WPI | Department of Physics

Graphing Motion

111X Lab 2R

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Abstract

We use linear motion to explore good graphing techniques and conversions between position, velocity, and acceleration. Motion graphs are a good way to visualize the motion of an object in one direction. They can provide information regarding the direction, velocity, and acceleration of an object. From driving your car to dropping an object, linear motion concepts apply to many situations encountered in everyday life. In this laboratory, we use linear motion to explore good graphing techniques and conversions between position, velocity, and acceleration.

Lab Objectives

- Reporting a measurement
- Linear fitting and statistics
- Interpreting graphs of motion

Lab Equipment

- Camera, a cell phone camera is perfect for this experiment.
- Tracker Software [4]
- Object of known length to calibrate on (ruler, friend of known height, 8"x11" piece of paper etc.).

Links for this lab

- Tracker Software [4]
- this whale shark

Experimental Background

Time Measurement

Your measurements are only as good as your instruments. Most smart phones shoot video at 30 frames per second (fps) [3] . When we analyze our data, however, we wish to keep track of time and position.

Position Measurement

Please download the Tracker software here. In the following section you will learn how to:

- track an object
- calibrate on an object of known length
- change the axes.

Introduction to video analysis

We will begin by all analyzing the same video, then we will ask you to create your own video to analyze.

Question 1 *Roughly sketch your best guess for the the velocity, v(t), and acceleration, a(t), graphs you would expect to get for the motion of this whale shark in the x direction using drawing tools in word. In word you can use Draw − >Draw with Trackpad to make a graph. Or you can do it with pen and paper and include a picture of your 2 graphs in your document.*

Getting started with Tracker

1. First download Tracker. We recommend using the site here and this short video here. Tracker is a free software designed for high school and college physics, and was written by a physicist. To that end if something breaks in your Tracker program please ask for help from us, or the community here.

2. After you have downloaded Tracker, download the file " WhaleShark.trz " from the Canvas site. It is also this gif from the Georgia Aquarium from our Canvas site[2]. You will see a whale shark swim across the screen in this gif.

3. Then move the whale shark video from the downloads folder to your Tracker folder.

4. Then open your file in Tracker using the open file button ().Sometimes Tracker cannot open .Mov files, if that is the case please try converting to a .mp4 file.

5. After opening up your tracker file go to Clip Settings, as highlighted in figure 8. We recommend only analyzing short clips, never longer than a minute long unless you are skipping many steps. **Please aim to have somewhere from 20 to 50 tracked points.**

