Computer Tools for Data Acquisition

Introduction to DataStudio

You will be using a computer to assist in taking and analyzing data throughout this course. The software, called DataStudio, is made specifically to work with the black interface boxes (PASCO Scientific's Science Workshop 750 Interface) connected to your computer. This interface can accept up to four digital inputs, the four receptacles on the front left (numbered 1-4), and up to three analog inputs, the three receptacles on the front right (labeled A, B, and C).

A digital input essentially detects either a "1" or "0". In other words it can detect whether something is "on" or "off." For compatibility with the integrated circuits inside the box, an electrical voltage of zero volts represents the "off" state and a voltage of 5 volts represents the "on" state. For example, a photogate consisting of an infrared light source in one arm and an infrared light detector in the other arm gives a zero volt output to the computer when something blocks the beam and gives a 5 volt output when the beam is unblocked. This allows the computer to time objects as they pass through the gate. For the study of motion, timing is an important tool, so most of the sensors that we plug into the interface will be of this digital nature.

The analog inputs detect electrical voltages between +10 volts and –10 volts. Thus the study of electrical circuits can be done directly since the signals are already electrical in nature. Other sensors can be constructed to convert forces, pressures, temperatures, etc., into electrical voltages. These kinds of sensors also use the analog inputs. If the computer software knows the relationship between the quantity of interest, say pressure, and the electrical voltage produced by the sensor, then the computer can display the pressure directly rather than simply displaying the voltage.

The DataStudio software assumes that you are working in SI units (meters, kilograms, seconds, and coulombs). Any numbers that you enter are assumed to be in these units, so convert any values to SI units before entering them into the program.

Setting up a new experiment

Make sure that the Science Workshop 750 Interface (SW 750, housed in a black box) is turned on. The on-off switch is located on the right rear of the box. When the power is on, a small green light should be glowing on the far left side of the front panel. (NOTE: The computers will not recognize the some of the SW 750 interface units if the interface is turned on after the computer has booted up. Restarting the computer will solve this problem. Interfaces that are connected to the computers via USB ports don't have this idiosyncrasy.)

The icon for the DataStudio software should be present on the left side of the desktop (the default screen when the computer is first turned on) when the log-in process is complete. Start the DataStudio software by finding and clicking on the DataStudio icon on the desktop of the computer. When DataStudio loads, a screen asking you what you want to do appears. Click on the “Create Experiment” option. If for some reason the software did not find the interface, it will give you a message to that effect. If necessary have the software scan again to find the interface or restart the computer after checking to make sure that the interface is turned on. An “Experiment Setup” screen should appear with a picture of the SW 750 interface when the interface is recognized and all is well.

If you have been using DataStudio and want to start over, clicking on “New Activity” from the drop-down menu under “File” allows you to start a new experiment with DataStudio. The Experiment Setup window should open automatically.

Choosing a sensor or sensors

Now you must choose the appropriate sensor to use for the particular exercise at hand. Usually the required sensors are provided along with the apparatus for the day’s exercises. Sensors come in two varieties, digital and analog. By looking at the connector on a sensor and comparing it to the digital and analog input receptacles on the front of the interface, one can easily determine whether it is an analog or digital sensor. Most sensors have only one connecting cable to the interface, but the rotary motion sensor and the ultrasonic motion sensor (described below) have two cables to be connected to adjacent digital inputs on the interface. Multiple sensors are also used in some experiments. Plug the connecting cable(s) from the sensor(s) into the interface. If you are using multiple sensors, this must be done in a thoughtful way so that you know what each sensor will be measuring.

