Experiment A9
Practical Implementation of Sensors
Procedure

Deliverables: Checked lab notebook, Brief Tech Memo

Recommended Reading: Section 7.3; Chapter 19 of the textbook

Telemetry of an RC Car

Background

The automotive industry has invested a great deal of time and money developing self-driving, autonomous vehicles. This is not an easy task, to say the least. Self-driving cars contain an array of sensors that produce large data sets. The data from these sensors must be rapidly processed and used to make split-second adjustments to the vehicle controls. To make matters worse, even the slightest sensor malfunction or error in data processing can result in death.

In this lab you will use a MEMS (micro-electro-mechanical system) accelerometer to measure the acceleration of a small RC car. You will first calibrate the sensor. Then you will use it to measure the acceleration in 3 directions while the car performs a few different tests at the Lab I Proving Grounds. Numerically integrating the acceleration data a_i will give the 3-dimensional velocity

$$\vec{v}_{i+1} = \vec{v}_i + \vec{a}_i \cdot \Delta t \quad . \tag{1}$$

Numerically integrating the velocity data yields the position of the car

$$\vec{x}_{i+1} = \vec{x}_i + \vec{v}_i \cdot \Delta t \tag{2}$$

as a function of time. Importantly, these are *indefinite integrals* or *anti-derivatives*, so v_i and x_i will be vectors in Matlab. Equations (1) and (2) also represent a *Riemann sum* method of numeric integration. Alternatively, one could use a *trapezoidal* method of integration, such as the one found in Ch. 19 of the textbook.

Experimental Procedure

You will use the ADXL337 MEMS accelerometer and Logomatic v2 SD Datalogger from SparkFun to collect telemetric data from the RC car. Please refer to the Logomatic hook-up guide for details on the device: **http://learn.sparkfun.com/tutorials/logomatic-hookup-guide**

Calibrating the Accelerometer

CAUTION: Do NOT remove the microUSB cable from the SparkFun logger board. Excessive pulling or bending of the cable will break the Logger board.

1. Make sure the battery is connected to the Logomatic. Connect it to the lab computer via the microUSB cable. Turn it ON using the small switch on the board. It should appear as a flash drive on the lab PC. If it does not appear or the computer gives you a “device not recognized” error, turn off the data logger and turn it back on again.

2. Open the folder for the Logomatic as you would for a normal flash drive. Delete all file except for the LOGCON.txt configuration file.
3. Open the "LOGCON.txt" configuration file. Check to make sure it matches the script in Appendix B. If it does not match, change it so that it does and save it. Note that the sampling frequency should be 200 Hz. Write this down in your lab notebook.
4. Turn OFF the Logomatic and disconnect the USB cable from the computer.
5. Make the following connections from the accelerometer (left) to the data logger (right):
    a. 3.3V to 3.3V
    b. GND to GND
    c. X to pin 1
    d. Y to pin 2
    e. Z to pin 3
6. Note the following important details regarding the operation of the Logomatic data logger:
    a. The data logger will begin collecting data as soon as you turn it ON. It will stop collecting data when you press the STOP button. The data logger will save the data as a text file.
    b. If you press the RESET button, it will collect a second data set and save it as a new text file.
    c. The data logger is configured to record analog voltages as 10 bit digital numbers. A value of 0 corresponds to 0 volts and 1023 corresponds to 3.3 volts.
7. Perform a 2-pt calibration of each channel (X, Y, and Z) of the accelerometer by holding the various edges and surface of the accelerometer flat against the table. While the data logger is ON and collecting data, start with the X arrow pointing up. Hold it in this orientation for about 3 seconds, then rotate it so the X vector points down and hold it in the downward orientation for another 3 seconds. This will yield accelerations of a_x = +1g and -1g. Repeat this for the Y and Z directions as well.

CAUTION: Be very careful with the microUSB cable. Excessive pulling or bending of the cable will break the Logger board.

8. When you are finished with the 2-point calibration procedure, press the STOP button, then turn OFF the logger.
9. Connect the logger to the lab computer, then turn ON the logger. Ignore and close any warnings from the Windows OS, and wait patiently for the computer to recognize the logger. If it does not recognize it, turn OFF the logger and turn it back ON again.
10. Open the logger as a folder to view the files and copy your calibration data "LOG**.txt" to the lab computer. Transfer the data files to the lab computer.

11. Open the .txt data file with Notepad. Check the values, then select File > Save as. Give it an intelligent file name and select **ANSI Encoding** from the drop down menu, and **save it to the desktop of the lab computer.**
12. Import the ANSI encdoded .txt file into Matlab with “Space” as a the delimeter.
    a. Click the “Import Data” button on the HOME tab.
    b. Select “Delimited” with “Space” as the column delimiter.
    c. Set the “Output Type” to be a column vector.
    d. Make sure the three columns are highlighted, and click the “Import Selection” button. The first column contains the X data, second column is Y data, and third column is Z data.
    e. Change the variable names at the top of each column from the default “VarName1” to names that are more brief and descriptive, i.e. “Xcal”.
    f. Check that the data has been correctly loaded in the Matlab “Workspace”, and save the workspace as “yourName_calibration_data.mat”.
    g. Email the .txt and .mat data to your lab partner.
13. Plot the three data sets. The flat portions of the data correspond to values of +1g and -1g. (For example, 400 maps to -1g and 600 maps +1g.) Use the values of the flat portions to create a linear calibration equation, which relates the digital value to the acceleration in units of m/s^2 for each of the three axes.