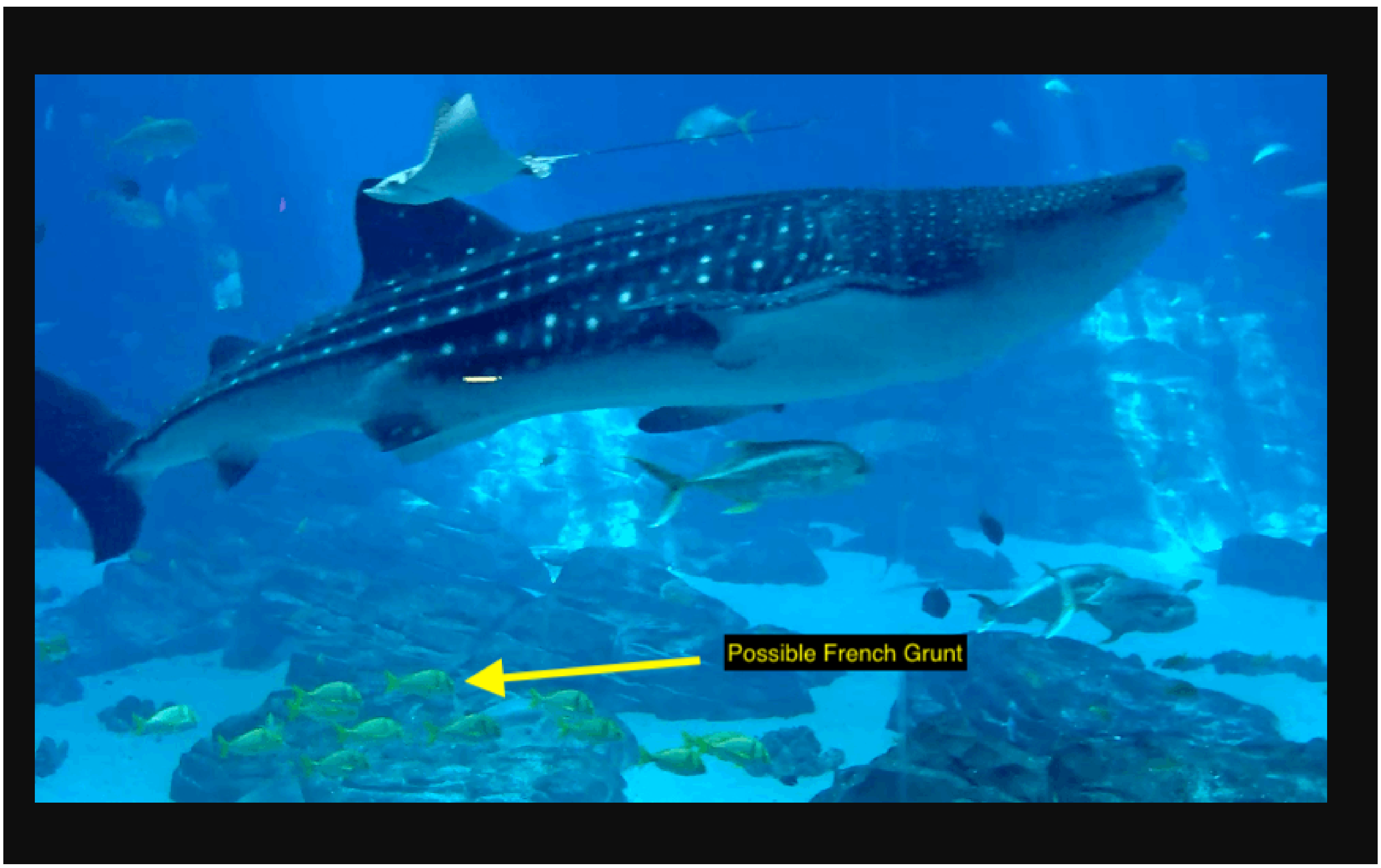
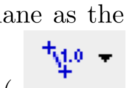


Figure 1: Screenshot of Whale Shark gift provided by the Georgia Aquarium. The yellow fish were identified as French Grunts, which grow to around 6 inches (or .15 meters) in length.

6. **Calibrate:** In the image captured in Figure 1 you can see that the yellow fish are on about the same plane as the whale shark. Therefore, we will use those as our calibration item. The calibrate button is in the top row (

). Then you will choose the Calibration Stick(see Figure 3), which you can move around by clicking the center of the stick or the ends which will let you resize it.

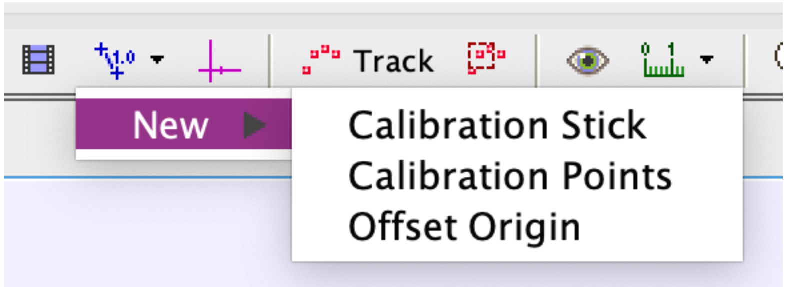


Figure 2: Screenshot of the Calibration menu. Use the Calibration stick to calibrate on

7. Use the calibration stick tool to label one of the yellow fish as 0.15 meters. To change the size of the calibration stick click the number in the center of the tool. In the picture below the calibration stick is set to 2.000 meters. This is only an approximate length of the French Grunt, as we consulted with a coral reef expert, not fish expert. Next we will track the whale shark as it moves across the screen.

