

## Physics 200 Lab 4: Projectile motion

### Objectives

- To examine the characteristics of motion in two dimensions
- To investigate the motion of an object in free fall with an initial horizontal velocity (projectile motion)
- To learn to use video capture to record and analyze the motion of an object

### Overview

Analyzing motion in two or three dimensions involves exactly the same concepts that we've been using all along: position, velocity, and acceleration. The only difference is that more dimensions are involved. The motion detector is a poor tool for obtaining information about motion that isn't along a straight line, so in one part of this lab we will analyze data in the form of a video clip which will give us images of moving objects at known time intervals (one image, or frame, every 1/30 sec). These images make up a movie, which has been transferred to a computer in a process called video capture.

After the video is edited, special software is used to analyze it. By clicking on the image of an object, its position can be recorded as a function of time. This information can then be used to obtain velocity and acceleration as a function of time.

### Part I: Studying Projectile Motion with Video Capture

In this lab, you'll study the motion of a thrown ball. Your task is to use the data you obtain to determine experimental answers to various questions about the motion of the ball.

The VideoPoint analysis software can produce graphs similar to those you've been seeing for the motion detector. You can get graphs of  $x$  vs.  $t$ ,  $v_x$  vs.  $t$ ,  $a_x$  vs.  $t$ , and  $y$  vs.  $t$ ,  $v_y$  vs.  $t$ , and  $a_y$  vs.  $t$ . You can also graph  $y$  vs.  $x$  to show the shape of the path the ball took through space.

VideoPoint also has the capability to find the equation of the curve that best fits your data, and to get averages and standard deviations, just like the Logger Pro software you used with the motion detector. For example, if the  $v$  vs.  $t$  graph looks like a straight line, the software will give you the equation of the line that fits it best, including the values of the slope and the  $y$ -intercept. You can also use a statistics function that will give you the average and standard deviation of the data.

### Instructions for capturing, editing, and analyzing video images

#### Capturing a video with Adobe Premiere 6 LE:

Turn the camcorder on, and set the dial to the shutter speed priority setting ("TV" on the camera dial control). Make sure that PRO. SCAN (Progressive Scan) appears on the camcorder's LCD screen or viewfinder. Check the focus and exposure (ask instructor for help if you need it).

Make sure the camera is on and that it is connected to the computer with the FireWire cable. Open **Adobe Premiere 6 LE**. A Load Project Settings window should appear. Make sure that the Optura preset is selected; if not, select it. Click OK.

After Premiere finishes loading, click on **File> