor.

Taking data Now you will try and replicate the graph by moving a notebook in front of the sensor. First examine the graph and answer the following questions.

1. How close should your notebook be to the motion sensor at the beginning?
2. How far away should you move it?
3. How long should your motion last?

Examine the graph before you take data and predict what your motion should be. Press the record button to begin recording data, and press the stop button to end the recording. The motion sensor will make a quiet clicking noise when it is on. Was your prediction a good one? Do more trials and try to improve your accuracy. To print out a copy of a graph for your report, put your bench number on the title bar, click File, Print Active Display, and OK. On some benches it may be necessary to click Print All Displays.

Analysis

1. Use the built-in Statistics tools in the Graph to determine the slopes of the best fit line for the middle section of your best position vs. time plot. Click the Statistics button and then click the Autoscale button to resize the graph to fit the data.
2. Use the cursor to click-and-draw a rectangle around the middle section of your plot.
3. Click the Statistics Menu button in the Statistics area of the Graph. Select Curve Fit, Linear Fit from the Statistics Menu. The a2 term of the equation in the Stats area is the slope of the selected region of motion. The slope of this part of the position vs. time plot is the velocity during the selected region of motion.
4. Determine how well your plot of motion fits the plot that was already in the graph. Examine the total abs. diff. (total absolute difference) and the chi^2 (goodness of fit) terms from the Statistics menu.

Questions

1. In the graph, what is the slope of the line of best fit for the middle section of your plot?
2. What is the description of your motion? (Example: Constant speed for 2 sections followed by no motion for 3 seconds, etc.)

4.3 Library Experiment P02

Open experiment PO2 in the same way that you opened PO1. Do not calculate any slopes of the given graph. Again, predict your motion before taking data. You will find the graph much harder to match and will probably want to take a number of runs.
Note your position vs. time as you match the given velocity vs. time graph. Make a very rough sketch of your position vs. time. The derivative of your position vs. time curve should roughly produce the given velocity vs. time graph. (Assume the corners of the velocity vs. time curve are rounded. Your position vs. time curve is the integral of the velocity vs. time curve.) Take data by trying to replicate this graph with the same method used for P01.

Questions

1. Which direction (positive or negative) should you go at the beginning?
2. What is the maximum speed (positive or negative) you must achieve?
3. How long should your motion last?
4. How good was your prediction?
5. With respect to the motion of the notebook, does it matter how far you are from the motion sensor when you take the data, assuming that you are always within the operating range of the sensor? Discuss.

Analysis

1. Use the built-in Statistics tools in the graph to determine how well your best plot of velocity vs. time matches the velocity vs time plot that was already on the graph. Click the Statistics button and then click the Autoscale button to resize the graph to fit your data.
2. Examine the total abs. diff. (total absolute difference) and the chi^2 (goodness of fit) terms from the Statistics area.
3. For your best attempt, how well did your plot of motion fit the plot that was already in the graph?

5 Part 3

5.1 Position, Velocity, Constant Acceleration

The motion sensor is used to measure the position of a glider on a tilted air track as a function of time. If there were no friction, Newton’s 2nd law predicts that the acceleration of the glider would be \( g \cdot \sin \theta \), where \( g \) is the acceleration of gravity and \( \theta \) is the angle between the air track and the horizontal. SWS calculates the velocity and acceleration from the position vs. time data. The acceleration does not depend on the glider mass.

Level the air track by turning on the blower, putting a glider on the track, and adjusting the single screw at one end of the air track so that the glider does not move. Measure the distance between the single supporting screw at one end of the air track and the line formed by the two supporting screws at the other end of the air track. Measure the thickness of the two blocks of wood with a meter stick and then raise the end of the air track that is supported by two screws with the thinner block. Calculate \( \theta \). On a scale, measure the masses of your 2 gliders.

Program SWS for the motion sensor. You may use the default trigger rate and default speed of sound. Program SWS for the graph display, choosing position, velocity, and acceleration. Place the motion sensor near the spring bumper at the high end of the air track so
that the grill looks down the track. The motion sensor does not work for less than 0.4 m, so place an object under the air track 0.4 m from the sensor and start your gliders from that point. Turn on the blower, place the smaller glider on the track, and release the glider and click Rec at the same time. Click Stop just before the glider hits the end of the air track. Make a number of runs, making small adjustments in the orientation of the sensor until you get the best data you can. You will probably find that if the sensor points slightly up the data will be best.

For your best run, click the auto scale button and examine the three graphs in the display and discuss them. Are they what you expect and what is predicted by the theory? By inspection, are the graphs related, and if so, how? Is it reasonable that the velocity curve is noisier than the position curve, and the acceleration curve noisier than the velocity curve?

Click the statistics button and then the auto scale button. The graphs will rescale so they are not blocked by the statistics window. For the position plot choose curve fit and then power fit. For the velocity plot choose curve fit and then linear fit. For the acceleration plot choose mean. In the statistics window, y refers to the vertical axis and x to the horizontal axis. If your data points are noisy near the ends, draw boxes to exclude the noisy data but include as much good data as possible. Draw the boxes so that they all begin and end at the same times. Your boxes should be lined up vertically. For the velocity plot the acceleration is given by $a_2$. Why? In the acceleration plot the average acceleration for the data in the box is given by the mean of y. Compare this to $a_2$. Compare these values to the theoretical one. For the position plot, the notation means that $(x+a_3)^{a_4}$ is raised to the $a_4$ power. What is $a_4$? What does the theory say it should be?

\subsection{5.2 Mass and $\theta$ Dependence}
In the following experiments, use $a_2$ as a measure of the glider acceleration. Determine $a_2$ for a reasonable amount of data using the previous procedures.

Measure the acceleration for a glider of different mass for the same $\theta$. Then change the $\theta$ by substituting the thicker block and measure the acceleration for the two different masses. Compare and discuss your results. Compare to the theory.

\subsection{5.3 A Bigger Picture and Dissipation}
Do the following for only one mass and one $\theta$. Follow the procedures above except let the glider hit the end of the air track 3 times before clicking the stop button. Discuss your graphs and results. Point out where on your graphs the glider hits the end of the air track. Does the velocity curve cross the axis (velocity=0) where you expect it to? Are the curves the same from bounce to bounce? If not, could you suggest why?

\section{6 Finishing Up}
Please leave your lab bench as you found it. Thank you.