Department of Physics

1D and 2D Motion

1110 Lab 3

Last Edited September 11, 2023
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In this lab we will continue to explore one-dimensional and two-dimensional motion. Using Tracker we will investigate how position, velocity and acceleration of an object change during free fall or for a projectile.

I Lab Objectives

- Data Collection
- Video analysis
- Linear and nonlinear fitting of the position and velocity versus time graphs.
- Two-dimensional analysis of the independent motions in the x (horizontal) and y (vertical) direction.

II Lab Equipment

- Camera
- Tracker software
- Object of known length
- Object that bounces [1]

III Introduction

In this experiment you will investigate free fall and projectile motion of a ball. You will do that by making movies of the motion and analyzing that motion in Tracker. Keep in mind that gravity is the only force acting on the ball, and g is the only acceleration.

In the last lab we explored linear motion in one dimension. A motion is said to be linear in time when it follows the equation of a line, x(t) = mt + c, where m and c are constants, t is time, and x(t) is the x-displacement. On the other hand, if there is a non-linearity in time such as x(t) = $At^2 + bt + c$ or $x(t) = Asin(\omega t)$ we call it non linear motion. Now we are goign to look at non-linear motion in two dimensions. By two dimensions we mean that the displacement can have a nonzero component in both x and y direction.

[1] Tennis balls work best, if you cannot find an object that bounces please contact your TA.

IV Experiment I: One-Dimensional Motion

IV.1. Experimental Procedure for Free Fall Motion

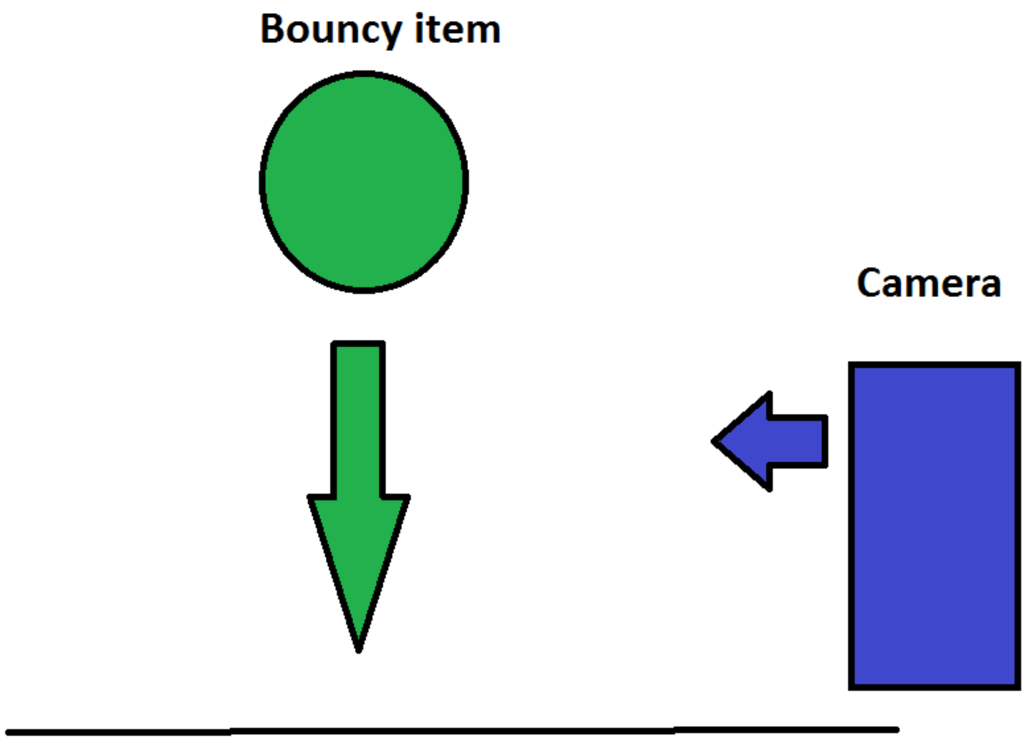

Figure 1: The green arrow points to the direction of bounce by the BNI. The blue arrow points to where the camera should be facing