Setting up DataStudio for your sensor

So far you have made all the necessary hardware connections. Now you must tell DataStudio, the software package, what sensor(s) you have connected and what quantities you wish to measure/observe with each sensor, since one sensor may be able to “measure” directly or indirectly a number of different variables such as position, velocity, and acceleration. On the computer monitor make sure that you see the “Setup” screen that shows a picture of the SW 750 interface with yellow circles around each input jack. If this screen is not displayed, find “Setup” on the tool bar at the upper left of the DataStudio window and click on it. If, for example, you have connected a digital sensor to digital Channel 1, move the cursor within the yellow circle surrounding the Channel 1 input and click it. This reveals an alphabetical list of all currently compatible digital sensors. Some of them have special names. If all else fails, look on the sensor itself for the name and match it with the appropriate name on the list. Move the cursor to the name of the sensor of choice, highlight it, and click OK. The software should now display the chosen sensor connected to Channel 1 along with a setup window specifically for that sensor. Change the default settings as necessary for your particular experiment. Also adjust the sampling rate that tells the computer how often to take a reading, or other quantities that are specific to your apparatus. The first time you use a new sensor, explore this window carefully to make sure that you understand the possible options. Analog sensors are set up in a similar fashion.

Displaying data

On the left side of the DataStudio window you will see a list of “Data,” that is, the quantities you have chosen in the setup phase to measure or were the default settings of the sensors that you picked. If the “Data” list is not correct, go back to the setup windows for the sensors and make the necessary adjustments. When you are satisfied with the “Data” list, you must choose how you wish each quantity to be displayed. The lower left corner of the window lists the options for possible “Displays.” The two most commonly used Displays are Graph and Table. For instance, if you wish to display the data for Position (under the “Data” list) as a graph, place your cursor on the word “Position” and drag and drop it onto “Graph”. If this is the first graph you have chosen, you will see “Graph 1” displayed subordinately to Graph. If you drag and drop another quantity to Graph 1, they will be displayed in the same window with a common horizontal time scale. Dragging and dropping another quantity simply to Graph will open Graph 2 in another window. Both formats can be useful.

Printing graphs

Before printing out a graph make sure that the horizontal and vertical scales are adjusted to show the data of interest in as large a format as possible. DataStudio allows you to adjust both scales arbitrarily. Moving the cursor to one of the numbers along the horizontal scale causes it to morph into “a spring with an arrow on each end.” Click and drag the cursor and the scale expands or contracts. The vertical axis can be adjusted in a similar fashion. You can move the whole x and y axes horizontally or vertically by moving the cursor over one of the axis lines until it morphs into a small hand. Clicking and dragging now allows you to adjust the position of the axes horizontally and vertically to give the best presentation of the desired data. Printing graphs in the “landscape” format is usually preferred to the “portrait” format since the long edge of the graph is printed along the long dimension of the paper—filling the sheet more efficiently and making the graph bigger. Unfortunately “portrait” is the default setting. The “Print” command is in the drop-down menu under “File” on the very top left hand corner of the main DataStudio window. “Print Setup” on the same drop-down menu can be used to specify the “landscape” format. It will be there somewhere, but the exact location is printer dependent. If it is not readily apparent, choose the printer “properties” tab and you should be able to find it under the options available in that window.

Uncertainty analysis with DataStudio

The mean, x_{avg}, and standard deviation, $\sigma(x)$, of a set of data are easily computed from tables and graphs. (On graphs, you can highlight the data you want to average with the cursor.) Click on the down arrow just to the right of the Σ on the toolbars at the tops of the graph and table windows to calculate means and standard deviations. In DataStudio and Excel, it is important to distinguish between the standard deviation of your data, $\sigma(x)$, and the standard deviation of the mean, $\sigma(x_{avg})$, which represents the uncertainty in x_{avg}. These are defined in the Uncertainty/Graphical Analysis Supplement to the lab manual. The standard deviation function in DataStudio and Excel returns $\sigma(x)$, the standard deviation of the selected data. To calculate the uncertainty in x_{avg}, you must divide $\sigma(x)$ by the $\sqrt{N}$, where N is the number of selected data points. The "Count" function in the Σ menu gives N, which you can use to compute $\sigma(x_{avg})$.

Linear "least squares fits" to graphical data (along with more complicated fits) are easily done. If you wish to fit only part of the data, first highlight the data you want to fit. For a linear fit, the software displays a box showing the slope and intercept of the linear equation along with standard errors of the slope and the intercept values. The standard error corresponds to $\sigma(x_{avg})$. You can find these options in the toolbars for the graph and table windows themselves. General curve fits to data, including linear fits, are chosen by clicking the "Fit" box on the graph toolbar.

