(The activities in this document are excerpts from the forthcoming Stamps in Class book Smart Sensors and Applications, by Andy Lindsay. © 2006 Parallax, Inc.)

ACTIVITY #5: RC CAR ACCELERATION STUDY

This activity demonstrates how use DatalogAcceleration.bs2 from the previous activity to analyze the acceleration forces on a radio controlled (RC) car during a variety of maneuvers. This activity also demonstrates how these datalogged acceleration forces can be used to track and plot the car's velocity and position. Although the actual equipment and calculations are somewhat more involved, deriving position from successive acceleration measurements is a component of the inertial guidance systems employed in rockets and spaceships. These systems use a combination of the 3-axis version of the acceleration measurements covered in this activity along with and gyroscopes that measure the vehicle's rotation.

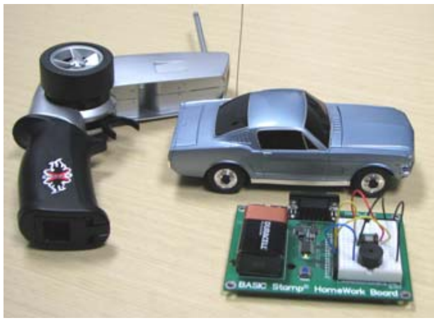
Parts, Equipment and Circuit Diagrams

In addition to the parts for Activity #4, you will need an RC car and controller. The circuit diagrams that should be built on your board are at the beginning of Activity #4 in this chapter.

Hardware and Setup

Figure 6-4a shows an inexpensive RC car that can be obtained at many hobby shops and retail electronics outlets. Figure 6-4b shows how the board was mounted. Rubber feet were affixed to the underside of the board in a way that prevented any of its electrical connections from coming in contact with any of the RC car's electrical metal parts. Another option would be to use double-stick tape to affix the board to the roof of the plastic shell.

Figure 6-4: RC Car with Acceleration Datalogger

a.


b.


Avoid accidental short-circuits. Make sure your board is mounted on the car so that exposed metal underneath the board has no way of coming in contact with any of the RC car's metal parts or electrical connections.

How it Works

Figure 6-5 shows a graph of the accelerometer's y-axis measurements as the car accelerated forward, slowed to a stop, and then accelerated backwards. The measurements were acquired with DatalogAcceleration.bs2 from Activity #4. After displaying them in the Debug Terminal, they were shaded, copied and pasted into Windows Notepad. From there, they were imported into the Microsoft Excel spreadsheet program and then graphed.

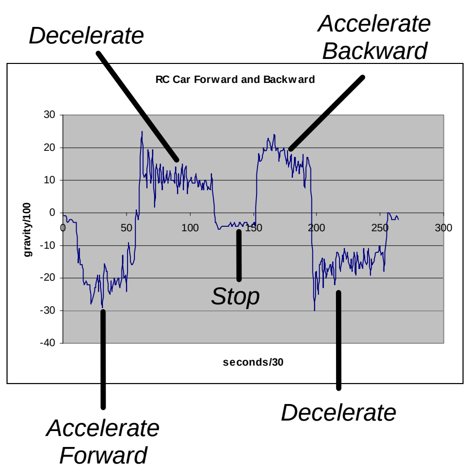


Figure 6-5
RC Car Accelerometer Y-Axis Measurements

The reason the forward acceleration is negative is because the y_m sensing axis is pointing to the back of the RC car as shown in Figure 6-6. So, as the car is accelerating forward, the acceleration is negative. When a car slows down, it is actually accelerating backwards. This is shown in Figure 6-5. First, the car accelerated forward, then it applied the breaks and slowed down (decelerated). The y measurement was positive, so acceleration was negative. After a brief stop, the car accelerated backwards. Notice that the y is again positive. Then, when it slows down (decelerates) from its backwards speed to stop again, the car is, in effect, accelerating forward, and the y measurement is negative again.

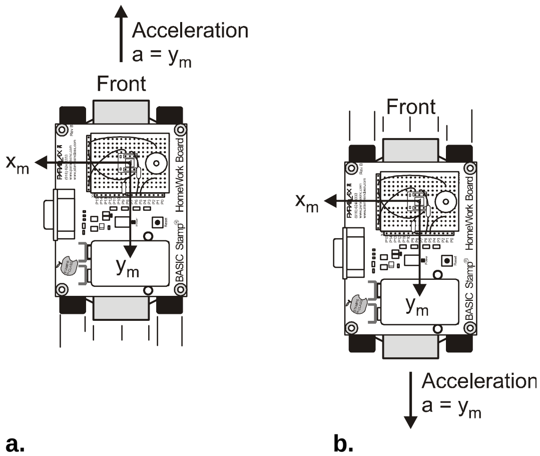


Figure 6-6
RC Car Acceleration vs Accelerometer Sensing Axes

If you're driving a car, when the car accelerates forward, you can feel the seat pushing you forward. Well, if you make a sharp right turn, the left side of the car pushes you to the right. That's because you are accelerating right as you turn. This is shown in Figure 6-7, which illustrates how an object can be traveling forward at a constant velocity, and to make it turn, it always has to be accelerating toward the center of the circle it is traveling in.