1. Adjust your camera so that it is pointed at the Bouncy Item (BNI). Make sure that it is perpendicular to the motion of the bouncing ball. Please refer to figure 1 if you are not sure how to position the camera.
2. Include an object of known height in the frame of your video. It should be parallel to the path of motion.
3. The object should be dropped at least 1 m above the table or a flat surface, but still within the frame of your camera. Allow it to get at least one good and complete bounce. This might take a few tries.
4. Import your video into Tracker. If .mov format does not work, try .mp4 or other video format.
5. Add calibration stick to your object of known length mentioned in point 2. See figure 2 for the position of the button in Tracker.
6. Change the frame such that you are looking at every third frame.
7. Add a point of mass to your item, and begin tracking it. Go to 'Track' → 'New Mass' → 'Point mass'. You will have to press 'Shift' then click on the mass to begin marking it's position in the frame.
8. Change your graph to look at the motion in the y-frame in one complete trip from the table surface and back again.
9. Download your position, velocity, and acceleration graphs. See the Tracker help page for more information.
10. Plot and fit your data. For this step, we suggest using Python. The code to run this analysis in Python is presented to you in the Appendix. You can ask the TA's for help on how to use Python. However, if you are familiar with a different programming language that allows you to do the same plots and data analysis, you may use that program.

