Lab 2 - Studying the biomechanics of the human gate using the accelerometer in your phone - Lab Instructions

Purdue University Northwest - Mechanics Lab - Professor Dolen

Introduction: In this lab you will measure your acceleration while walking. You will then use this data to calculate your velocity as a function of time as you walk. Finally, you will estimate your step distance (your displacement) using only acceleration data.

Important Concepts:

- Definitions of acceleration, velocity, and displacement
- Recording data with an accelerometer
- Motion with non-constant acceleration
- Calculating the change in the velocity of an object (Δv) with the integral of it's acceleration
- Calculating the change in the position of an object (Δy) with the integral of it's velocity
- Numerical integration

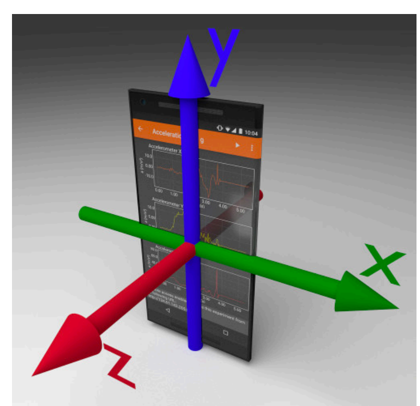
$$\Delta v_y = v_{2y} - v_{1y} = \int_{t_1}^{t_2} a_y(t)\ dt \qquad\qquad \Delta y = y_2 - y_1 = \int_{t_1}^{t_2} v_y(t)\ dt$$

Please note: This lab requires the use of a smartphone or tablet device with a built-in accelerometer (a device that measures acceleration or the rate of change of velocity). Almost every smartphone or tablet has an accelerometer built in. If you do not have access to such a device, please contact Professor Dolen or your lab instructor and they will help you. Please be gentle with your device (don't break anything!). I also recommend using a pencil rather than a pen when drawing the worksheet graphs.

Please also note: These instructions do not need to be handed in. The questions listed below are meant to make you think - you are not required to answer them directly here. On Brightspace you only need to submit the "Lab 2 Worksheet", which you will scan or take a picture of, and a screenshot of your data from the app (this is discussed further below).

Instructions:

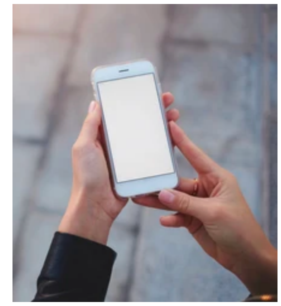
1. Download the free **physphox** app on your smartphone or tablet: https://phyphox.org/ . It is available for both Android and Apple devices. Physphox accesses the sensors in your phone and allows you to make real measurements!



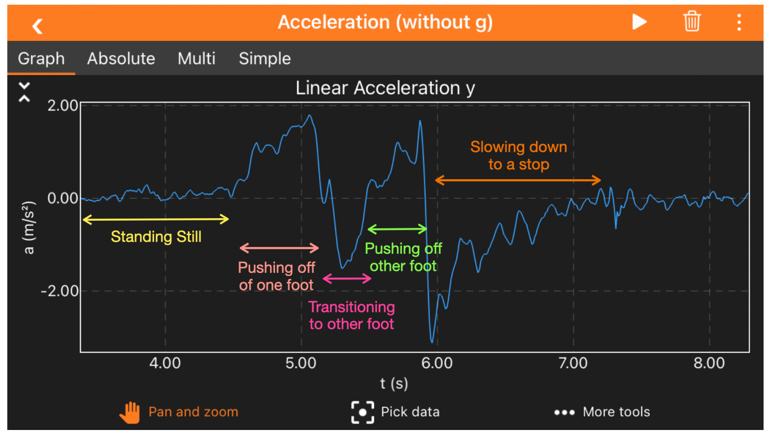
2. Open the app. Within the app click on **"Acceleration (without g)".** When you press play in this mode, the app will record and display the live acceleration readings from your phone's accelerometer. Please note the coordinate conventions:
   - The z axis is perpendicular to the screen, pointing out of it.
   - The x axis points to the right when holding the device in its default position. For phones this means, that it points to the right while looking at the screen in portrait (vertical) orientation.
   - The y axis points upwards along the long side of the phone. However, on some larger tablets, the default orientation can be landscape (horizontal), in which case x points along the long side of the device.