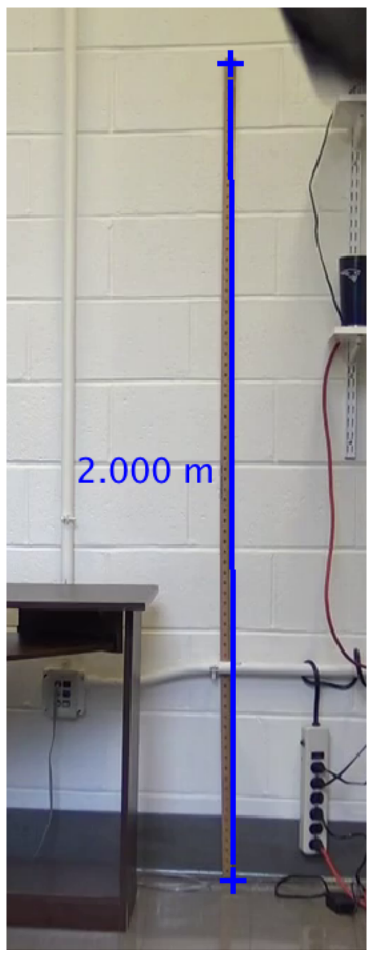


Figure 3: Example of calibration stick. To move it around click the center of the stick. To resize the calibration stick click on the t's on top or bottom of the stick. Then to change the calibration size you can click on the number. In this example it is 2.000 m.

Adding tracking points to the whale shark:

8. Click on the Track button () and go to Track → New → Point Mass. Your first mass will be mass A, second mass B and so on and so forth. You may relabel them if you like by double clicking on the mass.

9. Then move your mouse to the part of the whale shark you wish to track. You can choose any part of it so long as you're consistent.

10. To add the first tracking point hold down the shift key, and click on the spot you wish to put a point. Tracker will automatically move the movie to the next frame, so you can continue pressing shift-click until you are done. That will immediately show up on the graph on the right. You can change what the graph is looking at by double clicking on the vertical axis, as seen in figure 7.[1]

    Some notes about tracking

    - Try and stay consistent in the part of the whale shark you track.
    - When you add tracking points please try and limit the amount of points you add. This is just to minimize the amount of time it takes for you to process a video. We suggest you add a maximum of 50 tracked points. Unless you are using the Tracker auto-track feature.

    After you have added your points you will see a position versus time profile pop up. In Tracker and Logger Pro you can change that to show velocity versus time.

Question 2 **Describe graphed velocity**

Looking at the velocity profile, how would you characterize the whale shark's movement in x using words? (1-2 sentences)
Please include the following whale shark graphs:

- *Position, also written above as x(t)*
- *Velocity, also written above as v(t)*
- *Acceleration, also written above as a(t)*

Predict and recreate

In this experiment we will ask you to try and replicate the described motions with the video analysis software. You should record your own movement, unless you talk to the remote lab instructor. Here we are going to look at a non-linear motion.

Questions 3 describes a type of motion. For this motion predict the following in words:

Question 3 *An object moving past the camera with continuously decreasing speed.*

- *Qualitatively what will the graphs of x(t), v(t), and a(t) look like? (As an example, a straight line slanted up or slanted down, a constant, curving up, curving down etc.)*
- *Will the position, velocity, and acceleration be zero, positive or negative, or will it be more complex?*

(Two or three sentences)

For this experiment please use your camera to record motion you think will match question 3[2]. Then use the software to
(i) calibrate against the item of known length (ruler, lawn chair, book etc)
(ii) track the item moving across the screen
(iii) qualitatively analyze the position, velocity and acceleration profiles following the questions given in the analysis section. See fig. 4 for an example of what your tracker program will look like.

Again I want to reiterate to not track more than 50 points. Unless you are using auto-tracker it is not a good use of your time. Try and keep your video clips under a minute. Perfection is an unrealistic and undesired goal, so when you begin the process of recording video's and analyzing them please know we do not expect you to match the described velocities perfectly. This section should take you less than an hour to complete. If you find yourself still working on this section after an hour please move on or seek help from your TA's or your lab partner.

[1]Part of why we change the frame rate is so that when Tracker automatically updates to the next frame it's not every frame. This makes your overall Tracking experience faster

[2]If you can find a video online that matches the prompt then that's perfectly fine to use! Please include the link of the online video in your submission.