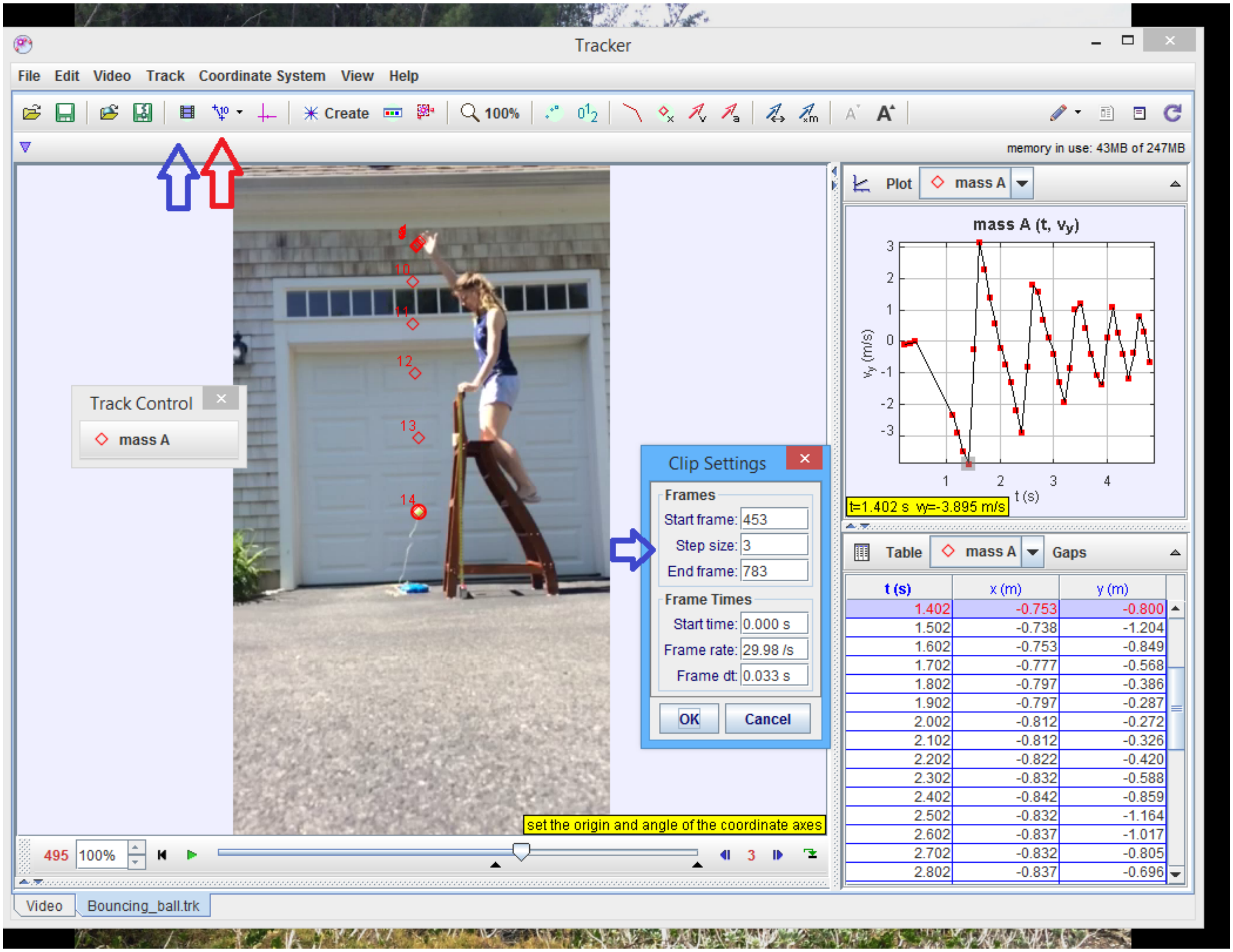

Figure 2: The blue arrow points to the 'Clip Settings' where you can change the frame rate. Analyzing every frame leads to smoother data, but takes far too long. The red arrow points to the calibration stick button.

V Analysis for free fall motion

In your programming language of choice please analyze the data from your BI drop. If you wish to use python we have example code in the Appendix and on Github you are welcome to refer to.

V.1. Position versus time

1. Perform a curve fit on the position versus time data. Based on your knowledge from lecture, what mathematical form of equation most closely describes the shape of the position graph? If you are unsure this is a good moment to go review last lecture, talk to a friend or TA during office hours.

Question 1 *Make a graph for the position in the y (vertical) direction, following all the figure and caption rules outlined in Lab 1 and the appendix. Include what form of equation describes the motion in a caption below the figure. Include your approximate fit based on the equation above. Also include a caption box outlining the fit parameters. Please add error bars on your data points representing the systematic error of Tracker or Logger Pro. For a longer discussion of systematic error please refer to the Appendix.*

Fit parameters are explained below: If a motion x(t) = 0.5t + 0.2 is fit using linear fit y = mt + L, m = 0.5, c = 0.2 are the fit parameters.

V.2. Velocity versus time

Perform a linear fit of the velocity versus time graph using Python or your program of choice. See figure 3 as a reference. Also create a caption box with the slope on it. As show in figure 3.

