

§ 1 Introduction

In this laboratory you will practice using the program Tracker to measure the position of an object and think a bit about experimental uncertainty and the definition of velocity. While you are doing this you will also be practicing the instructional procedures we will be using in this class.

§ 2 Get the program Tracker and test it

Procedure 2.a

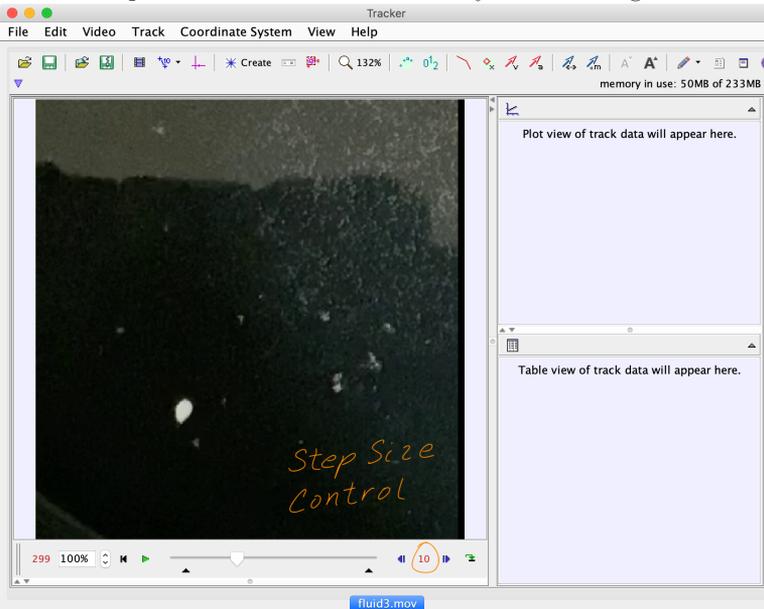
Download this [video](#). It is a video of a seed floating in water that is being heated from below. The seed follows the motion of the water and thus allows us to see the motion of the water.

Procedure 2.b

Go to the website <https://www.physlets.org/tracker/> and download and install the program Tracker onto your computer. Tracker has many features but we will only be using a few, so don't dive too deeply into the documentation unless you are just curious. There is a "Quick Start Video Tutorial" available under the help menu. The first minute and fifty seconds of this video will likely be enough to get you started.

Procedure 2.c

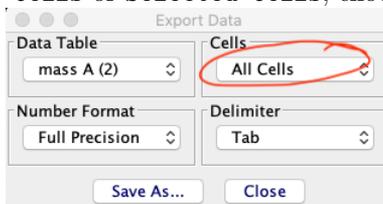
Launch Tracker and import the video to Tracker. You will find the import function under the **Video/Import** pull down menu. Once the video has been imported, track the motion of the seed. The tracking function is initiated by the **Track/New/Point Mass** menu. The seed is moving slowly so we do not need to track every frame, you should set the "step size" in Tracker to 10. See the screenshot below for the location of the step size control. If you click on the step size number in the window you can change it.



Notice that for each frame you track, Tracker enters the time of the frame and the (x, y) coordinates of the seed into a table.

Procedure 2.d

Once you are done tracking the seed, export this table to a text file called `water.txt`. The export function of Tracker is under the **File/Export/Data File** menu. Sometimes in the Export Data dialog box there is an option to export either **All Cells** or **Selected Cells**, choose **All Cells**.



Open the text file `water.txt` you just created to be sure that the numbers in the file are the same as Tracker's data table.

Procedure 2.e

Go to the [class webpage](#) and download the apps for this lab. In the folder you download there will be three applications. One is an installer for the app `Lab1p1`. When you install `Lab1p1` it will also install a supporting program Matlab Runtime from Mathworks. Use the default location for the installation of Matlab Runtime or there will be issues later. When we use similar analysis programs in the future this Matlab Runtime will not need to be installed again, so the process will go more quickly in the future.