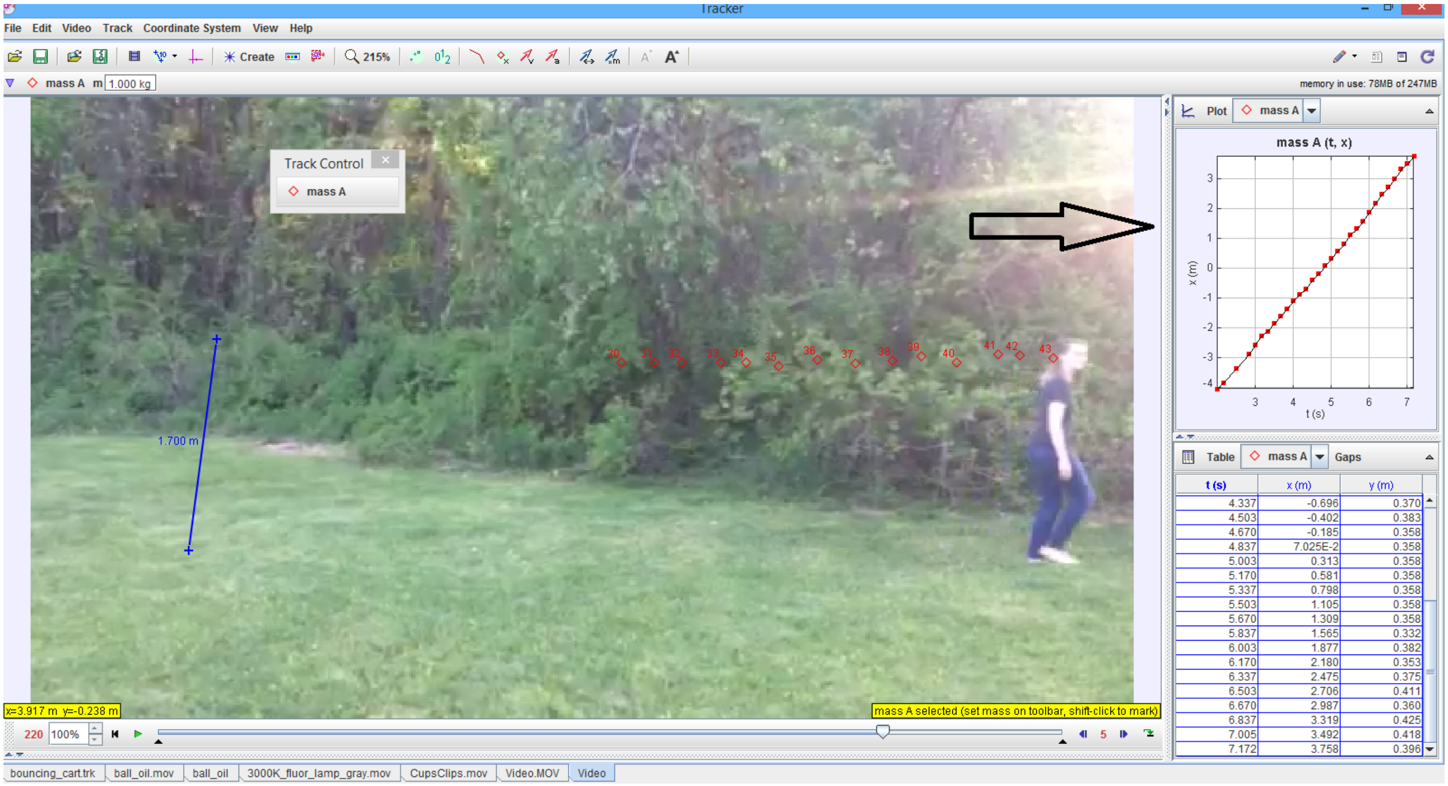


Figure 4: The black arrow points to the plot produced after adding tracker dots to your Lab Manager's face. The blue line on the left shows the calibration point, otherwise known as your lab manager's approximate height. You don't have to be walking necessary, Lab Instructor, for example, recorded a webcam video of themselves moving a pencil across the screen.

Recreate the movement

Now that you have predicted what the motion will look like, record a video recreating the movement.

Then add a new point of mass and track it through at least 20 frames on your video analysis software. If you're unsure how to do this we recommend looking at the Tracker website before you begin.

Insert your graphs into your worksheet (you can right click on the graphs to see a 'Snapshot' of the graph, then save it as a jpeg), for each motion into your answer sheet using the guidelines for Figures and Captions below.

Pay close attention to the rules for captions, as you will be graded for feedback on the axis labels. You should have a total of six figures from this part of the exercise.

Question 4 Graphing the motion

For each of your graphs, answer the following questions for the appropriate motion. Format this in the caption along with your basic description of the figure. Please include a position, velocity, and acceleration graph from your video analysis software data.