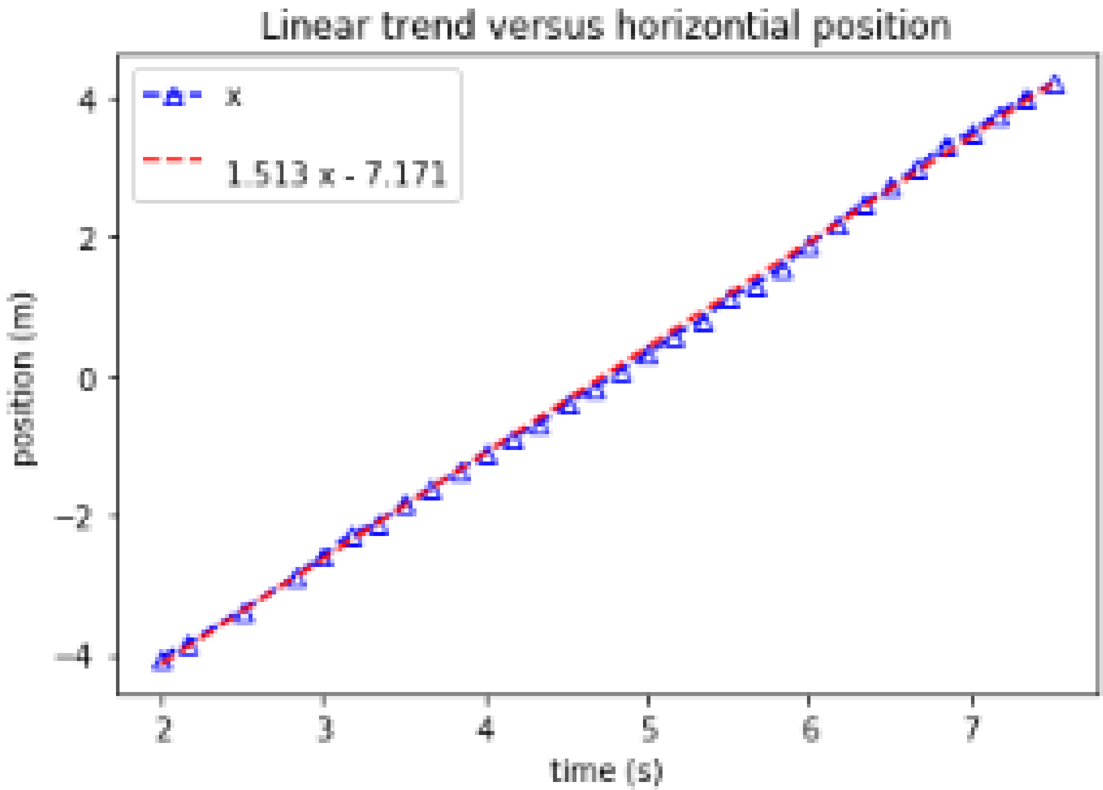

Figure 3: An example of plotting a linear trend onto the walking data that was presented in the last lab (Lab 2).

Question 2 *Graph the velocity in the y-direction, following figure and caption conventions. Include on the graph your linear fit, and what that slope is.*

Question 3 *Discuss what the linear slope on the velocity graph should represent. (3-4 sentences) Does the numerical value of the slope remind you of any other familiar constants?*

Question 4 *Include a link to your 1D motion (bouncy item) video as either a google drive link, drop box link, or some other sharing video platform that does not include uploading it to Canvas. Please make sure all the the appropriate permissions are fixed so your TA can view it. If they cannot view it we will not spend time chasing you down, we will just not give credit for this.* [a]

[a] Remember, you need to make your own video unless you talk to your Lab Instructor or Lab Manager ahead of time.

Question 5 *Experimental Method*
For this 1D motion experiment with the BNI, write down the five most important steps for your data collection, including why that step is important. Use complete sentences (one or two sentences per bullet point), and do not copy and paste the instructions above.

VI Experiment II: Two-Dimensional Motion

1. Open the file "basketball_shot.mp4" that is on the Canvas site.
2. Mark the basketball and follow it as it progresses.
3. There is a stick on the floor of the gym, which has a length of two meters. Use that for your calibration.
4. Use the origin tool in Tracker or Logger Pro to mark the first data point you made. This will make your first point zero in x (horizontal motion) and y (vertical motion). For images please see the Appendix.

VII Analysis

Question 6 *Attach two graphs of the basketball shot's movement. One should plot the movement in x- vs time, and the other in y- vs time with both the format rules (see Appendix), the appropriate fits and error bars, and a detailed caption (two to three sentences).*

VII.1. 1D BNI experiment I:

Question 7 *1D Conclusions*

Based on the data you took today please answer the following questions. Write a sentence or two for each question below:

(A) Using mathematical and physics terms, describe the motion of the bouncy item hitting the ground.

(B) What was the velocity and acceleration of the bouncy item in experiment I? Additionally, what mathematical shape was these graph of these values.

VII.2. 2D basketball experiment II:

Question 8 *2D Conclusions*
Write a sentence or two for each question below:

(A) Using mathematical and physics terms, describe the motion of the basketball in the movie.

(B) For the X direction motion, what was the velocity and acceleration, and what mathematical shape was the graph of these values?

(C) For the Y direction motion, what was the velocity and acceleration, what were the limits of the values and what mathematical shape was the graph of these values?

Based on your results listed above, what similarities of motion are there in the experiment you performed? What are the differences? If a quantity was constant write the value. If it was changing write the highest and lowest value of it.

VIII Extra Credit

Extra credit in lab only applies to lab. So if lab counts for 20% of your grade in this class, you can get a total of 20 points factored into your final grade. You cannot get over a 100% lab grade. Extra credit in lab is meant to be a challenging, interesting way to gain some points you may have lost for small errors. The extra credit assignments are often things we would love to include in the main experiment, but we just are not sure if there would be time in the two hours assigned to lab.

There is an extra credit assignment on the Canvas page titled 'WormExtraCredit1110.pdf'. For details please see that page.

