Accelerometry Laboratory

CleveLabs Laboratory Course System Version 6.0

Introduction

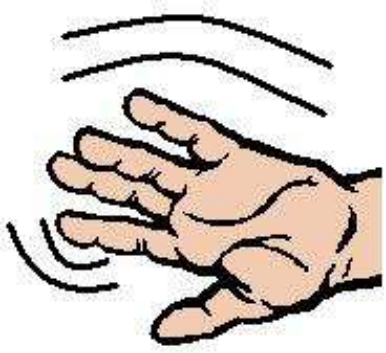


Figure 1. Movement disorder symptoms such as tremors can be monitored with motion sensors.

Motion sensing techniques are extremely important in many fields including biomechanics, engineering, and virtual reality applications. For example, in the automotive industry, motion sensors are particularly useful for providing feedback to algorithms that automatically improve vehicle control. Motion sensors are extremely valuable in many biomedical engineering applications as well. For example, sensors can be placed into artificial limbs to improve both control and feedback of the device. Sensors can also be worn by subjects to monitor activity and motion, providing researchers with valuable insight into the quantitative characteristics of movement disorders. Furthermore, combining motion sensors with electromyography can provide a powerful tool for biomechanics applications. By monitoring motion and electromyography at the same time, movement can be analyzed along with the muscle patterns being generated to create the motion.

There are many types of sensors that can be utilized to measure motion. Some examples of motion sensors include accelerometers, gyroscopes, camera mounted systems, and magnetic sensors. The type of sensor used depends on the particular application. For this laboratory session, you will be using a two-axis accelerometer that is embedded inside the BioRadio™150. An accelerometer measures linear accelerations along a particular axis.

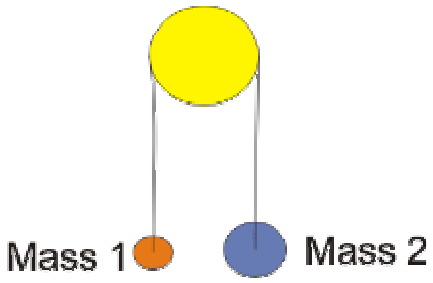
Equipment required:

- CleveLabs kit
- CleveLabs Course Software
- Five (5) Snap Leads
- Five (5) Snap Electrodes
- Microsoft® Excel, MATLAB®, or LabVIEW™

Background

Accelerometers measure acceleration about a particular axis. Therefore, let's begin with a brief review of physics. Acceleration is defined as the rate of change of an object's velocity. Recall from calculus that if you know the position (x) of an object over time (t), you can calculate that object's velocity (v = dx/dt) and acceleration (a = dv/dt) by taking the derivatives. Acceleration can be either a positive or negative number, depending on whether the object's velocity is being increased (accelerated) or decreased (decelerated) and is represented in feet/s/s (ft/s^2) or meter/s/s (m/s^2). Acceleration can also be represented as a function of "g", with one g equal to the acceleration of gravity on earth (32 ft/s^2 or 9.8 m/s^2). For example, if you were to ride in the space shuttle, you would experience 10g, or ten times the acceleration of gravity on earth during takeoff.

An accelerometer is a device that measures the acceleration of an object. The first accelerometer was created in 1783 by an English physicist named George Atwood. The Atwood machine utilized a pulley-wheel arrangement and Newton's Second Law (F = ma), or Force equals mass times acceleration, to enable the linear acceleration of known masses caused by the earth's gravity to be calculated. Fig 2 shows a simple Atwood machine along with the equation used to calculate the acceleration of the two masses.



$$Acceleration = \frac{(Mass2 - Mass1) * g}{(Mass1 + Mass2)}$$

Figure 2. A general schematic of an Atwood machine.

