Motion at Constant Velocity

Learning Goals:

Figure 1: 1 – Dimensional Motion

1. The purpose of this lab is to study the horizontal motion of an object. Specifically, this lab focuses on the motion at constant velocity.
2. You will investigate the relationship between the motion of an object and graphs of its position and velocity versus time.
3. Students will use the PASCO Motion Sensor and PASCO CAPSTONE SOFTWARE to view the motion of the object in real time.

Materials:

Motion sensor, Pasco 850 Universal Interface, PASCO Capstone software

References:

Giancoli, Physics, 7th Edition: Chapter 2, sections 2, 3

Introduction:

When describing the motion of an object, knowing where it is relative to a reference point, how fast and in what direction it is moving, is essential. A sonar ranging device such as the Motion Sensor uses pulses of ultrasound that reflect from an object to determine the position of this object. As the object moves, its position is measured many times each second. The position of an object at a particular time can be plotted on a graph. You can also graph the velocity of the object versus time. A graph is a mathematical picture of an object's motion. For this reason, it is important to understand how to interpret graphs of position or velocity versus time. In this activity you will plot a graph in real-time, that is, as the motion is happening.

Objects can remain stationary, move at constant velocity, or move with varying velocity. If an object is stationary, and placed at a distance d_o from some reference point, then its position d is described by equation (1):

$$d = d_o \tag{1}$$

and its velocity v by equation (2):

$$v = 0 \qquad (2)$$

If an object that was originally placed at a distance d_o (d_o = starting position) from the reference point moves with a constant velocity v_o then its motion is described by the following set of equations:

$$d = v_o t + d_o \qquad (3)$$

$$v = v_o \qquad (4)$$

where t denotes time.

Detailed description of motion with varying velocity is more complex, as you will find out later in this semester; however, a quantity called average velocity can be defined for such motion in the following way: if an object moved from a position d_o to a position d_f (d_f = final position), then we can say it moved by a displacement $\Delta d = d_f - d_o$ in the time interval $\Delta t = t_f - t_o$, and the average velocity v_{ave} is defined as

$$v_{\text{ave}} = \frac{\Delta d}{\Delta t} \qquad (5)$$

In the case of motion in one direction the average velocity is equal to the average speed.
The actual or instantaneous speed can vary from moment to moment; e.g., your car can stop and go as you pass through intersections, but if you travelled 50 miles in 1 hour, you know your **average** speed was 50 miles per hour, no matter how fast or slow you were going at any particular time.

If an object moves with a constant velocity v_o, then its instantaneous velocity at any moment and its average velocity will also be equal to v_o.

Equation (3) is an example of a linear equation. In general, a linear relation is defined by the equation

$$y = mx + b \qquad (6)$$

where m is the slope and b is the y-intercept.

Equation (4) is an example of a constant equation as the velocity doesn't change with time. In general, a constant relation is defined by the equation

$$y = \text{constant} \qquad (7)$$

Experiment

The experiment consists of several parts. First you will be introduced to the PASCO data acquisition interface and its software. This is a very important part of the lab, designed to acquaint you with

some equipment which you will use throughout this course. In this part you will not be taking any data.
Open **Capstone** and look at its main components. Double-click on the **Capstone** icon on the desktop. You will see the following options:

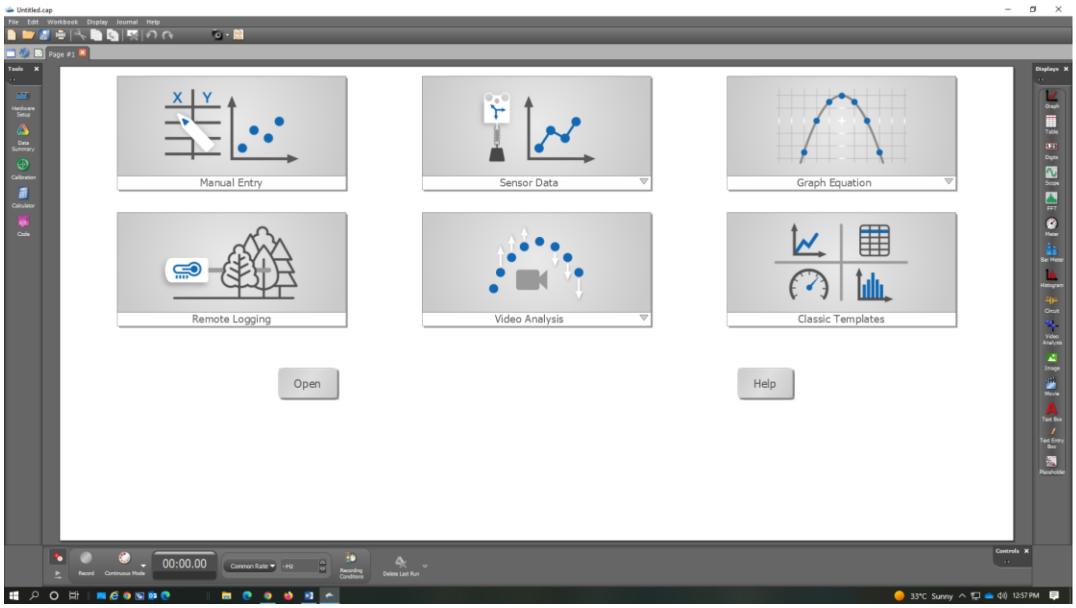

Figure 2: Capstone "Welcome Window"

Click on "Classic Templates". A new window opens up. Explore the different buttons in the window menu and the display and tools palettes.

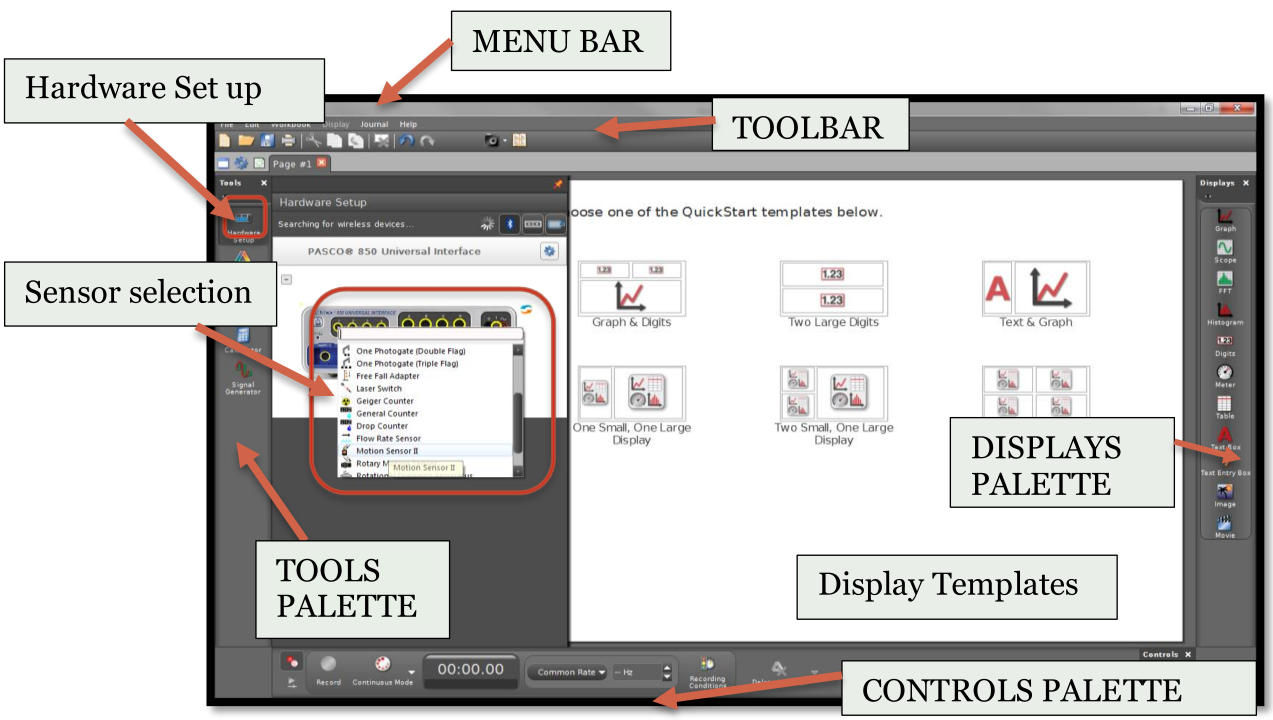

Figure 3: 1 – PASCO Capstone "Classic Templates"

Notice the three areas: **'Tools'**, **'Controls'**, and **'Displays'**. The **'Hardware Setup'** is where you will choose the sensors used in a particular experiment. At the bottom, in the **"Controls Palette"** you will adjust the data acquisition rate. Then, by pressing **'RECORD'**, the second button from the left in the "**Controls Palette**" data will begin to be taken. Each time the **'RECORD'** button is pressed a new **'Run'** will appear in the **'Data Summary'** window in the **"Tools Palette".** To stop the data collection, press the **'RECORD'** button again.