More details for specific sensors

Motion sensor (ultrasonic, digital)

Plug the leads from the motion sensor into the SW 750 using digital Channels 1 and 2. Note: Any two adjacent digital channels will work for the motion sensor. The motion sensor sends out a short high-frequency pulse of sound waves at about the limit of human hearing and measures the time for the echo to return. Thus position, velocity, and acceleration can be computed with that information. The sampling rate for the motion sensor is limited to 50 Hz or to 50 readings per second. You may need to adjust this rate from the default setting of 10 Hz to optimize the data collected for your particular experiment. Don't hesitate to experiment a little to determine the best setting. Position, velocity, and acceleration are the default data quantities. Deselect any unneeded ones on the Setup window for the motion sensor. Then choose your mode of displaying the data by dragging and dropping. Graphs are by far the most common display for this sensor. Positions $\lesssim$ 0.4 m and $\gtrsim$ 4 m cannot be measured by the device. At small distances the echo returns too quickly to be measured reliably while at large distances the echo is too weak. Relatively smooth, flat surfaces make better reflectors of sound. Beware of stationary objects close to your experiment that may reflect the sound waves and give you spurious results.

Rotary motion sensor (digital)

Plug the leads from the rotary motion sensor (RMS) into the SW 750 using Channels 1 and 2. Any two adjacent digital channels will work for the RMS. Note which channel is connected to the yellow input connector. Internally this sensor consists of two photogates. You can get a brief explanation of how it works at http:// www.sxlist.com/techref/io/sensor/pos/enc/quadrature.htm. You need to tell DataStudio that the rotary motion sensor is connected to the SW 750, what quantity is to be measured with the sensor, and how you want the resulting data displayed.

Click on one of the digital input channels outlined in yellow as shown in this window. A list of digital sensors will be displayed. Find the RMS in the sensor list. Highlight it by clicking on it with the cursor and hit OK. The RMS should now be displayed in the Experiment Setup window as connected to the SW 750 interface. The Sensor Properties are shown in the bottom half of the window. Under the measurement headings you find a list of all the measurements that the Rotary Motion Sensor can make for you. The default choice is the angular position in degrees. To measure position, velocity, and acceleration the software assumes that you are passing a string over a pulley placed on the shaft of the rotary motion sensor and then measuring the position, velocity, and acceleration of some point on the string. For a particular rotation rate of the sensor shaft, the string passing over a large radius pulley will be moving much faster than one over a small radius pulley. Thus the circumference of the pulley must be chosen as the “Linear Scale” under the “Rotary Motion Sensor” tab. If the standard black PASCO pulley is used, then you can choose “Large Pulley (groove),” “Med Pulley (groove),” or “Small Pulley (groove),” and the correct circumference will automatically be inserted in the “distance for one full rotation” box. For testing purposes connect the RMS to Channels 1 and 2, and check the boxes under the “Measurement” tab for “Angular Position, Ch 1&2 (deg)” and “Angular Velocity, Ch 1&2 (deg)” so they appear in the “Data” window at the upper left side of the screen. Click and drag “Angular Position, Ch 1&2 (deg)” down to Graph in the display menu at the lower left side of the screen. Then click and drag “Angular Velocity, Ch 1&2 (deg/s)” down to Graph 1 in the display menu. This should make both graphs appear in the same window. (Note: If you drag both data items simply to Graph in the display menu, then the graphs will appear in separate windows. There may be times when you want it that way.)

Click on the “Start” button and spin the shaft of the rotary motion sensor. After a few seconds click the “Stop” button. Since the computer arbitrarily set the scales of the graphs, the displayed data may be too small or too large. Once the data is taken, DataStudio can change the scale of the graphs to have the data fill the available space. The “Scale to Fit” feature must be applied to each graph separately. Click anywhere on the graph to highlight it with a line box around it. Then click on the “Scale to fit” icon on the far left in the toolbar at the top of the graph window or adjust the horizontal axis and vertical axis scales separately as discussed previously. When the scaling is complete, you can print out the graphs. Be sure that the graph window is highlighted so that’s what gets printed. If you reverse the direction of rotation of the sensor shaft, the signs (+, –) of the angular position and angular velocity change. Interchanging the input leads that are plugged into Channels 1 and 2 also changes the signs of these measured quantities. This feature allows you to choose the positive vertical axis for any experiment that you do.