Since the introduction of the Atwood machine, there have been significant strides made in accelerometer technology. Modern accelerometer sensors are placed directly on the object whose acceleration is being measured. Here, the accelerometer creates electrical outputs that correspond to the changes in acceleration. The most popular accelerometers used today are capacitive in nature. These accelerometers can sense a change in electrical capacitance by the movement of a capacitor plate during applied accelerations. The displacement of the capacitor plate creates an output voltage that corresponds to the applied acceleration. Furthermore, current leading edge technology with respect to accelerometers resides in Micro-Electrical-Mechanical Systems (MEMS). MEMS accelerometers are created using micro-fabrication techniques which create smaller, more reliable, and lighter accelerometers that are sold at a fraction of the cost. One example is a single, two-axis MEMS accelerometer produced by Analog Devices, Inc. that

is capable of measuring static and dynamic accelerations in two directions. This accelerometer functions by utilizing sensors that detect changes in capacitance caused by a beam that moves between two capacitor plates during an applied acceleration (Fig 3). The change in capacitance is measured and converted to an output voltage that corresponds to the applied acceleration. Orientating the sensors in different directions, acceleration can be measured along two axes. The BioRadio utilizes a two-axis accelerometer (Fig 4).

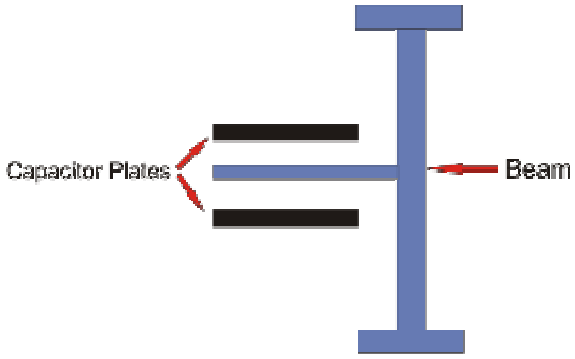


Figure 3. Graphic showing the generalized design of one acceleration sensor. As acceleration is applied, the beam moves, causing a change in capacitance that is then converted to an output voltage that corresponds to the applied acceleration.

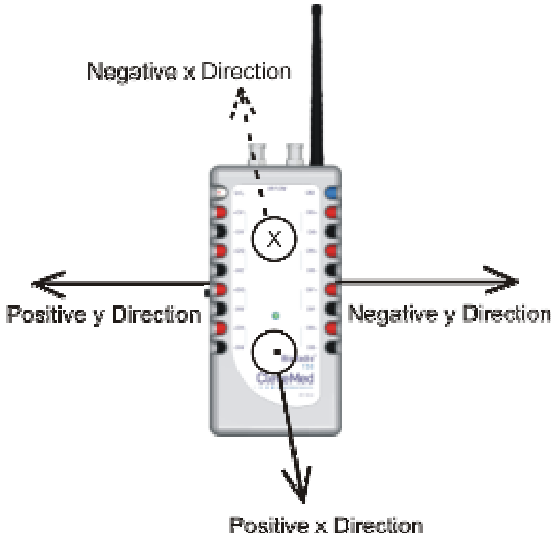


Figure 4. Graphic showing the x and y axes with respect to the BioRadio™150. The negative x direction is "into the page" while the positive x direction is "out of the page". The positive and negative y directions are as shown.

Accelerometers have many important biomedical applications that include their use in different movement disorder analysis systems. Accelerometers are particularly useful in these applications because they can provide position and velocity measurements through simple integrations of the acceleration data instead of having to add extra sensors. For example, one application may utilize accelerometers to constantly monitor body movements and detect clinically significant events by

comparing movement analysis to normal body movement data. A system such as this could be utilized to provide remote monitoring of a patient's recovery from debilitating illness or surgery.

While motion sensors can provide insight into the kinematics, recording EMG can detail the actual muscle patterns that were used to create the motion. Therefore, a system that integrates both EMG and motion recordings can prove a valuable research tool for biomedical engineering and biomechanics applications. For example, a researcher can analyze time delays between when the electrical activation of the muscle occurs versus when actual motion is created. In another example, gait analysis patterns could be analyzed. If the motion does not match normal motion as computed by the motion sensors, EMG could be reviewed to see how the muscle activation patterns differ from normal.