IX Appendix

IX.1. Python

According to the latest TIOBE Programming Community Index, Python is one of the top 10 most popular programming languages. Python is a free, general purpose, cross discipline programming language that has moved to the forefront of many disciplines. If you decide to use Python your TA's will help you troubleshoot your code. While they might be able to help you troubleshoot when you use a different program/ code, be aware of the fact that they are not familiar with all programming codes. There are many languages (R, Matlab, Opal, Julia, etc.) out there that are just as useful as Python, but we have chosen to use python here.

Feel free to use the examples incorporated in this lab as references. See this Github repository for our examples. We hope at the end of this term you will be able to add to your resume "Proficient in Python".

To upload your Tracker csv files to jupyter, see figure 4. To get the data in Tracker into a csv copy and paste the data table into an excel or notebook file and save as .csv. You may have to edit the headings of the csv to get it to properly run with this python example.

Then refer to figure 5 for an example of how to plot your data. This is data from Lab 2, question 1. The code is located on Github.

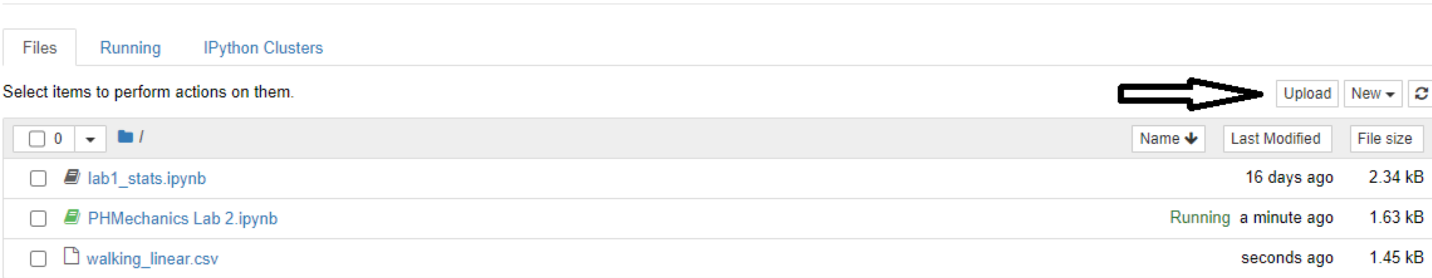

Figure 4: The black arrow points to the 'upload' function.

