2. Motion in One Dimension*

This is the first unit using video data capture to analyze the motion. There are two main points in this exercise. The first is to study motion using graphs when the acceleration is constant. The second is to learn video capture for data taking.

<table>
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<th>Learning Objectives:</th>
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<td>1. Learn how graphical representations relate to actual motion.</td>
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<td>2. Learn how kinematical data can be taken from video recordings.</td>
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<td>3. See the main sources of error that enter in taking data by video capture, learn ways to estimate the size of these errors and to apply video capture to solving motion problems.</td>
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Reading Assignment:
All students read the appendix to this lab book that deals with video capture equipment and software before coming to lab. Then in addition read the following sections. (Section numbers may be slightly different depending on the edition of your textbook: Check the section titles.) Study the following sections of your textbook before coming to lab. There will be a check to see that you have done this. 
Knight, Jones and Field (161): 2.1 Describing Motion, 2.2 Uniform Motion, 2.3 Instantaneous Velocity, 2.4 Acceleration, 2.5 Motion with Constant Acceleration
Serway and Vuille (211): 2.1 Displacement, 2.2 Velocity, 2.3 Acceleration, 2.4 Motion Diagrams, 2.5 One-Dimensional Motion with Constant Acceleration
Serway and Jewett (251): 2.1 Position, Velocity, and Speed, 2.2 Instantaneous Velocity and Speed, 2.3 Acceleration, 2.4 Motion Diagrams, 2.5 One-Dimensional Motion with Constant Acceleration

PRE-LAB EXERCISES Pre-lab questions check your reading and give you some idea what you are doing in lab. Before you come to the lab, answer Pre-lab Questions (1) through (5). At the beginning of the period your TA will check whether you have done the problems. You must have completed the pre-lab or the TA won’t let you in. Before you start working on the equipment there will be a discussion. Your group will answer questions relating to the pre-lab work. Then the recorder of your group write answers on the white board, and when your group is called the recorder must present the answers. There is a time limit on this activity. So, make sure you pay attention when you do the pre-lab problems. Hand in your

Moving away from the origin

Moving toward the origin

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answers to the pre-lab questions finally with your lab report.

In this exercises, suppose one member of your group pushes a cart that is confined to move on a dynamics track so that it has to move in a straight line. The cart may move at constant speed or may be accelerated with a constant rate.

1. On the left position axes on the previous page your prediction of the position-time graph of the cart moving to the right away from the origin at a steady (constant) velocity. On the left velocity axes below sketch your prediction of the velocity-time graph for the same motion.

2. On the right set of position axes in the same figure sketch your prediction of the position-time graph of the cart moving toward the origin from the right at a steady (constant) velocity. On the right velocity axes above sketch your prediction of the velocity-time graph for the same motion.

Exercise problems 3 and 4 refer to the situation when a cart is placed on a frictionless tilted track that is causing the cart to speed up or slow down.

3. Sketch on the axes below your predictions for the position-time and velocity-time graphs of the cart that starts from rest at the origin at $t = 0$, moving away from the origin toward the right and speeding up with a constant acceleration.

4. A cart originally moving toward the origin from the right is subjected to a constant acceleration in the direction away from the origin (that is, toward the right). Sketch position (left axes) and velocity (right axes) as a function of time, as the cart slows down moving toward the origin, then its velocity passes through zero, and then speeds up moving away from the origin. (Start your graph after the push that gets the cart moving, so that you need not consider any such push.)
The appendix USE OF VIDEO FOR DATA TAKING was part of your reading assignment. Before taking the videos your TA will review this material, but you should be familiar with it. This is to get you started using the video analysis component of the Logger Pro software. You will have more chance to fiddle the software later but for now just pay attention to what each button of the video analysis tool does.

**Equipment:** Dynamics track and carts (2), computer with Logger Pro, USB Webcam, stopwatch, meter stick, lab tape

**Problem 1: Constant velocity motion**

**Exploration:** We begin by studying motion on a level track. Normally in a problem solving lab there is a section called EXPLORATION where you and start fiddling the apparatus to figure out how the apparatus works. There are a few questions to help you working through this section. The next step is to PLAN the way you make the measurements. Usually you are expected to figure out what you need to measure and in what sequence (procedure) and to make data tables. In this lab since you are learning how to take video the step-by-step instruction is provided.