Telemetry of the RC Car

CAUTION: Be very careful with the microUSB cable. Excessive pulling or bending of the cable will break the Logger board.

1. Unplug the large end of USB cable from the computer. Leave the other end of the cable connected to the Logomatic.
2. Mount the accelerometer, Logomatic, USB cable, and battery to the chassis of the RC car using the 3M Velcro command strips (state-of-the-art dorm room technology!). The Y axis should point forward and the X axis should be oriented left-right.
3. Sketch a top view of the car with the axes of the accelerometer clearly marked.
4. Take the car to the Lab I Proving ground. Practice driving it for a few minutes.
5. The first test is simple back-and-forth motion. Use the tape measure to determine the distance between the two lines. Record the value in your lab notebook.
6. Turn on the logomatic. Wait a few seconds and drive the car back-and-forth one time between the two lines. Try to make the acceleration as vigorous as possible: full throttle going forward, and then slam it into reverse!
7. Press the STOP button on the Logomatic.
8. Press the RESET button and repeat the back-and-forth test. Repeat it several times so you will have several data sets to choose from.

9. Return to the lab and offload the data onto the lab computer. Open the .txt data file with Notepad. Check the values, then select File > Save as. Give it an intelligent file name and select **ANSI Encoding** from the drop down menu.
10. Email all data files to you and your partner. **Check that they all work on your own computer before you leave lab.**
11. Delete all data files from the logger, but NOT the LOGCON.txt configuration file. Remove the jumper cables connecting the data logger and accelerometer. Leave the USB cable connected to the Logomatic.

Data Processing

The raw data will come out fairly noisy with an artificial DC offset. You must do the following to calibrate the data, filter the noise, and subtract the DC offset.

1. Use your calibration data to create a linear calibration equation, which relates the digital value to the acceleration in units of m/s^2 for each of the three axes.
2. Load the data from the back-and-forth driving test. Make ruff plots of the y-acceleration data, and decide which data set has the best signal-to-noise ratio (SNR).
3. Delete the "dead time" where the vehicle is just sitting still either at the beginning and end of the test. Do this for all three components of acceleration, such that they are all cropped in the exact same fashion and span the exact same time frame.
4. Convert your acceleration data to units of m/s^2 using the calibration equation.
5. Use the sampling frequency to determine Δt between each data point and generate a time vector in Matlab.
6. Filter the data using the smooth() function in Matlab. Be sure to read the Mathworks' webpage for smooth(), so you understand exactly what it is doing.
7. Subtract the mean value (DC offset) of each data set from every data point in that set.
8. Numerically integrate the acceleration data to obtain the 3 components of velocity vs. time.
9. Numerically integrate the velocity data to obtain the 3 components of position vs. time.
10. Although measured data is typically plotted as individual markers, transient signals (such as acceleration vs. time) should be plotted as a continuous line.

Data Analysis and Deliverables

Create plots and other deliverables listed below. Save the plots as PDFs, import them into either Microsoft Word or LaTeX, and add an intelligent, concise caption. Make sure the axes are clearly labeled with units. Plots with multiple data sets on them should have a legend. **Additionally, write 1 – 3 paragraphs describing the items below.**

IMPORTANT: Refer to the "Data Processing" section of Part I for instruction on data processing.

1. A plot of the X, Y, and Z acceleration (units of m/s^2) as a function of time for one of the back-and-forth tests.
2. A plot of the X, Y, and Z velocity (units of m/s) as a function of time for the same back-and-forth test.
3. A plot of the XY positions (units of m) for the back-and-forth test. (This is often referred to the "locus" of points visited by the car.)

Talking Points – Please address the following questions in your paragraphs.

- Describe the motion in the back-and-forth test.
- What is the Z velocity for the back-and-fourth test? Does this make sense?
- What are the sources of error in the experimental method?

Appendix A

Equipment

- RC Car – Amazon #: B07QV62R4J
- 3M Command Small Refill Strips, White, (64 strips) – Amazon #: B0751RPC6Q
- MicroUSB **data** cable
- SparkFun Logomatic v2 - Serial SD Datalogger (FAT32)
- Lithium Ion Battery - 400mAh
- SparkFun Triple Axis Accelerometer Breakout - ADXL337
- Female jumper cables

Appendix B

MODE = 2
ASCII = Y
Baud = 4
Frequency = 200
Trigger Character = $
Text Frame = 100
AD1.3 = N
AD0.3 = Y
AD0.2 = Y
AD0.1 = Y
AD1.2 = N
AD0.4 = N
AD1.7 = N
AD1.6 = N
Safety On = Y