3. Experiment with your phone. Move your phone in +x, +y and +z and observe spikes in the acceleration versus time graph in each of these directions (you may need to place the phone on a table and push it around in order to isolate +x and +y). Press pause and then press the "trash can" icon to clear the data.

4. **Data Taking.** Now we are ready to conduct our experiment. Hold your phone so that it is completely horizontal to the ground, with the screen pointing up towards the ceiling and the long end of the phone pointing away from you (this should be a relatively natural way to hold your phone and view the screen). Our goal is to move in the +y direction. Make sure there is empty space in front of you (enough room to take two steps without hitting anything). Stand very still and hold the phone close to your body. Press the play button and wait for 1-2 seconds to allow the accelerometer to self-calibrate. Now, take two smooth steps forward. Briefly stand still and then press pause on the app.



5. Take a look at your acceleration data for your phone's +y axis. You should see that when you first started moving you had positive acceleration. Then, as you slowed down while transitioning to your other foot you should have a period of negative acceleration (presumably you had positive velocity throughout this motion, but during the transition between feet you slowed down a bit and the direction of the change of velocity was negative). Then, as you push off on to your second foot you should see positive acceleration. Finally, as you come to a stop you should see negative acceleration. Does your data match these expectations (two positive acceleration regions and two negative regions)? If your data does not make sense for a known reason, it may be a good idea to fix the problem and repeat the experiment.



Example acceleration data. Your data will be different, but the general regions of positive and negative acceleration should show a similar pattern.

6. **Data Analysis.** We will now analyze the recorded data to better understand the human gate. From this acceleration information we should be able to graph your velocity vs time as your moved through these two steps. How fast do you think you move while walking? This may also help us to gain some conceptual understanding of the m/s unit. Finally, from our velocity vs time graph we will estimate how far we walked in these two steps. Complete the following data analysis steps on the separate worksheet which you will hand in.

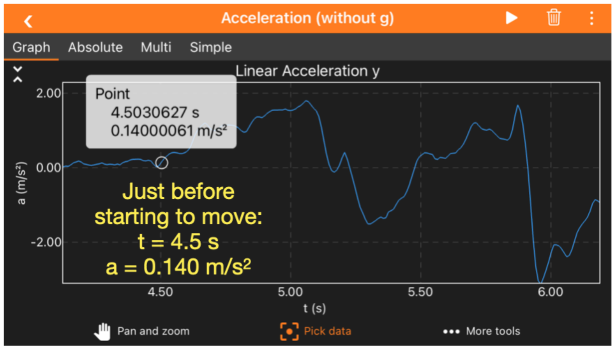
   6.A. In the Physphox app, click on the "Linear Acceleration y" graph. Turn your phone and look at your data in landscape mode. Make sure you are in "Pan and Zoom" mode and use typical two finger pinch to zoom methods to zoom in on the time period in which you were moving (the period in which the acceleration was not averaging zero). Take a screenshot and save this file to submit later.

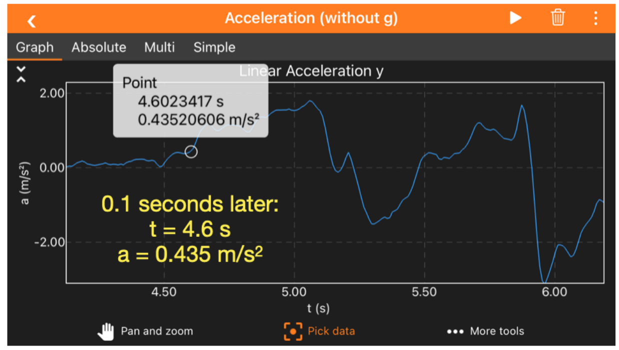
   6.B. Follow the instructions below in order to carefully **sample your recorded data and re-draw your linear acceleration in y versus time data** on the worksheet.