Procedure 2.f

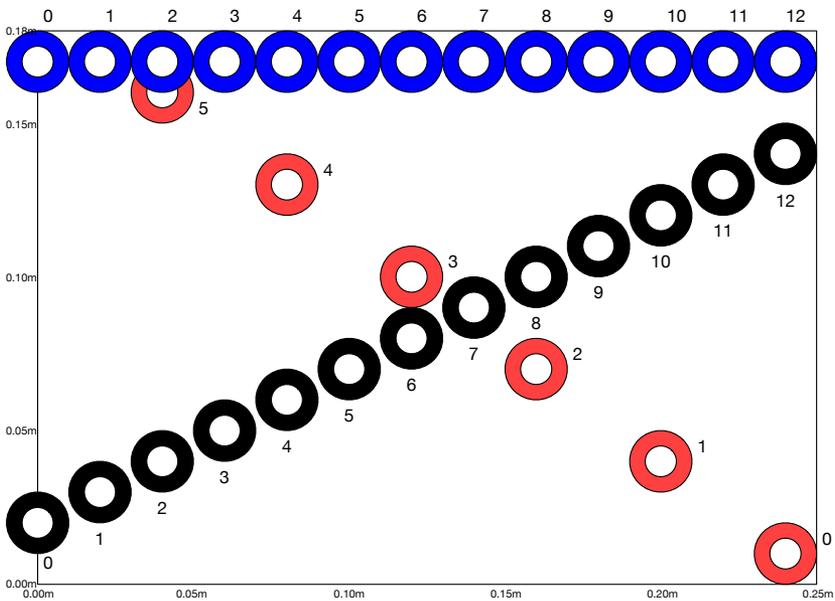
Now search your computer for the file `Lab1p1.app`, and launch it. Once the window is open press the "load data file" button and you will get a dialog box in which you can select the data file `water.txt` you created. After the data is loaded the program will make some graphs of the seed's motion.

▷ QUESTION 1

There are two times where the seed nearly stops moving. Using the graphs of position versus time find these two times. How do you know by the position versus time graph that it has stopped moving?

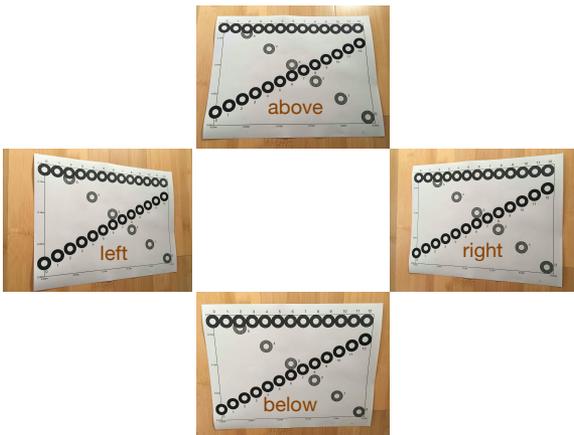
§ 3 Tracking a known trajectory

You will now track a trajectory with a known path so that we can check the accuracy of the video tracking measurements. You have been provided with a sheet of paper that looks something like this, but not colored ... sorry.

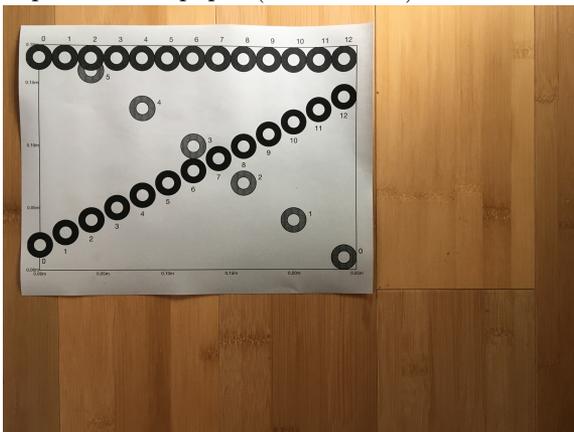


Procedure 3.a

Place the paper so that it is close against a flat surface. Set up the camera so that you can see all of the paper in the image. The camera cannot be hand held, since it will need to be absolutely motionless while recording the video. Be sure that the rectangle of the paper remains a rectangle in the image. In the images below one can see that sides of the paper are not parallel. This is because the camera was not directly over the paper and was still aimed at the paper. This caused the plane of the camera to tilt relative to the plane of the paper.

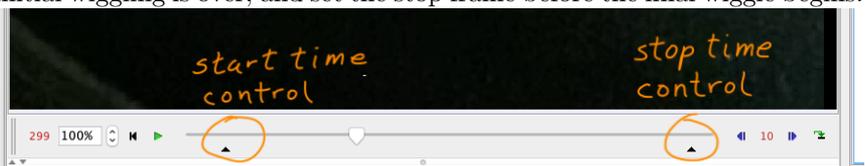


If you keep the plane of the camera parallel to the plane of the paper, the rectangle will remain a rectangle. In the following image the camera was below and to the right of the paper, but the plane of the camera remained parallel to the plane of the paper (more or less).



Tracker has the capacity to correct for a misalignment of the planes, menu item **Video/Filters/Perspective**, but it is easier to just avoid the need for the correction by setting up the camera so that its plane is parallel to the plane you are trying to image.