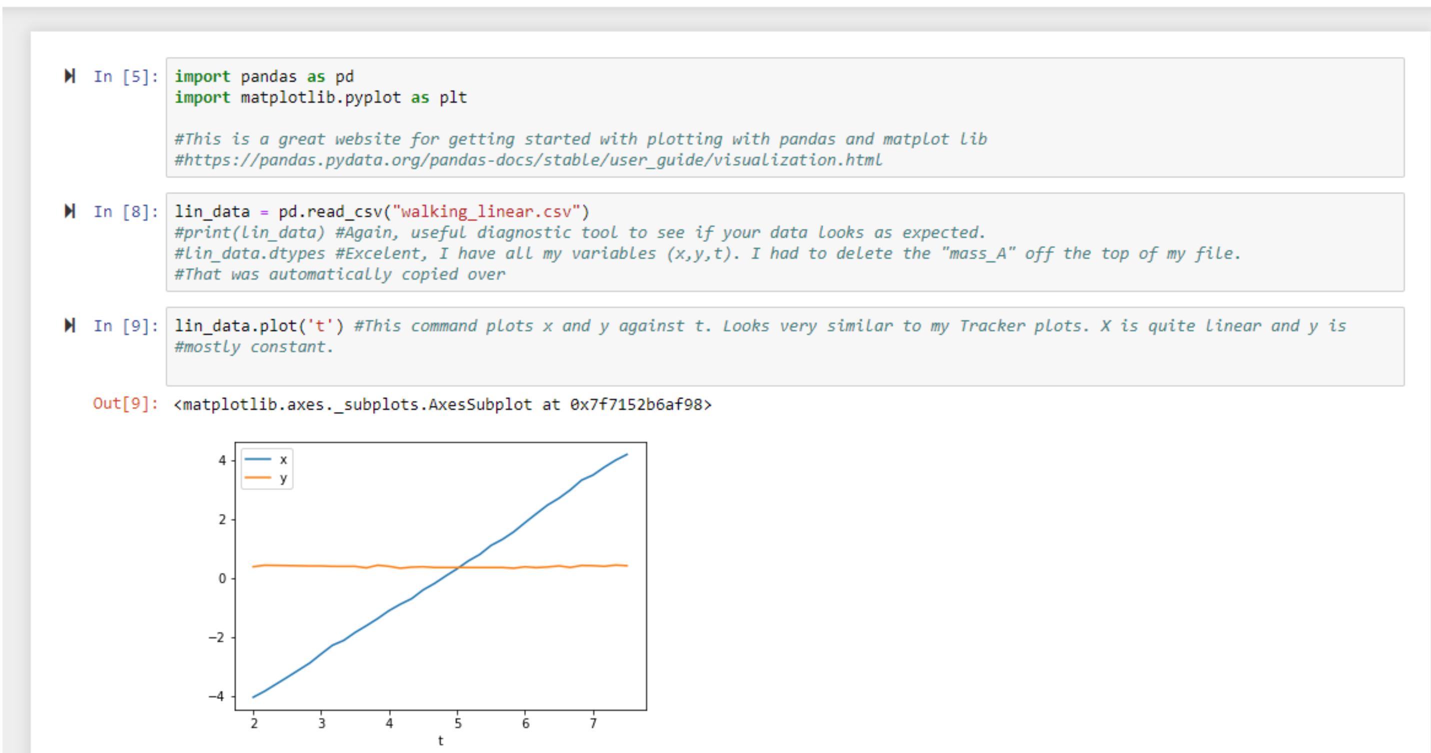

Figure 5: Example of how to upload your data (named walking_ linear.csv in this example) into your jupyter python code. Use the link https://jupyterhub.wpi.edu/hub/login to access the jupyter hub.

```
In [53]: fit_bounce1 = numpy.polyfit(t_bounce1, y_bounce1, 2) #notice that it's t (time) then x (position). 1 refers to linear here.
         p = numpy.poly1d(fit_bounce1) #Do this to convert it into a usable form for plotting
```

```
In [54]: fig=plt.figure() #initiate the figure
         ax=fig.add_subplot(111) #So we can add multiple lines

         ax.plot(t_bounce1, y_bounce1, c='b',marker="^",ls='--',label='y',fillstyle='none') #Data is horizontial axis, then vertical axis
         #ax.plot(ball.t,ball.y,c='g',marker=(8,2,0),ls='--',label='y') #Saving time versus vertical position for later
         ax.plot(t_bounce1, p(t_bounce1), c = 'r', ls = '--', label= p) #plotting the linear formula

         #plt.text(2, 0.65, 'y = {} x + {}'.format(m, b)

         plt.legend(loc=2) #Legends are very useful
         plt.draw()
         plt.title("Polynomial trend versus vertical position")
         ax.set_xlabel('time (s)')
         ax.set_ylabel('position (m)')
         print(p) #So you can see the form of the polynomial that was fitted. In this case it is y = mx + b
         #plt.text? #another way to add annotations to a plot
```

```
        2
-3.636 x + 14.52 x - 14.76
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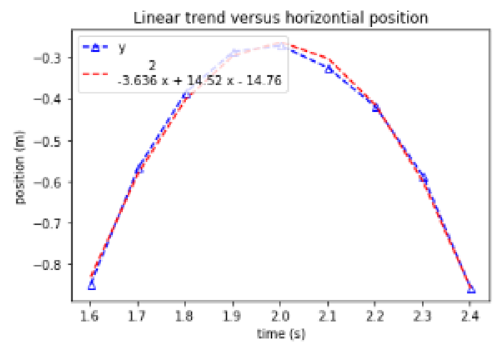


Figure 6: This is an example of a fitted bounce.

IX.2. Review of Figure Guidelines

There are a few very important aspects to creating a proper figure and caption. If you follow these rules, not only will you get points on your physics lab grades, you will impress your instructors and peers in the future. When you submit to a journal they will have very specific guidelines for your captions and figures, for example Physical Review letters publishes their guidelines here.