      6.B.1. Click on the "pick data" icon within the app. In this mode, when you click on the graph at a given point it will display the recorded acceleration at that moment (in units of m/s^2) and the time (measured in seconds). We are going to use this mode to sample the data every 0.1 seconds.

      6.B.2. Use the **"sampled data table" on the worksheet** to record your time and acceleration data. First, use "pick data" to find a time just before you started moving. Record this time and the acceleration at this moment in time (it should be close to zero). Now, select a time 0.1 seconds later by clicking on the graph in "pick data" mode. It may take some experimentation, but you should be able to get close to 0.1 seconds later (it is okay if it is not exactly 0.1 seconds). It may help to go back into "pan and zoom" mode and zoom in further before using "pick data".

Record this time and the corresponding acceleration at this moment in your table (I would suggest keeping 3 sig figs). Repeat this procedure every 0.1 seconds throughout the time period in which you were moving. In my case it took me about 2.5 seconds to complete my two steps, and therefore I needed to sample the data 25 times. *An example of using "pick data" is below, and a partial example of this table can be found on the next page.*





6.B.3. Use the sampled data table to **graph your sampled data "by hand"** on the worksheet "acceleration vs. time" graph. I recommend using a pencil for this step. The graph axes and gridlines have been pre-drawn on the worksheet, and the axes are already labeled. You will, however, note that neither graph axis contains numbers. It is up to you to **label each grid line** of the graph with the proper number (if you write small you can label each line). On the horizontal axis (the time axis) you should have enough tick marks to mark every 0.1 seconds for 3.0 seconds. On the vertical axis you will have to decide what value each gridline represents such that all of the acceleration data from your table fits within the limits of the graph (for example, every grid line could represent 0.1 m/s² or 0.2 m/s² or 0.25 m/s²...it is up to you). Draw a dot with a pencil on the graph to record each data point from your table. Finally, connect each dot with a straight line. *A partial example of this graph can be found below.*

6.C. In this step you will **perform an approximate integral of your acceleration data** by calculating the area under your graph numerically. We conceptually understand that the integral of an acceleration vs time graph tells us the change in velocity (Δv) within the integrated time period. By performing this integral every 0.1 seconds, we will be able to record and graph the velocity versus time at every time step during the experiment.

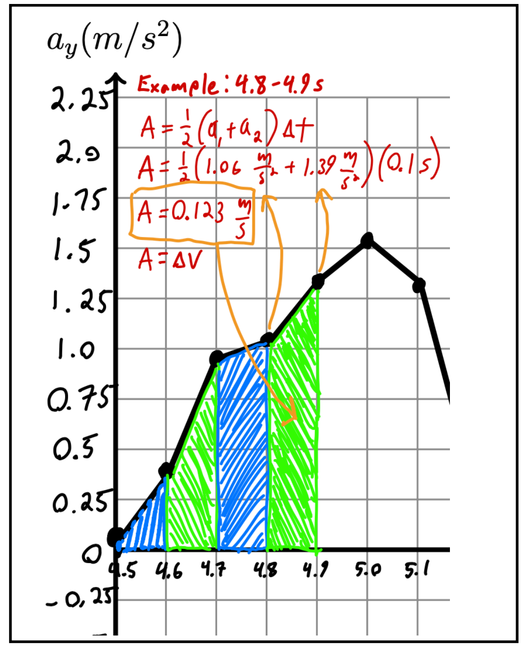
6.C.A. We do not know the exact functional form of our acceleration. Therefore we will utilize **numerical integration** techniques to calculate the integral. Numerical integration is not exact (there will be some associated uncertainty) but it is often our best option.