- *How do your position, velocity and acceleration graphs compare with your prediction? If you predicted ZERO for velocity or acceleration, was it exactly zero at all times? If you predicted non-zero velocity or acceleration, was the sign what you predicted?*
- *What would you estimate is the uncertainty on your graphs? Where does that uncertainty come from?*

Question 5 Method

If you could tell your past self 3 ways you could do the experiment easier, or faster what would you say?

Please reflect on what we worked through today, and write 3-4 sentences on what you think you learned during this lab.

BEFORE YOU SUBMIT, CHECK THIS

Figures and Captions

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.

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).

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 5 and 6 show velocity versus time data. The two plots are the same data, but Figure 6 reveals much more information. Be sure your graphs look more like Figure 6, with detail easy to see rather than like Figure 5.

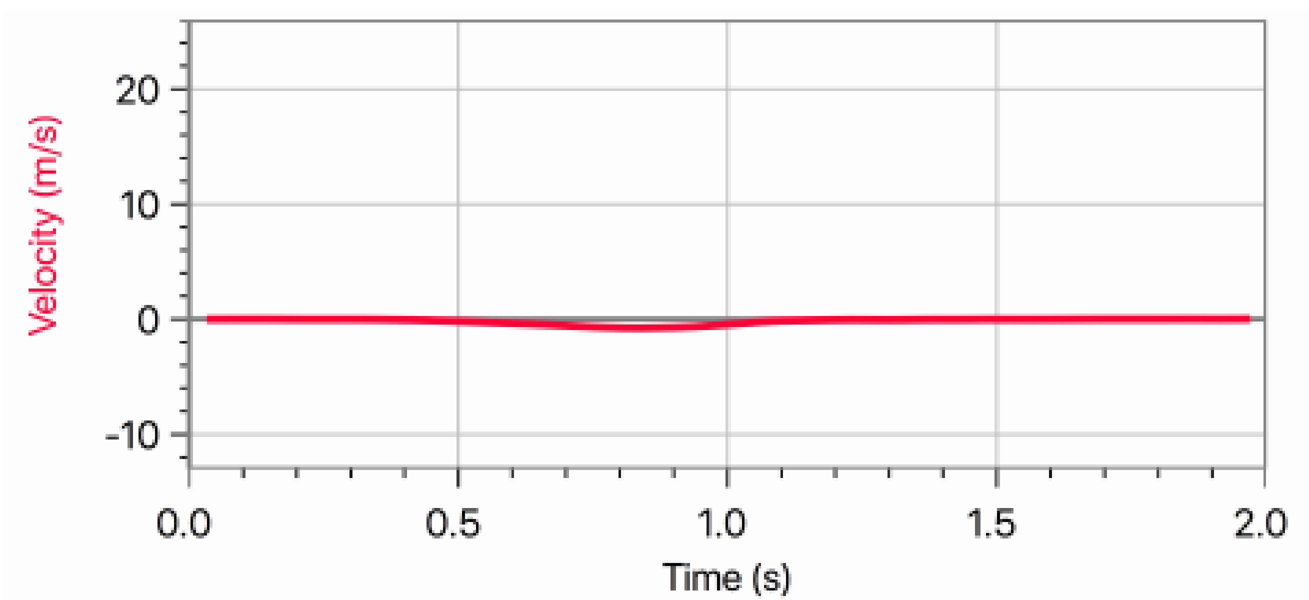


Figure 5: Above is an incorrectly scaled velocity vs time graph. Note that the velocity dip is not well defined and there is a lot of wasted space. At least the axes are labeled and units are included!

