Computer Tools for Data Acquisition

Introduction to Capstone

You will be using a computer to assist in taking and analyzing data throughout this course. The software, called Capstone, is made specifically to work with the interface unit connected to your computer. This may be either the black PASCO Scientific Science Workshop 750 Interface, or the blue and gray PASCO 850 Universal Interface. These interface units can accept up to four digital inputs (the four receptacles on the front left, numbered 1–4), and at least 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 consists of an infrared light source in one arm and an infrared light detector in the other arm, and sends a zero volt signal to the computer when something blocks the beam and sends a 5 volt signal 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 electrical circuits can be monitored 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 Capstone 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 interface unit connected to your computer is turned on. The on-off switch is located on the right rear of the ScienceWorkshop 750 (SW 750) units and on the left front of the 850 Universal Interface (850 UI) units. When the power is on, a small green light should be glowing on the far left side of the front panel. (Note: SW 750 interface units connected to the computer with USB adaptors are not recognized by the computer if the interface is turned on after the computer has booted up. Restarting the computer will solve this problem. Interface units that do not need special USB adaptors don't have this idiosyncrasy.)

The icon for the Capstone 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 Capstone software by finding and clicking on the Capstone icon on the desktop of the computer. When Capstone loads, the display screen appears. Use the Tools Palette on the left hand side of the Display Area to set up the sensors for your experiment and the Display Palette on the right hand side of the Display Area to set up your data display. Both palettes can hidden or rendered visible using the Workbook menu at the top of the screen.

Click on the uppermost icon in the Tools Palette is a picture of a 850 UI unit, labeled "Hardware Setup". If for some reason the software did not find the interface, a yellow warning triangle will appear along with a message to that effect. If you get this message, check the USB connection and make sure the interface unit is powered up. Then have the software scan again for the interface. Interface units with USB adaptors will also require you to restart the computer. The Hardware Setup screen should appear with a picture of your interface unit when the interface is recognized and all is well.

Choosing a sensor or sensors

Now you must choose the appropriate sensor(s) to use for your particular experiment. 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 Capstone for your sensor

After connecting the hardware, you must tell Capstone software which sensor(s) you have connected. On the computer monitor make sure that you see the "Hardware Setup" screen with a picture of your interface unit. Yellow circles will mark the position of each input and output jack. 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. The more complex sensors are labeled with their names. 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. You may have to edit settings that are specific to your sensor using the Properties window, which can be opened by clicking on the word "Properties" to the right and below the picture of your interface unit. For instance, the resolution of some sensors can be changed in the Properties window.

Analog sensors are set up in a similar fashion. You will often need to adjust the sampling rate—how often to take a reading. The sampling rate can be adjusted using the Controls Palette below the Display Area.

To exit the Hardware Setup screen, click again on the 850 UI icon. You can return to the Hardware Setup screen at any time to make changes.

Displaying data

The two most commonly used displays are Graph and Table. For instance, if you wish to graph you data, drag the Graph icon from the Display Palette into the Display Area. A graph will appear that fills the entire Display Area.

Below the horizontal axis is a <Select Measurement> button. Clicking on this will bring up a list of quantities that can be plotted on the horizontal axis. A similar button on the vertical axis allows you to choose the quantity to be plotted on the vertical axis. Only the quantities available for the sensors you have set up are shown. (Some of the options are calculated from the data reported by your sensor. For instance, velocity and acceleration values can be calculated from position measurements from a motion sensor.) Capstone will provide the appropriate axis labels, showing the quantity followed by the SI abbreviation for its units in parentheses. These labels are required for all graphs, whether they are drawn from Capstone or not. If you use other software or draw a graph by hand, you will have to manually provide these labels.

To plot more than one graph in the same Display Area, click on the "Add new plot area to the Graph display" icon along the top of the graph. These graphs will have the same horizontal axes, but different vertical axes. To plot a second quantity with the same units using the same horizontal axis, but with the y-axis values listed on the right hand side of the graph, click on the "Add new y-axis to the active plot area" icon along the top of the graph. Finally, to plot a second quantity using the same horizontal and vertical axis, click on the vertical axis label button and choose "Add similar measurement" from the menu that appears. A list of the available similar measurements (for instance, potential energy in a graph of kinetic energy versus time) will appear. Choose the quantity to be plotted from the list. Each of these formats will prove useful.

All graphs should have titles. In Capstone, the title can be typed into the lower left hand corner of the Display Area, to replace the text "[Graph title here]". If you forget to type the title in, you can print the title across the top of your graph by hand. Similarly, horizontal and vertical axes labels may be printed by hand if they are not provided by the software.