Once the camera is well positioned make a short video maybe 3-5 seconds. The camera may wiggle a little when you start and/or stop the video but this is ok, since you can in Tracker set the start frame after the initial wiggling is over, and set the stop frame before the final wiggle begins.



Procedure 3.b

The paper has a rectangle on it that is 0.25m wide by 0.18m tall. Set the axis of Tracker so that the origin is at the bottom left of the rectangle, and the x -axis is along the bottom edge of the rectangle. Use the 0.25m side to set the “calibration stick” of Tracker. If the y -axis is not along the left edge of the rectangle, then the video will need to be retaken or you will need to use the perspective correction filter.

Procedure 3.c

Now clearly nothing is really moving in this video, but we will imagine that at $t = 0$ (the first frame) the black, red and blue objects are at the location marked 0 and that in the second frame the objects move to the locations marked with 1 and so on. Track the motion of the black object as a point mass, **Track/New/Point Mass**. Tracker will refer to this as “mass A” from here on. Do the same for the blue object (mass B) and red object (mass C). Also track the black object a second time (mass D). Then save the data

tables for these four tracks to a text files as you did with seed track.

Procedure 3.d

In the downloaded folder there is also the app **Lab1p2**. Launch **Lab1p2** and have the app load the data file for the red object. The program makes a number of calculations and plots some graphs.

The first calculation and graph is of the velocity. The velocity is calculated as follows. We start with the data table of times and positions. For the red object we have six times $t_0, t_1, t_2, t_3, t_4,$ and t_5 . Similarly we have six horizontal positions x_n and six vertical positions y_n . Velocity is defined to be the rate of change of position with time. For the horizontal position this is

$$v_x = \frac{x_{\text{final}} - x_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}$$

which is the slope of the x versus t graph. So for example we could take two consecutive positions x_3 and x_4 and calculate

$$v_x = \frac{x_4 - x_3}{t_4 - t_3}$$

which gives us an estimate of the velocity at the time midway between t_3 and t_4

$$t_{\text{mid}} = \frac{t_4 + t_3}{2}.$$

▷ QUESTION 2

Use your data table for the red object and verify the programs graph of v_x at the time $\frac{t_4+t_3}{2}$. Note that if you hover over a point in the graph the coordinates of that point will be displayed. Do the same for the time $\frac{t_3+t_2}{2}$.

When the program has finished computing the velocity it next computes the acceleration. The acceleration is the rate of change of velocity with time. That is acceleration is compute from velocity in the same way that velocity was compute from position.

$$a_x = \frac{v_{\text{final}} - v_{\text{initial}}}{t_{\text{final}} - t_{\text{initial}}}$$

▷ QUESTION 3

Using two consecutive points in the v_x graph compute one acceleration in the a_x graph. Does that point in the graph of acceleration have the value you computed?

Procedure 3.e

Run the other two data sets and save the images produced.

▷ QUESTION 4

Since the actual motion was know in this case the program was able to also compute the measurement error in our observations. These errors are inherent in our measurement system. The error in position and velocity is graphed. The error in acceleration was not graphed because the actual acceleration is zero and any measured acceleration is an error. Note the quality of the errors for the three objects. Do the errors appear to be random or is there a pattern to the errors? What do you think is the source of the errors?

Procedure 3.f

Launch the app **Lab1p3**. This program will allow you to load both of the data files you have for the black circles, and it will compare these two measurements.

▷ QUESTION 5

Does this comparison help you clarify the sources of measurement error?

▷ QUESTION 6

Roughly we expect for this measuring system that the size of the error in position will be a percentage of the width visible in the image. Estimate the percent error in position using the largest error δx observed for your positions.

If we compute the velocity with positions containing errors then we will have errors in the computed velocity. Let δx be the upper bound on the error in a given position. That is

$$x_{\text{observed}} = x_{\text{actual}} \pm \delta x$$

The error δx could either be added or subtracted from the true value, thus the error in $\Delta x = x_{\text{final}} - x_{\text{initial}}$ will be two times δx since both x_{final} and x_{initial} have a potential error of $\pm \delta x$. This leads to an estimate of the upper bound of error in velocity to be

$$\delta v = \frac{2\delta x}{\Delta t}$$

where $\Delta t = t_{\text{final}} - t_{\text{initial}}$ and we assume that the times are exact. For most videos $\Delta t = 0.033\text{s}$.

▷ QUESTION 7

Compute $\frac{2\delta x}{\Delta t}$ and compare it with the actual error you see in velocity.