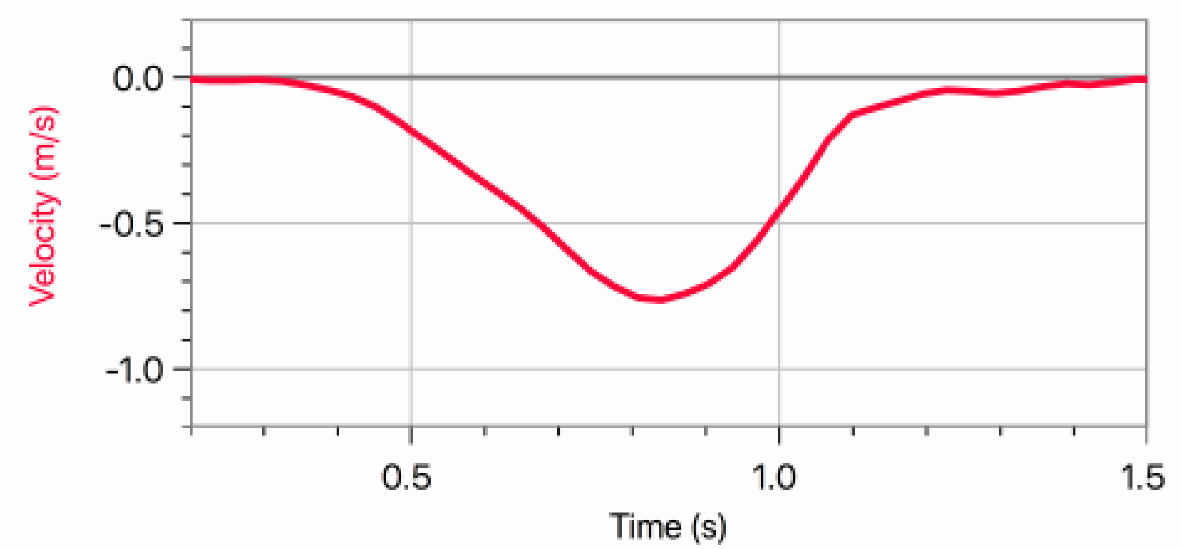


Figure 6: This is a correctly scaled velocity vs time graph. We can see that the minimum value for the velocity is between -0.5 and -1 m/s and occurs between 0.5 and 0.1 seconds.

Summary of Deliverables

1. Roughly sketch your best guess for the the velocity, v(t), and acceleration, a(t), graphs you would expect to get for the motion of the whale shark in the x direction using drawing tools in word. In word you can use Draw $->$Draw with Trackpad to make a graph. Or you can do it with pen and paper and include a picture of your graph in your document.
2. Describe graphed velocity Looking at the velocity profile, how would you characterize the whale shark's movement in x using words? (1-2 sentences)
3. Questions 3 describes a type of motion. For this motion predict the following in words:

   An object moving past the camera with continuously decreasing speed.

   - Qualitatively what will the graph of x(t) look like? Will the position be positive or negative, or will it be more complex? (As an example, a straight line slanted up or slanted down, a constant, curving up, curving down etc.)
   - Qualitatively what will the graph of v(t) look like? Will the velocity be positive or negative, or will it be more complex?
   - Qualitatively what will the graph of a(t) look like? Will the acceleration be positive or negative, or will it be more complex?

   (Two or three sentences)
4. Graphing the motion For each of your graphs, answer the following questions for the appropriate motion. Format this in the caption along with your basic description of the figure. Please include a position, velocity, and acceleration graph from your video analysis software data.

   - How do your position, velocity and acceleration graphs compare with your prediction? If you predicted ZERO for velocity or acceleration, was it exactly zero at all times? If you predicted non-zero velocity or acceleration, was the sign what you predicted?
   - What would you estimate is the uncertainty on your graphs? Where does that uncertainty come from?
5. Method

   If you could tell your past self 3 ways you could do the experiment easier, or faster what would you say?

   Please reflect on what we worked through today, and write 3-4 sentences on what you think you learned during this lab.

Graph and Data Checklist:

For each graph include an appropriate title, axes labels with the correct units, and a complete caption.

- Include three graphs of the whale shark's
  - Position, also written above as x(t)
  - Velocity, also written above as v(t)
  - Acceleration, also written above as a(t)
- You should have three graphs of the movement of question 3
  - Position, also written above as x(t)
  - Velocity, also written above as v(t)
  - Acceleration, also written above as a(t)

Appendix

Assorted Tracker problems and how to solve them

Douglas Brown, the developer of Tracker, often responds to questions on the forum in the link we just posted. We encourage you to post for help there if you have an unique problem, but please be very polite. If you ever want someone to look over your wording before posting, please ask.

When first opening the whale shark gif your tracker may complain that it's out of memory. To increase the amount of memory your Tracker program is allowed to use click on the top right notification that says "memory in use: xxMB of yyMB". There you can set memory size. We recommend 500 MB for processing this shark clip.