In the **"Displays Palette"** you can choose the right display for your data. Explore the different display options.

More than one run can be displayed in one graph. Using the data summary icon on top of the graph you can choose the runs you want to be displayed. Sometimes you need to remove some data from the graph. Select the data you wish to remove by clicking on the 'highlight' icon in the menu above the graph. Resize the rectangle so that only the data you want to remove are highlighted. Right click the selected area and select **"Deletions."**

Sometimes we want to view two or more different plots on one graph, e.g. position versus time and velocity versus time. This can be accomplished by first creating one plot, e.g. a position versus time, then adding the second one by clicking on the small icon on the toolbar of the **'Graph'** window, showing a coordinate system. By pulling it to the bottom half of the first plot you can create a second plot, e.g. for velocity vs. time.

In order to accurately read the coordinates of a point from the graph you can use the **'Smart Tool'**, which is also located on the toolbar of the **'Graph'** window. It will give you much more precise coordinates of a given point on your plot than you can get by eye.

To analyze the data, we will frequently need to fit it with a particular function. First you need to select the range of data which you wish to fit (not all collected data will always be good or interesting). To do this use the mouse to click-and-draw a rectangle around the section of your plot that contains the data to be fitted. The selected data should now be highlighted in yellow. Next, in the **'Graph'** window select the **'Fit'** button, and then from a pull-down menu select the type of relation you want to fit your data with. A window will appear with the results of the fit: the type of function, the values of the fitted parameters in it, and the statistics which tell us how good or bad our fit was.

Data Collection and Analysis:

Part 1: Motion at constant speed

Activity 1:

1. In the '**TOOLS PALETTE'** double-click the PASCO Interface icon **'Hardware Setup'**, then choose the port where you want to connect your sensor, click on it and choose motion sensor II from the drop-down menu. In the **'CONTROLS PALETTE'** adjust the sample rate to 40 Hz. Choose a graph plus table display from the templates.

2. Create plots of position vs. time and velocity vs. time on one graph. Click on **"Select measurements"** in both table and graph and choose time for x-axis and position for y-axis. Add a second display and choose time for x-axis and velocity for y-axis.

3. Position the **Motion Sensor** so that it is aimed at your midsection when you are standing in front it. Make sure that you are more than 15 cm away from the sensor and that you can move at least 2 meters away from the motion sensor without running into any obstacles.

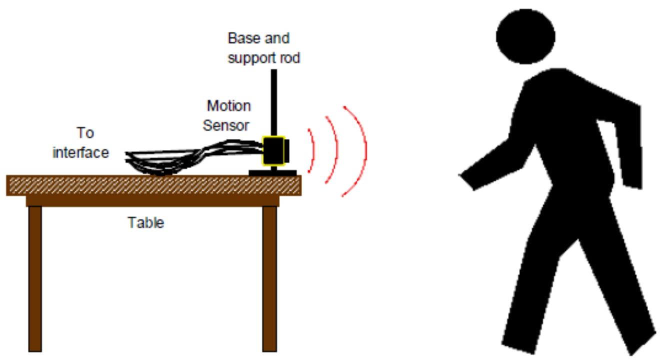

Figure 4: 1 – Experiment

4. Click the **'RECORD'** button to begin recording data. (Data recording will begin almost immediately. The motion sensor will make a faint clicking noise.)

5. Walk away from the motion sensor until you cannot walk any further. Practice walking at an even pace so that the plot of your motion on the computer screen shows a smooth straight line.

6. Stop taking data.

7. Repeat the data recording process a second and a third time. Select the data run that gives the smoothest (i.e. least bumpy) graph as you move away from the motion sensor. Delete the other runs and analyse the best run as described below. Save your data – computers crash frequently.