Preparing graphs for printing

Graphs can be extremely useful device for displaying the results of an experiment. However, much of their value is lost if certain mistakes are made. Without titles or axes labels, the reader will not know what is plotted. Graphs that are too small, or are dominated by data that is irrelevant to the goal of the experiment, are almost useless. For lab notes, certain information must be recorded directly on the graph. For instance, the results of curve fitting procedures should be noted on the graph along with their uncertainties; you should also indicate on the graph which data were included in the curve fitting process. Observations about the plotted data—especially comments about relationships between plotted quantities, are much more clear if they are written on the graph itself. For instance, a vertical line can show that the minimum of one quantity coincides with the the maximum of another quantity. To make room for these notes, the important parts of your data must be plotted in as large a format as possible.

Before printing 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. Capstone allows you to adjust both scales arbitrarily. When the cursor is moved over one of the numbers along the horizontal scale, it morphs 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.

The data in most graphs occupies a larger portion of the page if printed in the "landscape" format, as opposed to the "portrait" format, since the long edge of the graph is printed along the long dimension of the paper. This fills the sheet more efficiently and makes 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 Capstone window. "Print Page 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.

Full credit will not be awarded for graphs without a title or where labels are missing. Graphs that are smaller than necessary or include a lot of unnecessary data will also not receive full credit. In lab notes, graphs with curve fits will not receive full credit unless they include the results of the curve fit(s), their uncertainty, and a clear indication of which data were included in the curve fit.

Uncertainty analysis with Capstone

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 Capstone 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 Capstone 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.

"Least squares fits" to graphical data are easily done. If you wish to fit only part of the data, first select the data you want to fit using the "Highlight range of points in active data" tool (icon with yellow pencil and blue dots) above the Display Area. For a linear fit, select "Linear: y = mt+b" from the "Apply selected curve fits to active data" tool (icon with red line and blue points) above the Display Area. 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 $\sigma(x_{avg})$.

Changing data precision in Capstone

Although Caption acquires and stores data at the maximum precision provided by the sensor, the precision of values in tables and graphs is often lower. When the least significant figure of the displayed data (or the least significant figure of a value determined from a curve fit) is larger than the indicated uncertainty, you need more precise data in the display. To increase the precision, select the graph or table with the data and click on the "Data Summary" icon in the Tools Palette on the left side of the screen. The Data Summary window displays a list of your data. Select the data you wish to modify, then click on the gear icon to its right. From the Properties window that opens, click on the "Numerical Format" tab and adjust the number of decimal places in the text entry box.

More details for specific sensors

Motion sensor (ultrasonic, digital)

Plug the leads from the motion sensor into the digital Channels 1 and 2 of the interface unit. Any two adjacent digital channels will work for the motion sensor, but the yellow plug must be to the left of the black plug. In the Hardware Setup window, assign the motion sensor to the input channel with the yellow-banded plug. 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 20 Hz to optimize the data collected for your particular experiment. The sampling rate is set in the Control Palette along the bottom of the Display Area. Don't hesitate to experiment a little to determine the best setting. Position, velocity, and acceleration are the default data quantities. Graphs are by far the most common display for this sensor. Objects less than 0.4 m (0.25 m for the newer model) or more than 4 m from the motion sensor are not reliably detected. 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 Channels 1 and 2 (digital) of the interface unit. Any two adjacent digital channels will work for the RMS, but the yellow plug must be to the left of the black plug. 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 Capstone that the rotary motion sensor is connected to the interface unit, what quantity is to be measured with the sensor, and how you want the resulting data displayed.

On the image of the interface unit in the Hardware Setup window, click on the digital input channel with the yellow plug. 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 Hardware Setup window as connected to the interface. Click on the Properties button along the bottom half of the window. To measure position, velocity, and acceleration the software assumes that you are passing a string over a pulley on the shaft of the rotary motion sensor, and that the position, velocity, and acceleration will be the speed of the string. For a particular rotation rate, the string will move much faster if it passes over a large-radius pulley than over a small-radius pulley. Thus the circumference of the pulley must be indicated. 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 "Linear Conversion Value" box. For some experiments, the lab manual will also direct you to change the "Resolution" setting.

When setting up a graph or a table, you will select the measurement you wish to display using the <Select Measurement> button. Note that all the angle measurements are in radians. The kinematic equations for angular motion conventionally use radians and not degrees. This makes it simple to convert angular displacements, velocities, and accelerations to their corresponding linear displacements, velocities, and accelerations. If you display a linear quantity, it is important to have the correct pulley selected in the Hardware Setup Properties window of the RMS.

Click on the "Record" 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, Capstone 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 above. When the scaling is complete, you can print out the graphs. Be sure that the graph window is active 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 '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 Hardware Setup window is already displayed, click on Channel 1 on the image of the interface unit to display a list of digital sensors. (The Hardware Setup window can be opened by clicking on the interface unit icon in the Tools Pallete.) After clicking on Channel 1, select "Photogate" from the pull-down menu that appears. If done successfully, you should see a picture of the photogate connected to the chosen digital channel. Note that there are other sensor choices for specialized applications of the photogate.