**Plan:** (Usually you create a plan for solving some problem, but in this case the plan is given and is mostly instructions for using the equipment and software. Think of this as an example of what a plan would look like.) One member of your group gives the cart a little push and releases it, and another member starts taking the video, as you would have planned. Other members use stopwatch and a meter stick to estimate the speed of the cart (see the step 5 below). Remember, you would usually write your own measurement plan.

1. Make sure the track is level by adjusting the leveling screws on its feet. Use a carpenter’s level to see if the track is not tilted. (If the track is level, what happens to a cart sitting anywhere on it?)
2. Start Logger Pro.
3. Place two markers (use colored lab tape) about 1 m apart on the side of the track.
4. Place a meter stick at the side of the track so that your camera sees the meter stick. It is important for you to figure out what this meter stick is for. What is its purpose?
5. Click the insert button on the main menu of the Logger Pro then click the Video Capture button. The Video Capture tab appears on your screen. If your video camera is not lined up perpendicular to the center of the motion path of the moving object the error caused by distortion will be huge. You should be able to explain why this is. Check the orientation of the camera by viewing the image on your screen. If the track is horizontal and appears centered, the orientation of the camera is about right.
6. Click the Start Capture button. This button actually takes care of both starting video capture and stopping the capture. In other words it toggles. Observe that as soon as you click on this button the label changes from Start Capture to Stop Capture.
7. Give a slight push to the cart to start it moving smoothly on the track. The motion of interest is the after you release the cart, not while it is being pushed.
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8. While you are taking the video, you can also make measurements the old fashioned way. Thus, when the cart passes the first marker, one of your group members should start the stopwatch, then when the cart passes the second marker stop the stopwatch. Record the distance between the markers and the time elapsed when the cart passed the two markers.

Everyone in your team should get the chance to operate the camera and the Logger Pro Program. At some point your TA may come around, like your work supervisor, and check that everyone can do this. So be ready.

Before attempting to use a video to make measurements, practice pushing and releasing the cart to get an optimum speed. Preview the video you have taken. If the quality is not good try taking the video again.

Technical note: If one tries to take a video of a rapidly moving object the default shutter speed will be too long. As a result one will see a blurred image, not adequate for data analysis. If your image of the cart is blurred you may have to change the shutter speed. You do this after inserting video capture into the Logger Pro screen in the following way:

Click on options button then from Video Capture Options tab select your camera’s setting: Camera Setting → Driver Setting → Advanced Then unclick Automatic Gain Control and adjust the exposure to shorter time. (say 1/60 to 1/120 s). But if you select an exposure time too short the image gets dark. So, you may have to adjust the brightness as well. To do this select Camera Settings → Device Settings then adjust the brightness.

Analysis:

Normally the analysis would be designed by you as part of your measurement plan.

Looking at the video frame by frame allows you to check whether the computer has missed any frames.

There are several tools on Logger Pro for analyzing a video you have taken. Try the play, stop, rewind, previous frame and next frame buttons at the bottom of your video screen. Using these buttons run through the video frames to the point where you would like to start reading the data (digitizing). Everyone should try this, because you all need to be able to do it.

Click the Enable/Disable video analysis button located at the lower right corner on your video screen. What happens?
A column of video analysis tools will appear on the right edge of the screen. Find out what each button does. For instance, you will need some way to know how distance on the screen corresponds to actual distance. That’s why you include a meter stick in the movie you take. Click Set Scale (fourth from the top) and drag the cursor along the image of the meter stick on the video clip. A Scale tab appears on the screen. Type in the distance and units and click OK. This process defines the length scale of your video image.

Notice that as soon as video analysis button is clicked, in addition to the $x$- and $y$- position, time, two new columns, $x$-velocity and $y$-velocity, appear.

Click the Add point button located at the second from the top in the video analysis tools and then move the cursor over the video frame to the point where cart is at that moment. This point you would like to include in your data. Click on it. See what happens on the graph on the screen. The computer screen automatically goes to the next frame of the video clip. Move the cursor to the next position and click to enter the next data point so on.

**Question:** On your graph both red points and blue points appear. What kinematics quantities do they represent? The horizontal axis represents time elapsed. Which function (red or blue) is of interest? Record your answer here.