6.C.2. The numerical integration technique we will be using is known as the **"trapezoid rule"**. We know the area of a trapezoid is given by $A = (1/2)(a + b)w$, where a and b are the length of the parallel long and short sides of the trapezoid, and w is the distance between the parallel sides. Looking at our graph from part 6.B., we can see that the area under the line between any two neighboring data points forms a trapezoid. Therefore we can easily calculate the area of this trapezoid with the formula:

$$A = \frac{1}{2}(a_1 + a_2)\Delta t$$

Here a_1 and a_2 are the two measured acceleration values and Δt is the time elapsed between the two measurements (Δt should always be 0.1 seconds for our sampled data).

6.C.3. **The "sampled data table" on the worksheet contains two additional columns:** Δv, corresponding to the change in velocity, and v, corresponding to the instantaneous velocity, respectively, at each time step. The first row of your table corresponds to the time just before you started moving, and therefore both Δv and v will be zero. Determine your change in velocity during the next 0.1 seconds by estimating the area under the graph during this time period using the trapezoid rule. Record the area of this trapezoid within the Δv column in your table. The velocity for each time step will be equal to the velocity in the previous time sample + Δv. Repeat this every 0.1 seconds in order to record Δv in each time step (the area under the acceleration graph during that time step) and the corresponding velocity at each moment (again, the velocity at one time step will be equal to the velocity at the previous time step + the Δv during that time step). Remember that negative area indicates negative acceleration.



Time (s)	a_y (m/s^2)	Δv_y (m/s)
4.5	0.140	0.0
4.6	0.435	0.0288
4.7	0.987	0.0711
4.8	1.06	0.102
4.9	1.39	0.123

6.C.4. Use your velocity column in the table to **fill in your velocity vs time graph**. First, label all grid lines on the vertical axis (again, you will have to determine the spacing on your own such that all of your velocity data fits within the graph). The grid lines on the horizontal axis should represent the same times as in the acceleration graph. Use your table to draw a dot representing your calculated instantaneous velocity at each given time-step. Finally, draw a straight line connected each neighboring data point.

6.C.5. Record on the worksheet what your maximum velocity was during your steps.

6.C.6. Record on the worksheet what your calculated final velocity was (this should correspond to the area of the entire acceleration vs time graph).

6.D. We will now use the velocity vs time graph to calculate your displacement during your two steps. You can either follow the same procedure as in part 6.C., or you can perform a faster but less accurate estimation by calculating the area of one box on your graph and then multiplying by the total number of boxes under your velocity line. This area should correspond to your displacement during this motion. Record this displacement in the worksheet.

7. Consider what you did here. Using your phone's accelerometer (which measures acceleration only - not velocity or displacement) you were able to calculate your velocity as a function of time and your displacement. You could conceivably do this in x, y, and z and track, at all times, your acceleration vector, velocity vector, and displacement vector. So even if GPS did not exist, you could still track your relative changes in position and velocity on earth. This is how the "Inertial navigation system" in airplanes, ships, missiles, and spacecraft work! **I hope you use this knowledge in your future careers at NASA, Fitbit, Apple, Lockheed Martin, Google, or working for any company building fitness trackers or navigation devices!**

Footnote (for those interested): There is an approximation uncertainty associated with the trapezoid rule for integration. In general, if you estimate the integral of a function f(x) from position a to position b using the trapezoid rule, the approximation uncertainty on your integral will be given by the equation $\delta = (1/12)w^2[f'(t_1) - f'(t_2)]$. Here w is the width of the trapezoid (the distance between the two parallel sides of one trapezoid) and $f'(t_1)$ and $f'(t_2)$ are the values of the derivative of the function at the location of our first data point and last data point. The derivative of the acceleration function in our example will vary, but we can estimate that the value of the term in square brackets will be around 1. This means the error in our integral of the acceleration is likely of the order $\delta \approx (1/12)(0.1s)^2[1\ m/s^3] = 0.0008\ m/s$. The errors we introduced by sampling the data and by rounding are significantly larger than this approximation error.