There are several movement disorders that can be quantified by the combination of motion and EMG. Parkinson's disease is one example. People with Parkinson's disease may exhibit several symptoms including tremor, bradykinesia, and rigidity. Tremor is involuntary oscillations of a body part. Tremor typically occurs at a frequency of 4-6 Hz. Bradykinesia refers to slowed movements or hesitations during movement activities. Finally, rigidity is an increased level of muscle activation to antagonistic muscles acting on a joint. This causes a joint to become very rigid and can lead to low amplitude movements. These symptoms are often treated with pharmaceutical interventions including L-dopa therapy. However, an interesting side effect may occur with this therapy. If no medication is given, Parkinson's patients may experience tremor, bradykinesia, or rigidity. If the perfect amount of medication is administered, these symptoms may subside. However, if too much medication is in the patient's system, patients may experience dyskinesias. Dyskinesias are wild, involuntary movements of the body that can be a side effect of L-Dopa therapy. Therefore, a system that measures motion can provide great quantitative insight into how a particular pharmaceutical intervention is affecting patient symptoms.

Experimental Methods

Experimental set-up

1. For this laboratory, you will need 5 snap leads and 5 snap electrodes from the CleveLabs kit. The accelerometer used in this lab session is located inside the BioRadio, so only EMG recording materials are needed.

2. You will be placing electrodes on the skin to record surface EMG signals. Remember that the electrodes need to have good contact with the skin to obtain a quality recording. The surface of the skin should be cleaned with alcohol prior to electrode attachment. For the best recordings, it is best to mildly abrade the surface of the skin with pumice, or equivalent, to minimize contact resistance by removing the outer dry skin layer.

3. For this lab session, we will be measuring the EMG activity of the carpi extensor (wrist extensor) and palmaris longus (wrist flexor) muscle groups during certain activities. Attach two electrodes approximately one inch apart over the wrist extensor muscles. The wrist extensor muscles are located on the dorsal side of the arm about one third of the way up from the wrist to the elbow. You can find this muscle by feeling the dorsal forearm as you extend and relax your wrist.

4. Next, attach two electrodes to the palmaris longus, or wrist flexor muscles located on the ventral side of the arm about halfway between the wrist and the elbow. You can find this muscle by feeling the ventral forearm as you flex and relax your wrist.

5. Finally, attach the last electrode to the elbow. This will serve as the ground electrode for the experiment.

6. Attach the snap leads to the electrodes and connect them to channels 1 and 2 of the BioRadio as shown below (Fig 5). For EMG recordings the polarity of the signal does not matter. However, the wrist extensor inputs should be connected to channel 1 and the wrist flexor inputs to channel 2.

7. Turn the BioRadio on

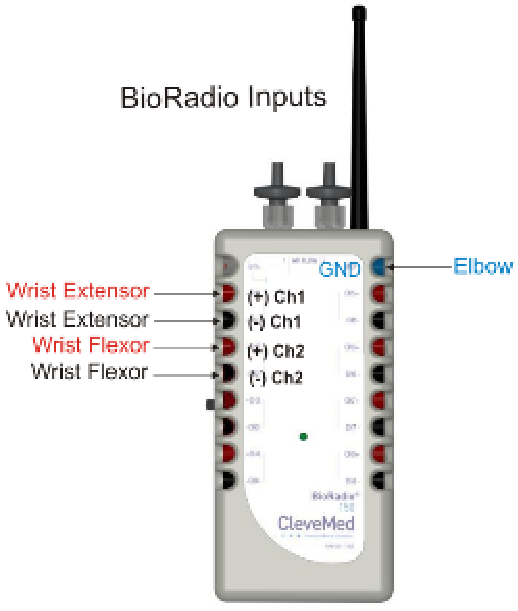


Figure 5. BioRadio set-up for the accelerometry laboratory session

Procedure

1. Run the CleveLabs Course software. Log in and select the "Accelerometry Lab" located under the "Engineering Basics" subheading and click the "Begin Lab" button. The CleveLabs software will automatically program the BioRadio to the "Accelerometry" configuration.

2. Click on the BioRadio Data Tab, then click on the "Start" button. Two channels of EMG data and a digital display of acceleration output voltage should be scrolling across the screen.