Here $x$ and $y$ are actual directions in space. Since the track should be level and so cart should not go up and down along $y$-axis, the value should be about constant as a function of time. You could check it by looking at the graph. Except for this use, the $y$ graph is not useful for our analysis so you may want to drop it. To do this click on anywhere on your graph then click on Options from the menu and select Graph Options. On the Graph Options tab select Axes Option button then select appropriate data set you want to plot then click on the Done button.
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Observe what happened on your screen. Now you have only one graph.

Is there any point on your graph that is way out of line with every other point? If there is, does this reflect an error introduced by, say, clicking on a wrong point? If you think so, you might want to remove it. This can be done using Strike Through: Just select the data cells you wish to ignore by clicking and dragging the cells in a table object, or by dragging a selection in your graph, then choose Strike Through Data Cells from the Edit menu. Logger Pro will not include any struck-through points on the graph, or use them in calculations.

Logger Pro can fit several different kinds of functions to your data, such as exponential, parabolic, exponential and so on. To “fit” a function means this: In a mathematical function like \( y = mx + b \) there are constants, or parameters, like \( m \) and \( b \) in this example. In fitting, the software chooses the constants to get the curve as close as possible to your experimental data points. Fitting the data is done using the Curve Fit button on the main menu.

**Question:** What mathematical function would you expect to represent the position-versus-time graph in this experiment, based on what you know from your textbook or from lecture? Would it be a straight line? Parabola? Sine curve? Answer here, giving a few details (more than just two words).

When you fit a curve to your position-versus-time or velocity-versus-time data, you can learn the values of the constants that make the best fit. This is only meaningful when you fit the right kind of function so that you know what the meaning of the constants is supposed to be. In other words, you should have some reason to expect a curve of a certain shape. Remember that the constants have dimensions, or in other words units. The meanings of the constants also help you see what the units are supposed to be.

Now how do you fit your data to a curve? After removing any “bad” points from your data using strike through, by clicking and dragging select a portion of the graph that you want to include for the data analysis. Click on the Curve-Fit button on the main menu. There are some standard functions to choose from. It’s going to be up to you to know what kind of function makes sense in a given situation. That’s where physics comes in. It doesn’t make sense to fit a function that doesn’t connect to the physics. Notice that it is also possible to define a function manually, if the function you want doesn’t appear on the tab. Select the function of your choice and then click the Try-Fit button. See if the fit is reasonably good. Try other functions too, just to see how they work.

**Question:** Try fitting the position-versus-time data to a cubic function of time, for example. Is the fit better than the one you originally had? (Careful, this question needs a thoughtful answer.)

Explain your reasons for the choices you make on which functions to fit to the position-versus-time and to the velocity-versus-time data. Each time you decide a fit is reasonable, you can click OK to get back to your graph. You will see a new box has appeared on the graph with curve fit information.

**Conclusion:** What did you learn by doing this problem? Are your predictions right on target or only qualitatively correct? Quantitatively correct? How close the average speed of the cart you obtained from the stopwatch method to the result of video analysis
Problem 2: Motion on an incline

Exploration and Plan:
Some wooden blocks are provided. Insert one of the blocks underneath one side of the track. Start with a small angle (thinner block) and with the cart at rest near the top of the track. Observe the cart as it moves down the incline. Is the cart moving with a constant speed, slowing down or speeding up? You can do a video analysis. If the angle is too large, you may not get enough video frames, and thus you may not get enough position and time measurements to measure the acceleration accurately. If the angle is too small the acceleration may be too small to measure accurately with the precision of your measuring instruments. Select the best angle for this measurement. Select a position where you are going to release the cart and make a note of the number on the yellow meter tape on the track.

Implementation and analysis:
The analysis involves relating your data to what you learned in class. So you need to analyze graphical data. The first thing to think about is setting up a coordinate system. You do this in the video analysis very much like you would do it to solve a problem in class. For instance, you can choose the $x$-axis to be along the track, even though the track may be tilted in the experiment. This is just as you would do in solving a textbook homework problem. First click the Set Origin button (third button) on the video analysis menu. Yellow coordinates show up on your video screen. Rotate the direction of the $x$-axis by clicking and dragging the small circle behind the coordinate origin.

Because now the acceleration is not zero the velocity changes as a function of time. So, both position vs. time graph and velocity vs. time graph will be of interest. Proceed with the analysis as described in Problem 1. Plot the both position and velocity on the same graph. To do this click options on the main menu then select Graph option >> Axis option and check both $x$(m) and $x$-velocity (m/s). Now you will see both plots. If you want to know the velocity as a function of time you can analyze the position graph or by analyzing directly the velocity graph. Which method would give more accurate result would you think? Why is this? Explain.