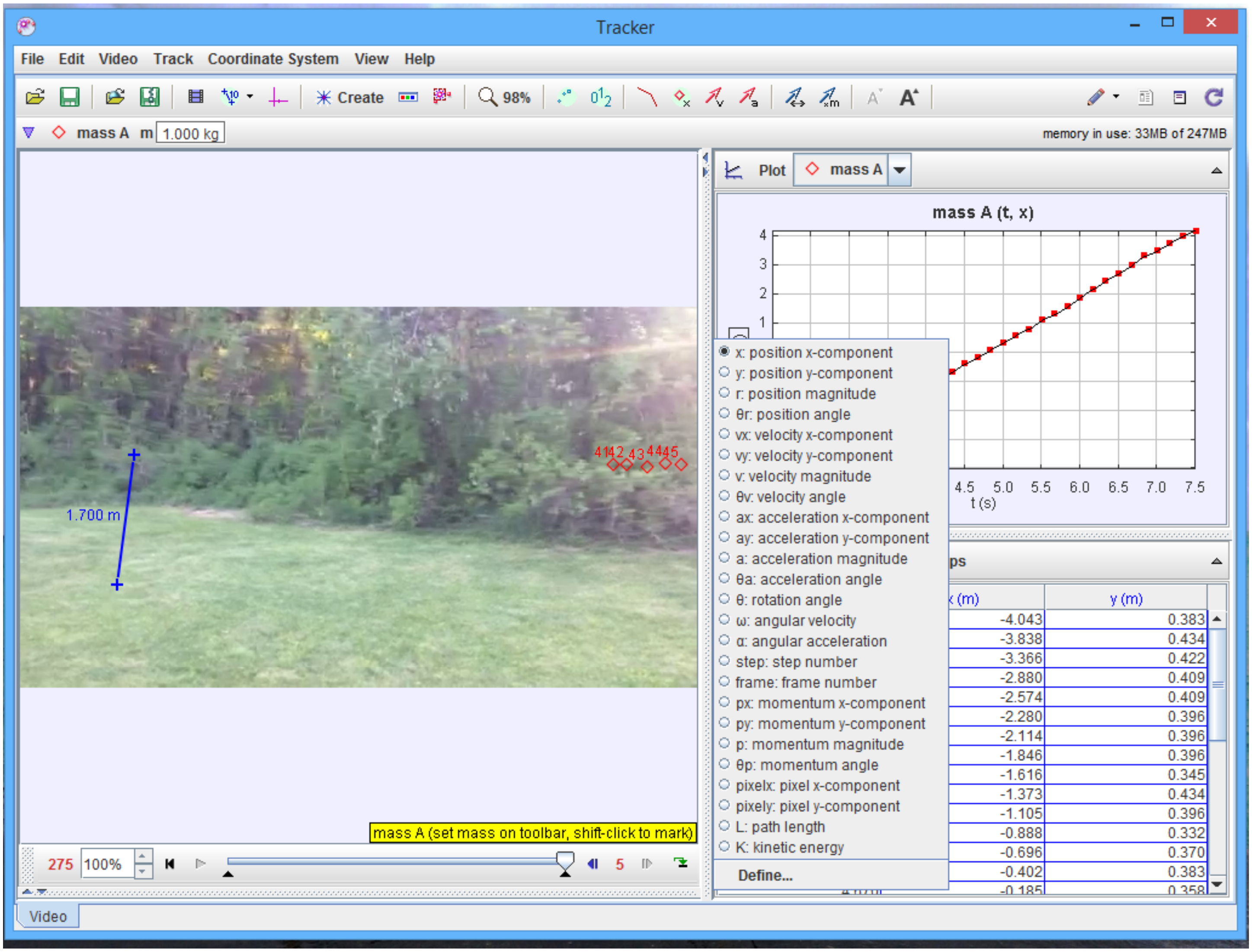


Figure 7: Here you can see the different graphs video analysis software will produce after you add your point of interest. For more information on how to use video analysis software we recommend this video. Please limit your number of tracking points to under 50 in an effort to not spend too much time on this.