Photogate (infrared so you won’t see the light!)—digital

Plug the “Accessory Photogate” into one of the four digital channel receptacles, say Channel 1. Make sure that the plug is inserted all the way into the receptacle. The photogate consists of an infrared light source in one arm and an infrared light detector in the other arm. It outputs zero volts to the computer when something blocks the beam and 5 volts when the beam is unblocked. Now that the hardware is connected, you need to inform the software what is connected to the interface. If the Experiment Setup window is already displayed, click on Channel 1 to display a list of digital sensors. If the Experiment Setup window is not displayed, click on Setup shown at the upper left side of the main DataStudio window. Scroll down through these until you find “photogate.” Highlight “photogate” and click OK. If done successfully, you should see a picture of the photogate connected to the chosen digital channel. Note that there are two other sensor choices with specialized photogate uses which are useful in some applications.

The software now understands that a photogate is connected to Channel 1, but does not know what you want to measure. Click on one or more of the “measurements” displayed in the lower left side of the Experiment Setup window. If you click on the box by the word, “Velocity (m/s),” then you must also set the “constant” value (the default is 0.050 m) to match the size of the object passing through the beam. If the object size and the “constant” value don’t match, then displayed velocities will differ from the true velocities by a constant scale factor. The “Time in Gate” is just the length of time that the light beam is blocked and is displayed in seconds.

To take some test data find a pen or pencil, click on the “Start” button near the top left of the screen, pass the pen or pencil back and forth through the photogate a few times, then click the “Stop” button that appeared where the “Start” button had been. Click and drag the data measurements shown in the upper left of the DataStudio window down to a single table for display purposes. The table now displays some times along with voltages or time intervals or velocities depending on what measurements you chose.

When you activate the “Start” button, an internal clock is started. When the light beam is blocked or unblocked, the time when it is blocked or unblocked is recorded relative to the arbitrary “zero time” point when you hit the “Start” button. If necessary, repeat the data collection process to aid in clarifying any of the details. Notice that the second set of data is simply named “Run #2.”

If you wish to determine the velocity of your pencil as it passes through the photogate, enter the diameter of the pencil (in meters) as the “constant” in the photogate setup window, uncheck the “State, Ch# (V)” and “Time in Gate (s)” measurements, and check the “Velocity (m/s)” measurement. Drag the velocity measurement from the Data section at the upper left side of the screen down to the Table display. Hit the “Start” button and you should now see velocity values displayed along with a column of times. If you include the state voltages on the same table, you can figure out where the times that are displayed actually come from. The “State, Ch# (V)” records a “state voltage” of 0 volts at the instant the infrared light beam is blocked by some object starting to pass through the photogate and records a “state voltage” of 5 volts at the instant the light beam is unblocked as the object moves out of the photogate. The corresponding times for the transitions from an unblocked to a blocked state and vice versa are also displayed. These times are measured from the instant that you hit the “Start” button. In and of themselves these times are not very useful because the zero starting point is arbitrary, but taking differences in these time readings can tell us how long an object blocked the beam as it was passing through.

You can connect a photogate to any of the four digital channels of the SW 750 interface and they will work just the same.

Smart pulley (digital)

The Smart Pulley is just a photogate in conjunction with a pulley, thus it is plugged into one of the digital inputs like a photogate. As the pulley turns, the spokes of the pulley successively block and unblock the light beam from the photogate. The Smart Pulley can be used much like the Rotary Motion Sensor, but with one serious limitation. The Smart Pulley has no way of determining which direction the pulley is rotating, so distances are always considered to be positive. If the motion that we want to monitor only occurs in one direction, this limitation poses no problems. The software knows the circumference of the pulley and can compute position, velocity, and acceleration as a string passes over the pulley and turns it. Angular quantities can also be measured. In the sensor properties window for the smart pulley you can choose which measurements you wish to make. Then these quantities can be graphed, displayed in a table, or whatever.