Conclusion:
Fit graphs as described in the section in the Problem 1. Find the acceleration from velocity vs. time graph. Is it constant? Positive? Negative? Describe in your own words the motion of the cart. In what way this problem is different form Problem 1?
Problem 3: Motion up and then down incline

During one portion of a roller-coaster ride at the Valley Fair amusement park, the roller coaster car is initially travelling up along an incline at some speed then is slowed down by the influence of gravity. Near the top of the track, the car reverses direction and rolls back down. As a member of the safety committee, you have been asked to compute the acceleration of the car throughout the ride. To check your results, you decide to build a laboratory model of the ride.

Is the acceleration of an object moving up a ramp different from that of an object moving down the same ramp? Assume to start with that the friction of the ramp is negligible.

Use the same setup as Problem 2 but instead of releasing the cart from the top of the inclined plane hold the cart at the lower end of the inclined plane and then push up and release.

Prediction: When the cart moves up the track then down the track, do you think the acceleration of the cart moving up an inclined track will be greater than (in the same direction), the same as, or exactly opposite to the acceleration of the cart moving back down the same section of the? Explain your reasoning.

Exploration: Start the cart moving up with a gentle push. Be sure to catch the cart before it hits the end of the track on its way down. Observe the cart as it moves up in the inclined track. At the instant the cart reverses its direction, what is its velocity? Its acceleration? Observe the cart as it moves down the inclined track. Do your observations agree with your prediction? If not, this is a good time to change your prediction. What do you think?

As you see, the entire motion of the cart has two parts: going up and then going down. You are using the same video clip but maybe you want to separate the analysis into case (1) going up then case and (2) going down.

Measurement: Make a video of the cart moving up and then down the track at your chosen angle and apply your plan. Record any necessary notes or ancillary data here.

Analysis: While tracing the position of the cart on your video near the point where its velocity changes sign, you will find too many dots close together. To avoid this you can click off the toggle trail button (the third button from the bottom).
From the position-versus-time graph estimate the values of the constants appearing in the function. What kinematics quantities do these constants represent? Can you tell from your graph when the cart reaches its highest point? Do the same for the velocity versus time graph. How does this function relate to the position versus time function?

Can you tell from your velocity-time graph where cart reaches its highest point?

Remember, the original problem?

"Is the acceleration of an object moving up a ramp different from that of an object moving down the same ramp?"

Now it’s time to use what you know to answer this question. For this you could to create an acceleration-versus-position graph. This doesn’t really work very well, due to reasons you need to figure out. But to create the graph, go to Options then Graph Options. Select acceleration for the y-axis and x(m) for the x-axis. Or you could answer by looking at velocity versus time graph. Which one of these procedures gives the more accurate (and reliable) answer to the question? (To answer this, of course, you have to try both.)

A better way to go at this analysis of the acceleration would be to fit a parabola (quadratic function of time) to the position versus time data, (Mizuho, please insert an explanation of how to fit the position data to a formula) and then compare the fitted function to the formula for position as a function of time. To do this, plot position vs. time graph from your video data. Click on Curve Fit button and then select the appropriate function. Then click on Try Fit button and OK. Now that you have fit a formula to the data which looks like \( y = Ax^2 + Bx + C \), you need to figure out what physical quantities the coefficients represent. Clearly \( x \) is not position, in this formula. What does it mean, rally? What quantity does it correspond to in the formula for position from your reading? Similarly what physical quantities do the constants \( A, B \) and \( C \) in the fitted formula correspond to in the experiment? Compare to the motion formulas from your reading. From these coefficients you should determine the acceleration.

**Conclusion:**

Did the acceleration change direction? Was the acceleration zero at the top of the motion? How did you determine this from your research? Did the results agree with your predictions? If not, or perhaps not quite, explain why not.

For your report in this case, besides the questions you answered along the way, each member of your team should include a copy of each graph related to each of the problems, as well as an explanation of the analysis and a result. At the end, include also a comment on how the lab activities related to each of the objectives.
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Reference

1. Pre-lab problems are adapted from David R. Sokoloff and Ronald K. Thornton, Interactive lecture Demonstrations: Active Learning in Introductory Physics (John Wiley & Sons Inc. 2004).