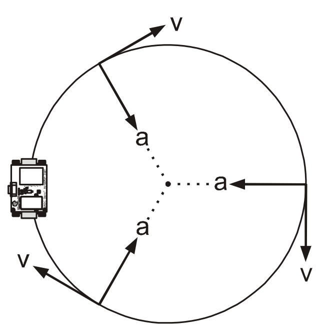


Figure 6-7
Traveling in a Circle

This causes continuous acceleration toward the center.

Figure 6-8 shows a graph of the accelerometer's x-axis measurements as the RC car is first driven in circles turning left, then in circles turning right. Notice how the x-axis measurement shows positive acceleration as the RC car circles to the left, and negative acceleration as the car circles to the right.

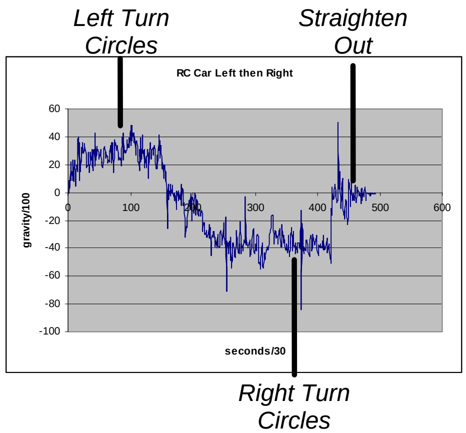
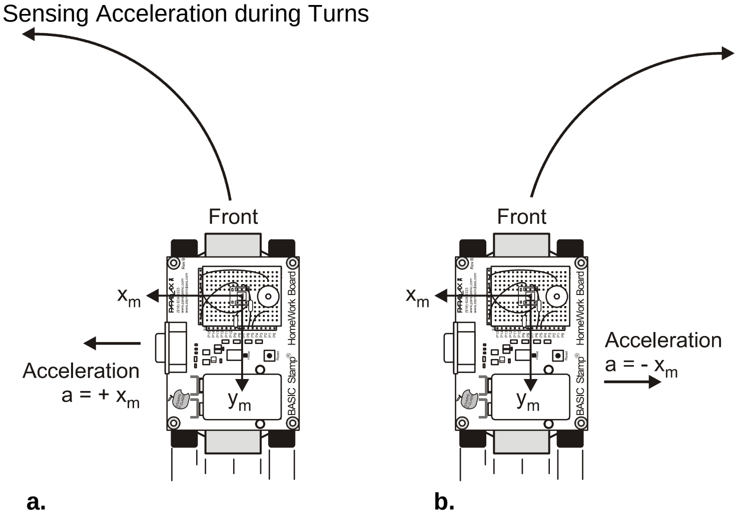


Figure 6-8
RC Car Accelerometer Measurements while Driving in Circles

Figure 6-9 shows how the accelerometer's x-axis is oriented, and the acceleration it measures. For a left turn, the car is accelerating to the left, which for the accelerometer is a positive x-axis acceleration measurement. When it turns right, acceleration is in the opposite direction of the positive x-axis, so the x-axis measurement it negative.

Figure 6-9: Sensing Acceleration during Turns



Procedure

The procedure for measuring and then graphing RC car acceleration is as follows.

- √ Attach your board to the RC car.
- √ Download DatalogAcceleration.bs2 into the BASIC Stamp.
- √ Set the car down in open area and press/release the board's Reset button.
- √ Wait for the countdown to indicate that datalogging has started.
- √ Drive the car through these maneuvers, in about 15 seconds:
  - o Accelerate the car forward, then come to a stop.
  - o Accelerate the car backward, then come to a stop.
  - o Drive in a figure-eight.
- √ When the board beeps again (after about fifteen seconds) it means the datalogging is over. Connect the board back to your PC.
- √ Run DatalogAcceleration.bs2 again.
- √ Click the Debug Terminal's transmit windowpane.
- √ Type D to display the data.
- √ Use your mouse to shade the table headings and all the measurements in the Debug Terminal's blue receive windowpane. (Don't shade the menu.)

- √ Press CRTL + C to copy the records.
- √ Open Notepad.
- √ Click Edit and select Paste.
- √ Save the file.

These next instructions explain how to import the .txt file into Microsoft Excel 2002 and graph it. If you are using a different spreadsheet program, the keywords such as space delimited, XY scatter plot may provide leads on how to accomplish it with your particular spreadsheet software.