3. The first part of this lab will consist of familiarizing yourself with the accelerometer function of the BioRadio. Observe what happens to the acceleration output as the BioRadio is rotated about its different axes.

4. Now click on the "Spectral Analysis" Tab, and then click on the "time domain" subtab. Change the channel to process to be 3. The order of the channels to process is 1. EMG 1, 2. EMG 2, 3. Accel X, and 4. Accel Y. Move the BioRadio back and forth and observe the time plot. Make sure you have a clear understanding of which axis the Acceleration X is sensitive to and which the Acceleration Y is sensitive to.

5. Now, click on the "frequency domain" sub tab. Move the BioRadio back and forth with small amplitude as quickly as you can. Observe what happens to the spectral content of the signal.

6. Repeat step 5, but now set the filter to a high pass filter with a cutoff of 0.5 Hz. Move the BioRadio back and forth with small amplitude as quickly as you can. Observe what happens to the spectral content of the signal.

7. Click on the "Accelerometer Calibration" tab. You will now calibrate the accelerometer channels to gravity by calculating the correct gains and offsets to multiply the electrical output by. When the vector for a particular axis is pointing in the direction of gravity the output of this plot should read 1G. When it is pointing in the opposite direction of gravity it should read –1G. When it is pointing in a direction perpendicular to the gravity vector it should read 0 G. Select appropriate gains and offsets for both accelerometers to accomplish this. Note the gains and offsets that you use.

8. Now measure a known distance of one foot. Begin moving the BioRadio back and forth in a straight line over the one-foot distance. The BioRadio should be moving in parallel with its x-axis. Record a data file approximately 20 seconds long while you do this. Name the data file "distanceX".

9. Now measure a known distance of one foot. Begin moving the BioRadio back and forth in a straight line over the one-foot distance. The BioRadio should be moving in parallel

with its y-axis. Record a data file approximately 20 seconds long while you do this. Name the data file "distanceY".

10. Finally, we will collect a series of data points that will allow you to design an algorithm that inputs either accelerometer or EMG data and outputs your wrist angle. Holding the BioRadio in the palm of your hand in a prone position, record approximately five seconds of data by clicking the "Save" button. Name this file "angle0". Extend the wrist to 45º and 90º, recording 5 seconds of data at each, naming the files "extend45" and "extend90" respectively. Finally, flex the wrist to both 45º and 90º, again recoding 5 seconds of data at each step, naming the files "flex45" and "flex90".

Data Analysis

Note: The sampling rate for the accelerometers was set to 1/10 the sampling rate of the electromyography channels during the data collection.

1. Using the mathematical tool of your choice, open the data file named "distanceX". Compute a single and double integration on the calibrated accelerometer X data channel.

2. Using the mathematical tool of your choice, open the data file named "distanceY". Compute a single and double integration on the calibrated accelerometer Y data channel.

3. Using the programming tool of your choice, open the data files that you recorded while you held the BioRadio and moved your wrist through different angles. Design an algorithm or equation that will input your accelerometer voltage outputs and automatically calculate wrist angle. Determine its accuracy.

4. Using the programming tool of your choice, open the data files that you recorded while you held the BioRadio and moved your wrist through different angles. Design an algorithm or equation that will input your EMG voltage outputs and automatically calculate wrist angle. Determine its accuracy.

Discussion Questions

1. Describe some biomedical applications in which motion sensing would be an important parameter to measure.

2. Explain how a MEMS based accelerometer works.

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3. What was the maximum frequency you were able to move the BioRadio back and forth at?

4. Why was it important to first high pass filter the accelerometer data to see a shift in frequency during oscillatory movement?

5. How accurate was the double integration as compared to the actual distance that you moved the BioRadio back and forth? What are some reasons that the two measurements were not exactly the same?

6. Were you able to successfully calibrate accelerometer values to provide an accurate wrist angle? Were you able to successfully calibrate EMG values to provide an accurate wrist angle? What method proved to be more accurate and why do you think this is?

7. Describe how a motion sensor worn on the hand could be used in a closed loop system to control medication levels in Parkinson's disease.

References

1. www.analogdevices.com
2. http://physics.kenyon.edu
3. www.parkinson.org