

MAE106 Laboratory Exercises

Lab # 3 Robotic Vestibular-Ocular Reflex

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Goals

- Implement a simple robot control system
- Gain insight into bandwidth, calibration, filtering, and feedback control.
- Gain experience modifying code for your final project robot

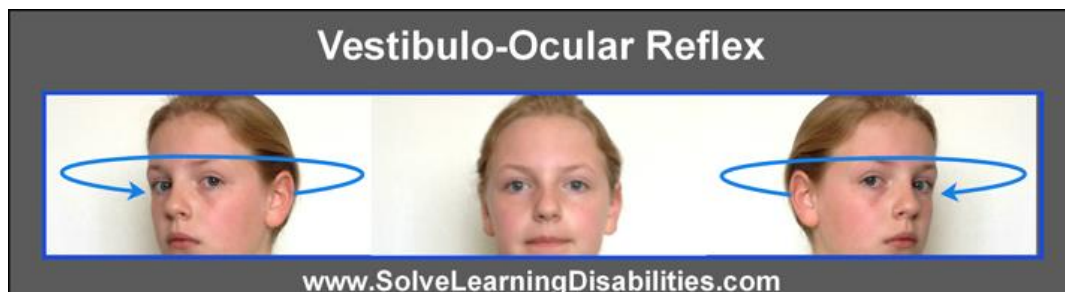
Parts & equipment

Qty	Part/Equipment
1	Final project test board (you should have fabricated this in open lab)
1	Power supply
Various	Wire
1	Oscilloscope
1	Multimeter

Introduction

Many mechanical engineering systems – including robots, planes, space vehicles, power plants, the human body, and autonomous cars – take readings about system performance from sensors then modify actuators based on those sensor readings. Such systems are called “closed loop” or “feedback” systems. To make such systems work well, you first need to calibrate the sensors. You also need to understand possible sources of sensor noise, so you can implement appropriate countermeasures, such as filtering. In this lab, you will go through these processes using your final project test board (FPTB), culminating in a closed loop robotic control system that mimics the human vestibular-ocular reflex (VOR).

The VOR is what allows you to keep your eyes fixed on an object when you rotate your head. Your inner ear measures the rotation of your head, then, based on that measurement, your nervous system sends a command to your eye muscles to counter-rotate your eyeballs. In this lab, you will build a robotic VOR so that as you rotate your FPTB, the servomotor always “looks” in the same direction.



Part 1: Bandwidth of the Human VOR

The bandwidth of a control system can be loosely defined as the range of input frequencies over which the control system performs well. Roughly estimate the bandwidth of the human VOR by staring at your finger and rotating your head back and forth faster and faster. The VOR works to keep your eyes fixed on your finger. Estimate the frequency of head movement at which the VOR can no longer keep up and your finger becomes blurry or you see double. Write this number down to show the TA later and be able to explain how you estimated the frequency of head movement. Note who in your lab group has the highest bandwidth VOR.

Part 2: Calibrating a Magnetometer to Serve as a Compass

Like your cell phone does, you can use a magnetometer to sense the direction that you are facing. This is because earth produces a magnetic field and the magnetometer can sense this field and serve as a compass. You will use this compass ability in your final project to steer your robot. In Part 4 of this lab, you will also use this compass ability to create a robotic VOR.

Due to manufacturing variations, your magnetometer does not respond equally in all three of its axes. In order to use it effectively, you need to calibrate it so each axis responds equally to the same amount of rotation. Generally speaking, calibration is a process in which you correlate the readings of a sensor with those of a gold standard in order to determine how to mathematically manipulate the sensor readings to produce an accurate reading.

Devise a way to rotate your FPTB exactly 90 degrees in the horizontal plane. Download the "heading" Arduino sketch provided with the library for the LSM303 magnetometer (click Files -> Examples -> LSM303 -> heading; you should have already installed the LSM303 library using Tools -> Manage Libraries; make sure it's the LSM303 library from Pololu). Using "heading", measure how much your magnetometer says that you rotated. Write the angle down to show the TA later.

Now, calibrate your magnetometer in the x and y axes (i.e. the horizontal axes). To do this you need to measure the minimum and maximum counts from each axis as you rotate your FPTB through 360 degrees. Using the example "calibrate" sketch provided with LSM303 magnetometer, find these values.