- √ In Excel, click File and select Open.
- √ In the files of type field, select All files (*.*).
- √ Find the .txt file you saved with notepad, select it, and click the Open button.
- √ In Text Import Wizard Step 1, click the Delimited radio button, then click Next.
- √ Click the checkbox next to Space to indicate that the file is space delimited.
- √ Make sure the checkbox for "Treat consecutive delimiters as one" box is also checked, then click next.
- √ Make sure the radio button for General column data format is selected, then click finish.
- √ Your spreadsheet should be three columns wide and about 503 rows long.

The next step, which is also documented for Microsoft Excel 2002, is to run the chart utility and tell it what to graph and how you want it to look.

- √ Place the cursor in a cell somewhere to the right of your three columns of data.
- √ Click Insert and select Chart.
- √ In the Standard Types tab, select XY (Scatter). Also click the graphic that configures it to "Scatter with data points connected to smoothed Lines without markers". Then, click Next.
- √ Assuming your y-axis data is begins in C3 and ends in C503, type C3..C503 in the Data range. Click the radio button next to Columns to indicate that the series of data points is in a column. Then, click Next.
- √ Fill in the chart title and axis information, then click Finish.
- √ Repeat for the x-axis.

Only portions of each graph are relevant. Keep in mind that the data that will make sense for the y-axis is the portion of time the car accelerated forward and backward. Likewise, the part of the graph that will make sense for the x-axis is the portion of the graph when the car was turning.

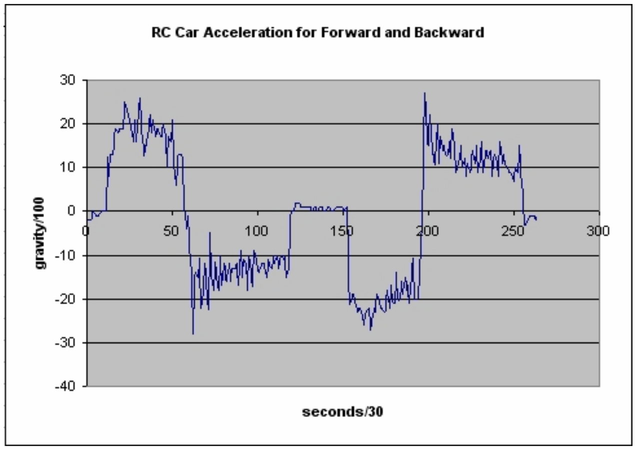
Graphing the Car's Position and Velocity

If you know the initial position and velocity of an object, you can use the acceleration during a period of time to calculate its position. These calculations can be made iteratively in a spreadsheet to plot the velocity and the path of the RC car.

Downloading the Spreadsheet. The MS Excel spreadsheets used to plot these graphs are available for download from the Smart Sensors and Applications pages at www.parallax.com. Download the spreadsheet and examine the equations in the various columns along with the settings for each plot.

For example, the acceleration plot in Figure 6-10 shows a plot of the RC car as it accelerates forward and backward. (The spreadsheet was modified so that positive values indicate forward acceleration and negative values indicate backward acceleration or deceleration.) So, this graph shows that the car accelerated forward at an average of around 0.16 g for a little under 2 seconds. Then, it decelerated at an average of around 1.4 g for a little over 2 seconds. Then it rested for about 1 second. After that, it accelerated backward, and then decelerated (accelerated forward) to a second stop.

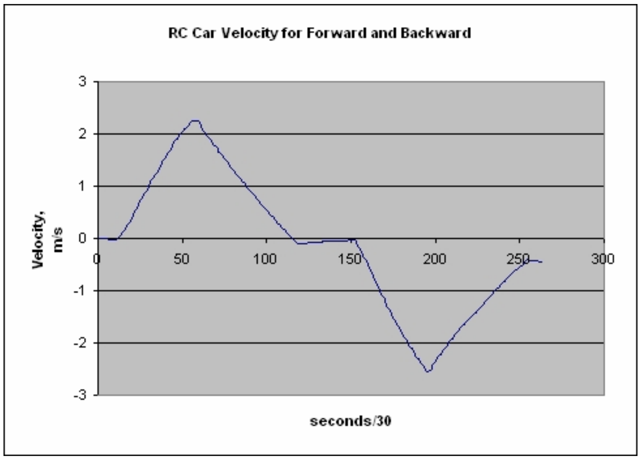
Figure 6-10: Acceleration Graph Modified with Positive Acceleration Indicating Forward



Selecting Data to Graph. Right-click the line in the plot with the title "RC Car Acceleration for Forward and Backward. Then choose source data and click the Series tab. Note that the series being plotted is from F229 to F492. This is the second of two forward/backward tests that were performed during the datalogging session. The same applies to the Velocity and Position graphs.