IX.2.1 The Caption

- The caption should start with a label so you can reference the figure from other places in your paper/report. For this course you should use "Figure 1", "Figure 2", etc.
- The caption should allow the figure to be standalone; that is to say, by reading the caption and looking at the figure, it should be clear what the figure is about and why it was included without reading the whole paper.
- The caption should contain complete sentences and be as brief as possible while still conveying your information clearly (this is not always easy).

IX.2.2 The Figure

- Make sure that the resolution is high enough to not be pixelated at its final size.
- Check that any text is readable at the final size
- For graphs, ensure that the axes are labeled (including units) and that there is a legend if you have multiple data sets on the same graphs.
- Re-scale every plot to reveal as much information as possible. Figures 7 and 8 show velocity versus time data. The two plots are the same data, but Figure 8 reveals much more information. Be sure your graphs look more like Figure 8, with detail easy to see rather than like Figure 7.

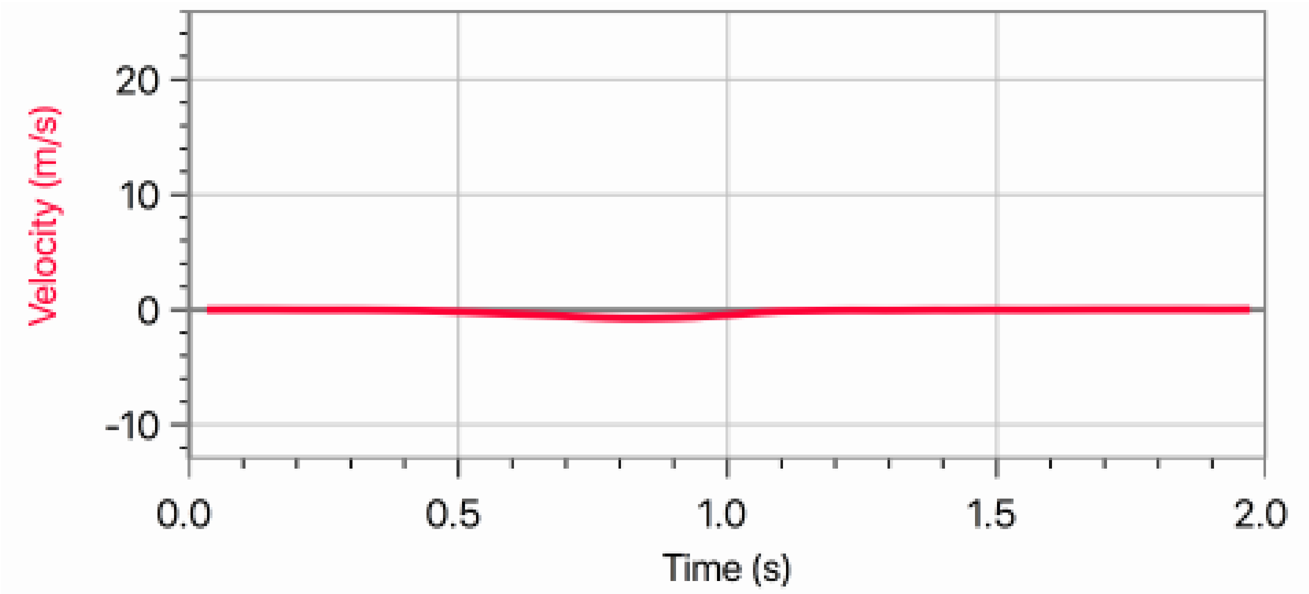


Figure 7: Above is an incorrectly scaled velocity vs time graph. Note that the velocity dip is not well defined and there is a lot of wasted space. At least the axes are labeled and units are included!

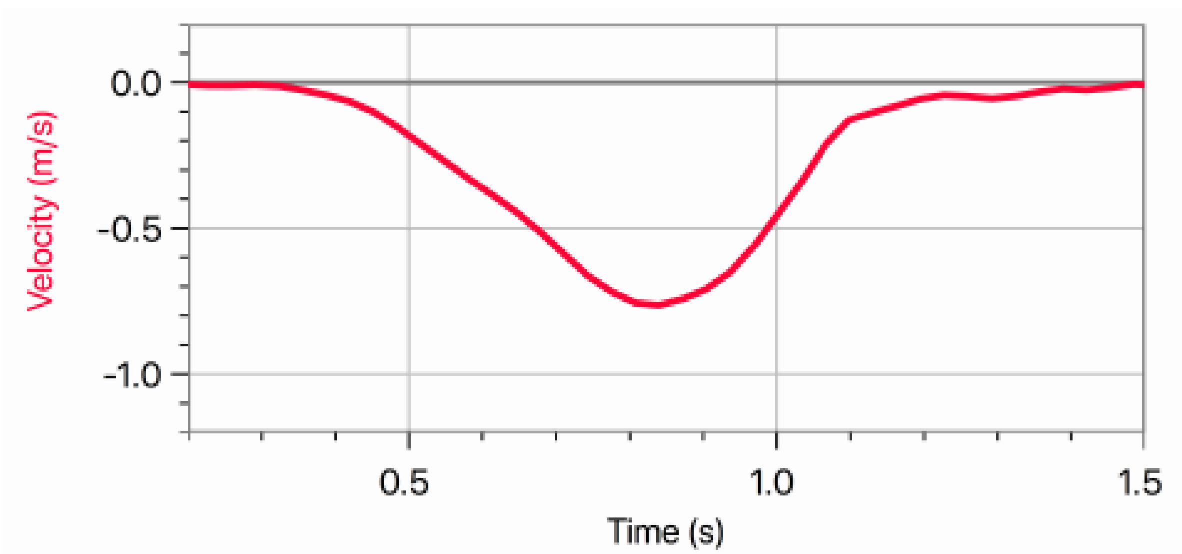


Figure 8: This is a correctly scaled velocity vs time graph. We can see that the minimum value for the velocity is between -0.5 and -1 m/s and occurs between 0.5 and 0.1 seconds.

IX.3. Systematic Error

As a review from lab 1, systematic errors are due to identifiable causes and can sometimes be eliminated. Caused by biases in the equipment or experimental procedure they cause values to be shifted positively or negatively from the real value. They can sometimes be caused by human errors.