The software now understands that a photogate is connected to Channel 1, but does not know what you want to measure. To continue, click on the “Photogate Timer” icon just below the Hardware Setup icon in the Tools Palette. Capstone will guide you through the steps to set up your time. Photogates are often used to measure the speed of small objects that pass through the infrared beam. For this application, select the default “Choose a Pre-Configured Timer” option and click on the <Next> button to complete the first step of the setup. In Step 2, make sure the box next to your photogate “Photogate, Ch 1”, is checked and click on the <Next> button. To measure speed, choose “One Photogate (Single Flag)” option from the list in Step 3. In Step 4, make sure that the “Speed” option is checked. You may also want to check the “Time in Gate” option. Capstone will calculate the speed of your object by dividing the width of the object (the Flag Length) by the time the beam is blocked as the object passes through. Enter the width of the object (in meters) whose speed you wish to measure into the Flag Length block in Step 5. Finally, you can give your timer a name in Step 6. Exit the Photogate Timer setup window by clicking once on the Photogate Timer icon in the Tools Palette.

To display your speed measurement(s) in a table, drag the Table icon from the Display Palette on the right into the Display area. A table with two columns will appear. Select the measurements to display from the menus that appears when you click on the <Select Measurement> buttons. Putting the time in seconds in one column and the speed in m/s in the other will work for now. If you plan to print your Table for inclusion in your lab notes, describe of your data briefly on the [Table Title Here] line.

To take some test data find a pen or pencil, click on the “Record” button along the bottom left of the Display Area, and pass the pen or pencil back and forth through the photogate a few times; then click the “Stop” button that appears where the “Record” button had been. The table now displays some times along with the measured speeds. When you activate the “Record” 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” when you hit the “Record” button. If necessary, repeat the data collection process to clarify the details. Notice that the second set of data is simply named “Run #2.”

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

Photogate with pulley (digital)

A photogate can be used to measure displacement and velocity of objects connected to a string that runs over a pulley. The photogate must be plugged into a digital Channel on the interface unit. Choose the “Photogate with Pulley” option when you set up the interface unit. As the pulley turns, the spokes of the pulley successively block and unblock the light beam from the photogate. With the pulley, the photogate works much like the Rotary Motion Sensor, but with one serious limitation. The photogate has no way of determining which direction the pulley is rotating, so distances are always considered to be positive. If the object that we are studying moves in only 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. These quantities can be graphed, displayed in a table, or whatever.

Force sensor (analog)

The Force Sensor must be plugged into one of the analog Channels, A, B, or C. In the "Hardware Setup" window click on the analog channel with your sensor and choose the "Force Sensor" option [not "Force Sensor (student)"]. The default measurement of the sensor is force in newtons. The data from the sensor is usually most useful when shown in a table. 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. The sampling rate is set in the Control Palette along the bottom of the Display Area. 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 really reads zero after pushing the tare button by clicking the "Record" button and checking 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 Capstone software.

If we measure something multiple times but get slightly different answers each time, then the average value or "mean" value is often 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 large are the variations from the mean value? Statistically speaking, the standard deviation is a measure of this variation. You can read more about how these quantities are defined and used in the "Uncertainty Analysis Using Capstone" 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 along the top of the Table window, look for the Greek symbol Σ. This Capstone's "statistics" icon. Clicking on the down arrow just to the right of the Σ opens a drop-down menu that includes the mean and standard deviation. Make sure a check mark appears by each function you want to display. Then clicking on the Σ causes these numbers to appear at the bottom of your table. If you want increase the number of significant figures in the display (say, to minimize round-off error), you can increase the number of displayed digits by clicking on the "0.0 $\rightarrow$ 0.00" icon along the top of your table. (To decrease the precision, click on the "0.00 $\rightarrow$ 0.0" icon.) 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. Capstone will display N if you also check the "Count" function in 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 interface unit. 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 extremely useful.

Geiger counter (digital)

The Geiger counter is used to detect certain types of radiation, including beta particles and gamma rays. Our older Geiger counters have an AC power cord must be connected to a regular electrical outlet. The signal cable is inserted into one of the digital input channels. Our newer Geiger counters are powered by the cable that connects to the interface unit.

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 is the length of time for each individual counting period. The default is 1 Hz (counts per second), but it can be changed in the Control Palette along the bottom of the Display Area. To set the duration of data collection, click on the “Recording Conditions” icon in the Control Palette along the bottom of the Display Area; then set the “Stop Conditions” option for “Condition Type” to “Time Based” and the “Record Time” to 100 s.

When the resulting data is displayed in a table, you can use the statistics options to compute the average count rate, its standard deviation, and the standard deviation of the mean. The procedure is described above in the Force Sensor section. Geiger counter data is often plotted in a histogram, with the count rate (counts per second) along the horizontal axis, and the number of samples with each specified count rate along the vertical axis. To display a histogram, drag the “Histogram” icon from the Display Palette on the right into the Display Area. The table and histogram views fit nicely side by side.