A column with an equation was added to the spreadsheet that calculates the change in velocity for each acceleration measurement. The equation for velocity in a straight line is $\mathbf{v = v_0 + at}$. That's the initial velocity ($\mathbf{v_0}$) plus the product of the acceleration (**a**) and the duration of that acceleration (**t**). Adding a column to the spreadsheet that recalculates velocity between each acceleration measurement makes it possible to graph the velocity as shown in Figure 6-11. As expected, when the car accelerates forward, its velocity increases. Then, when it slows down, its velocity decreases. As it accelerates backward, its velocity decreases further (increases in the negative direction). Then, as it slows its backward motion, its velocity returns to almost zero.

Figure 6-11: Velocity Graph Derived from Initial Position and Acceleration Data



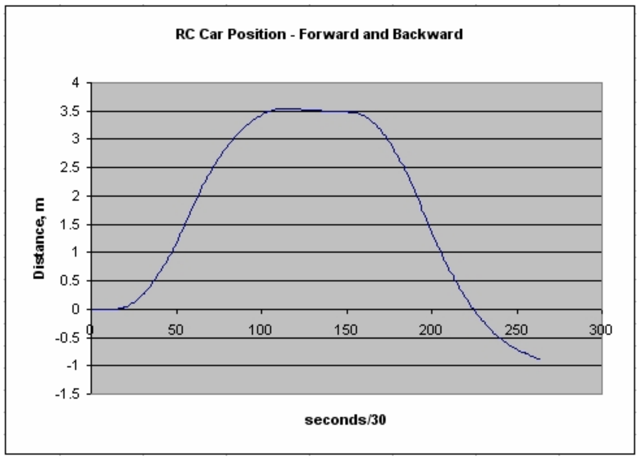
The calculations for this plot are made in the spreadsheet's column-F. If you click cell F-17 in the spreadsheet, this equation should appear in the function field:

=F16 + (0.03*9.8*E17/100)

In this case, F16 is the cell just above F17, and it has the previous velocity. This previous velocity is used as $\mathbf{V_0}$ for the sample interval. 0.03 is **t**, the time between samples, and 9.8 * E17 / 100 takes the E17 measurement, which is in hundredths of a g and converts it to meters per second (m/s^2). Dividing by 100 takes the value from hundredths of a g down to g and then multiplying by 9.8 converts from g to m/s^2. That's because 1 g is approximately 9.8 m/s^2.

With columns in the spreadsheet for acceleration and velocity, it is now possible to also keep track of the car's position using the equation $\mathbf{s = s_0 + v_0t + {}^1/_2\, at^2}$. That's the position of the car (**s**) is equal to the initial position ($\mathbf{s_0}$) plus the product of initial velocity and time ($\mathbf{v_0t}$), plus half the product of acceleration and the square of time ($\mathbf{{}^1/_2\, at^2}$). The resulting graph of position shown in Figure 6-12 is surprisingly accurate. The car did in fact go forward to about the 3.5 meter mark before stopping. Then, it backed up and came to rest almost a meter behind where it started.

Figure 6-12: Position Graph Derived from Initial Position, Initial Velocity and Acceleration Data



The equation that calculates position in the G17 cell is

=G16+(F16*0.03)+((0.5*E17*9.8/100)*(0.03^2))

G16 is the position after the previous sample, which is $\mathbf{S_0}$, the initial position. F16*0.03 is $\mathbf{v_0 t}$, initial velocity multiplied by time. (0.5*E17*9.8/100)*(0.03^2) is $^1/_2$ $\mathbf{at^2}$, where **t** is again 0.03 seconds.

While this technique is pretty accurate over short periods of time, some error creeps into each measurement from several sources. Rough surfaces and vibration will effect the acceleration measurements. Also, while the equations assume the acceleration between each measurement is constant, in many cases, the acceleration will change during the time between each sample. In addition, each accelerometer measurement will tend to be a few percent off because of the nature of the MX2125. The MX2125's datasheet (available from Memsic's web site - www.memsic.com) explains these errors, the largest of which are called zero offset and sensitivity errors. They will vary from one chip to a next, and they are also influenced by temperature. Taking precision measurements with the MX2125 involves an A/D converter, a floating point coprocessor, and data collected from calibration tests. This calibration procedure is outside the scope of this text. To find out more about this topic, consult *#AN-00MX-002 Thermal Acceleromters Temperature Compensation*, which is available at Memsic's web site.

Your Turn - Logging Your RC Car's Acceleration/Velocity/Position

As mentioned earlier, the MS Excel spreadsheets used to plot these graphs are available for download from the Smart Sensors and Applications pages at www.parallax.com. Download the spreadsheet and examine the equations in the various columns along with the settings for each plot. Then, experiment with plotting data gathered from your own RC vehicle. Whatever data you plot should start from a known position with the car at rest. That way you know the initial position ($\mathbf{s_0}$), and more importantly, the initial velocity, $\mathbf{v_0}$ is 0 m/s.