Now, enter those values in the appropriate place in the "heading" sketch. The compass sketch takes those values and uses them to calibrate the magnetometer readings. Re-run your experiment in which you rotate the FPTB precisely 90 degrees in the horizontal plane. Using "heading", record how accurate the magnetometer is now that you calibrated it.

Part 3: Sources of Noise for the Magnetometer

Every sensor is susceptible to some sort of noise or interference. Your magnetometer senses earth's magnetic field, but when you actuate your solenoid valve, you create a magnetic field that superimposes on earth's magnetic field. This is because your solenoid valve has a coil of wire in it, and, as you remember from Physics, passing current through a coil produces a magnetic field.

In your final project you need to actuate your solenoid valve to allow pressurized air into your cylinder. But, if you're not careful, this will cause noise on your magnetometer, causing your robot to think it is heading in the wrong direction.

Download the "Sample Code to Test Electrical Connections" (i.e. SampleCodeElectricalVerification1.ino) found on the Final Project web site in the Electrical Verification area. Modify the code to take into account your calibration. Run the code and watch the compass heading on the serial monitor. You should see heading change (by how much?) when the solenoid turns on.

Modify this code to save three variables – currentMillis, solenoidState, and heading – in three columns (without labels) on the serial monitor for exactly five seconds. Save two sets of data – one with the solenoid near the magnetometer, and one with it farther away (try at least 6-10"). You will need this data for the write-up. You can save the data by copying and pasting the data from the serial monitor into a text file.

Part 4: Robotic VOR

Modify SampleCodeElectricalVerification1.ino to create a robotic VOR. To do this, make your servomotor rotate by an angle equal and opposite to the heading measurement from your magnetometer. Again, make sure to include your calibration. Note: the servomotor can only rotate from 0 to 180, and the compass jumps back to zero when it reaches 360. To get your VOR to work well, you will want to use the servomotor and compass in their midranges.

Verification

After you have completed the lab, show your TA the following things:

- From Part 1: The estimated bandwidth of your own VOR (and who in your group has the highest bandwidth). Explain how you measured this frequency.
- From Part 2: The accuracy of your magnetometer in measuring a 90 degree rotation before and after calibration.
- From Part 3: The two data sets you collected showing the effect of the solenoid on the magnetometer when it was close by and farther away.
- From Part 4: A demonstration of your Robotic VOR.

Write-Up

1. Bandwidth is often formally defined as the frequency at which performance drops to 71% of its maximum – i.e. to a fractional value of $\sqrt{2}/2 = 0.7$ which is called the 3dB point, since the decibels of a signal X is defined as $20\log(X)$, and $20\log(\sqrt{2}/2) = -3$. Explain how this relates to the value of the magnitude response of a first-order low-pass filter at its cutoff frequency.
2. Since sensors are often designed to have linear responses, we often just need to figure out how much to offset and scale the readings from the sensor to give a correct reading. Assume you have a linear rotation sensor. You rotate it and find that it outputs sensor values of s_1 and s_2 at d_1 and d_2 degrees. Derive the calibration equation that converts sensor values into degrees.
3. Using Matlab, write a script to load in the two data sets [use the command `d = load('data.txt')`] and plot the data showing the effect of the solenoid when it is close by and farther away. Make sure to label your graphs well. In the same script, implement an off-line, digital low-pass filter, such as the 1st-order recursive filter you used in Lab 2:

$$y_k = (1 - a)u_k + a * y_{k-1}$$

Where $(y_k, y_{k-1}, y_{k-2}, \dots)$ are the past samples of the already filtered signal and $(u_k, u_{k-1}, u_{k-2}, \dots)$ are the present and past values of the unfiltered signal. Play with finding a good value for the constant a (note $0 \leq a \leq 1$) such that the noise from the solenoid is

reduced without delaying the sensor reading too much. Show your filtered signals with different colors or line styles on the same plot and state your selected value for α (there is no exactly right answer for α – it's a tradeoff you have to just choose). Note: you will probably want to use this filter for your final project to reduce the effects of the solenoid on your heading reading, besides putting the magnetometer as far away as possible from the solenoid.