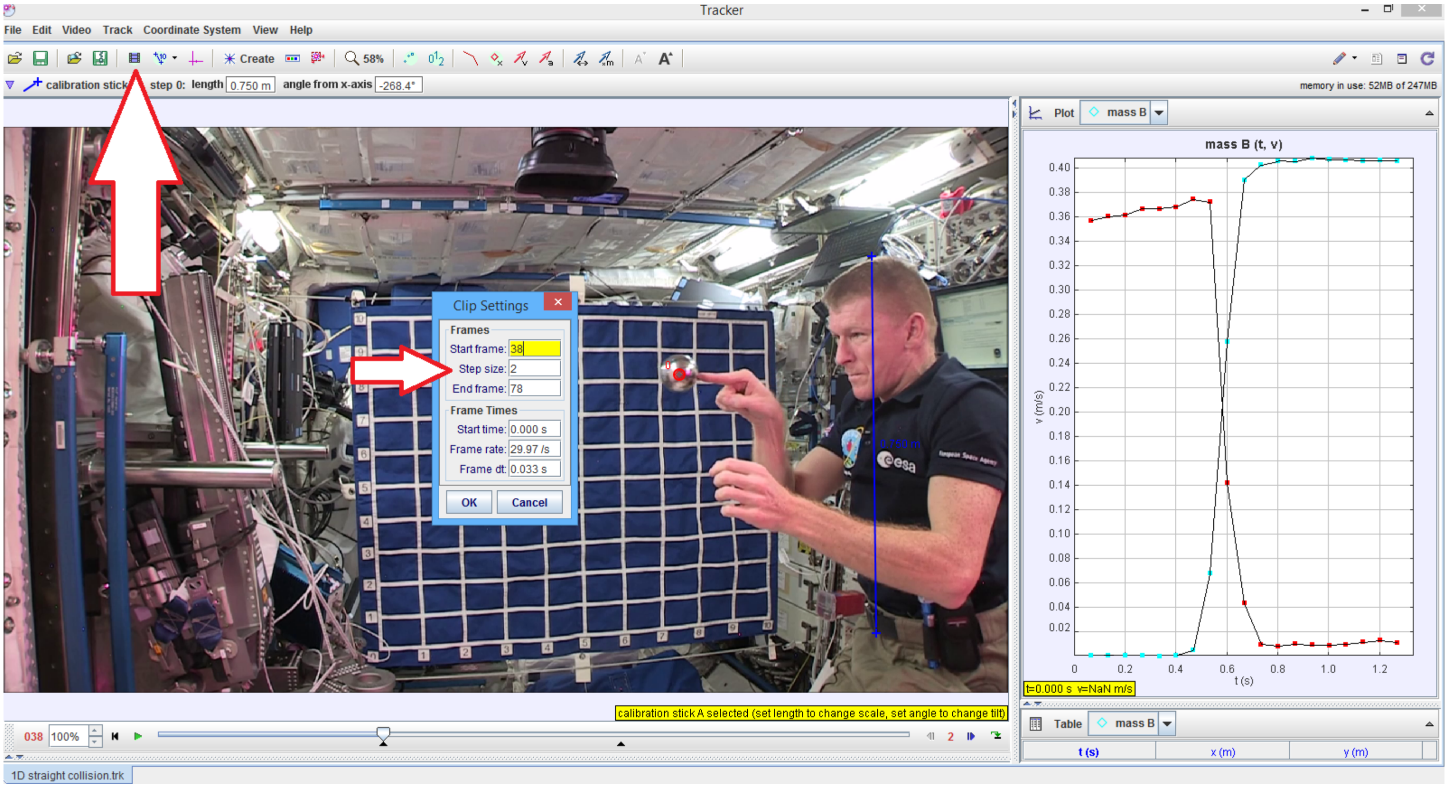


Figure 8: Red arrow points to where one can adjust the clip settings. We recommend changing the setting 'step size' to 3 or 5, as while your data will be less smooth it will take you less time to track your objects. Video screenshot from National Space Academy [1].

Figure 9: Here you can see a mistake in my acceleration profile. The acceleration jumps to 4.5 m/s from 0m/s for two points. The reason it does that is because I used autotracker to mark the mouth of the whale shark, and autotracker got confused for a few points about where the mouth of the shark is. That's fine, as these things happen. The smallest mistake sometimes when adding points can lead to large jumps in the acceleration. In addition, because these graphs are self scaling you will see large jumps sometimes that are really tiny jumps. That's also fine. If you're ever concerned you'll be marked down please ask! What's important is that I saw weird accelerations, and tried to figure out what was wrong. aka I had a prediction (that acceleration would be small) and when it didn't come true I tried to see why that might be!

Moreover, one of the boon's of Tracker is the 'AutoTrack' feature. This video explains how to use auto-tracker, which should shorten the video analysis significantly.

References

[1] National Space Academy. Collisions, 2020. NSA Website.

[2] Georgia Aquarium. Digital wallpapers, 2020.

[3] Boone Ashworth. 5 best slow-motion video apps, 2019.

[4] Douglas Brown. Tracker software help, 2020. Tracker website.

[5] WPI, 2020.