Activity 2:

1. Repeat procedure 1 starting with step 3 but walk considerable faster than you did before.

2. Plot position vs. time and velocity vs. time.

3. Determine the slope of the position.

Activity 3:

1. Now position yourself as far from the detector as you can. Repeat procedure 1 starting with step 4 while walking towards the detector with constant speed.

2. Create new graphs of position vs. time and velocity vs. time.

3. Determine the slope of the position graph.

Analysis:

1. From the **Fit** menu select **Linear Fit** to display the slope of the selected region of your position vs. time plot. The **"m"** term of the equation in the **Linear Fit** window is the slope fitted for the selected range of motion. The slope of this part of the position vs. time plot is the velocity during the selected region of motion.

   What was your average speed based on this fit?

2. Parameter *r* is a statistical quantity which tells us how well the fitted line describes the actual data points. The closer its value is to 1 (or -1 for negative slope), the better match exists between the fitted line and the experimental data, i.e. the data points lay closer to the fitted line.

   Record the value of parameter "r" from the Linear Fit window.
   Determine if your fit is good or not.

3. Use the mouse to click-and-draw a rectangle around the section of your plot where you are moving away from the detector at constant speed. This is the part of the data you'll be analysing. Study this portion of the position versus time plot, and use **Smart Tool** (located in the top toolbar of your graph window) to determine the following:

   a. *What are the coordinates of the first highlighted data point?*
   What was your distance d_o from the motion sensor at that time?
   Record t_o and d_o in your report.

   b. *What are the coordinates of the <u>last</u> highlighted data point?*
   What was your distance d_f from the motion sensor at that time?
   Record t_f and d_f in your report.

   c. *Find differences $\Delta t = t_f - t_o$ and $\Delta d = d_f - d_o$ and record them in the report.*

   d. Determine v_{ave} from the graph in Capstone. Use the highlighter to select the data for our time period of interest and then use the **"Statistics"** button to find the mean value of the velocity during this time period.
   Is this value roughly in agreement with the average velocity obtained from the differences of position and time in (c)? Calculate the percent difference.

4. Now export the data to Excel. It is better to copy the data table of your best "run" into Excel. If you export the data you export "all" data from all runs to Excel.

   For the part of your data corresponding to the period through which you moved at constant speed calculate your average speed v_{ave} using equation (5) and determine the standard deviation.

   Compare this value with the value of v_{ave} you have calculated in Capstone. Are the two values in agreement? What does it mean?

5. Look at the corresponding velocity vs. time plot.

   a. Was your speed indeed constant?
   b. Was your instantaneous speed always the same as your average speed?

6. Repeat the above analysis for procedure 2 and 3.

   Discuss how the slope in the position vs. time plot changes depending on how fast you walked, and why.

Part 2: Investigating motion

In **Part 1** you were told to move in a certain way and observe the resulting graphs of your motion produced by PASCO CAPSTONE on the computer. In this part we will reverse the process: in figure 5 you will find a plot of position versus time. Your task is now to move in such way in front of the **Motion Sensor** so as to reproduce the graph. The graph in figure 5 deliberately lacks a scale since you are only required to reproduce the general shape and not specific values.

Copy your plot which resembles the graph in figures 5 most closely into your report.

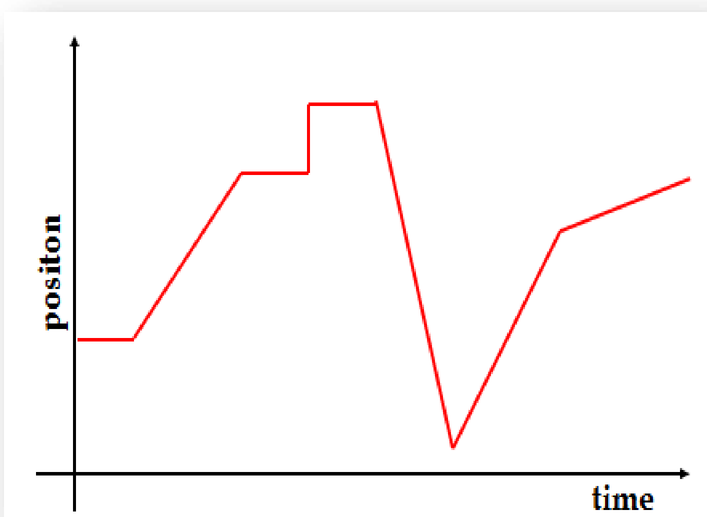

Figure 5: Motion Graph