Force sensor (analog)

The “Force Sensor” [not “Force Sensor (student)”] must be plugged into one of the analog Channels, A, B, or C. In the “Experiment Setup” window click on one of the analog channels outlined in yellow to display a list of analog sensors, and choose the “Force Sensor.” The default measurement of the sensor is force in newtons. The data from the sensor is usually most useful when shown in a table. In the sensor properties window you can change the “sampling rate,” that is, how often the computer reads the output of the force sensor. The default sampling rate is 10 Hz, or 10 times a second. For some applications, this can be reduced to 1 Hz, or one reading each second. It is necessary to “zero” the sensor by pushing the small tare button located on the side of the sensor. This is exactly analogous to zeroing an electronic balance before weighing something. It is good practice to make sure that the force sensor reading is really zero after pushing the tare button by clicking the “Start” button and looking at the resulting data table. You will notice that the force value is not exactly zero, but varies a bit. This is normal. These variations will also be present if a mass is suspended from the sensor. So, what is the “real” value of the force? Answering this question will introduce you to some of the data analysis options available with the DataStudio software.

If we measure something multiple times but get slightly different answers each time, then the average value or “mean” value comes to mind as the “best value.” When using a mean value, it is important that each time the measurement is made nothing significantly changes. In other words the conditions under which the measurements are made must remain essentially unchanged. As long as the hanging mass is not swinging or something, the conditions are unchanged. One question remains, how precise is the mean value that we have? That is, how large are the variations from the mean value? Statistically speaking, the “standard deviation of the mean” is a measure of this variation. You can read more about how these quantities are defined and used in the “Uncertainty Analysis Using DataStudio” section earlier in this document.

The standard deviation of the mean is a useful estimate of the uncertainty of the average value of x. Throughout this course the standard deviation of the mean will play this role, and you will have occasion to use it again and again. On the toolbar in the Table window, look for the Greek symbol Σ that is the icon used for statistics by the software. Clicking on the down arrow just to the right of the Σ opens a drop-down menu that includes mean and standard deviation. Clicking on each one causes it to be displayed at the bottom of the table for your data. If you need to display more digits for the mean value and standard deviation to minimize round-off errors, you can increase the number of digits displayed by clicking on the down arrow of the right-most icon of the toolbar at the top of the Table window and clicking on “increase precision.” This procedure adds one more digit to the right of the decimal point in all the columns displayed. Repeat the procedure to add more digits to the right of the decimal. A “decrease precision” option is also available if necessary. To calculate the standard deviation of the mean from the standard deviation, divide the standard deviation by the square root of N, the number of measurements. DataStudio will display N if you also select the “Count” function under the Σ menu.

Voltage sensor (analog)

The Voltage Sensor is simply two wires with a special plug that connects from the circuit of interest to one of the analog Channels A, B, or C of the SW750 interface. The interface then serves as a voltmeter. The voltage can then be observed using various displays. If the voltage remains constant with time, using the "meter," "digits," or "table" display may serve you well. For voltages that vary with time the "graph" or "scope" display may be more useful. The "graph" display is often best for a one-time event where the voltage varies with time. For repetitive voltage signals, that is, those that repeat in time, the "scope" display is very useful.

Geiger counter (digital)

The Geiger Counter is useful for detecting certain types of radiation, including beta particles and gamma rays. An AC line cord must be connected to a regular electrical outlet to run the electronics inside the device. Then the other connecting cable is inserted into one of the digital input channels.

The device can be controlled to count for a specified length of time, then record the number of counts, then repeat the process for as many times as you like, before stopping. The sampling rate adjusts the length of time for each individual counting period. The "Sampling Options" on the toolbar at the top of the Geiger counter setup window allow you to set a total length of time after which it takes no more data. Of course, the total time must be longer than the sampling time for this to work correctly.

The resulting data is often displayed in the form of a histogram or table. Drag and drop "Geiger counts" from the data list down to the display of your choice.