As opposed to statistical errors which are positive and negative fluctuations that cause measurements to be either too high or too low. They can often be eliminated by taking more measurements. Sometimes called random error, as it's often random in nature.

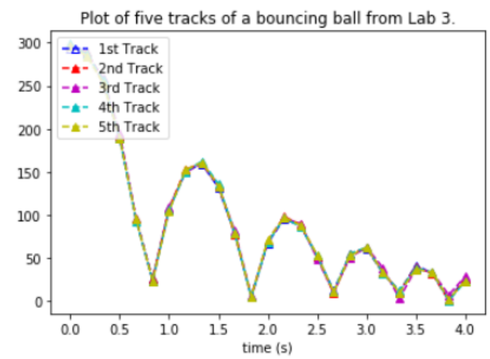
You will all know that adding measurements is trivial, but what about adding the uncertainties? In the case of adding and subtracting measurement values together the equation for combining uncertainties is:

$$\delta x = \delta x_1 + \delta x_2 + \delta x_3, \tag{1}$$

where δx is the total uncertainty in your length calculation and δx_1, δx_2, δx_3 are the uncertainties of your individual measurements. This is called error propagation. Notice that your final error is much larger than the error of any individual measurement.

I

This 2009 article provides a great theoretical basis for how to find the systematic error in Tracker, but the images have been lost [?]. The author, Rhett Allain who now writes for Wired, begins by assuming most of their error will be from humans placing the points on the Tracker software. To that end he tracks the same motion 5 times, and then looks at the differences in between those tracks. You can see a replication of that in 9.



As you can see they are all fairly similar to each other, but there do seem to be slight differences. We can quantify that a bit more by looking at how different they really are from each other. Thinking about it some more, however, I should have considered calibrating because that is going to introduce a lot of error into this. Maybe next lab.

Figure 9: Analyzing the video of the Lab Manager dropping a tennis ball (you can see a screenshot of that video above), and then tracked the tennis ball 5 times, resetting the data each time. There were 24 points per tracking sequence, so a total of 120 points.

His conclusion that the human error of placing the tracker marks down comes to less than 1%.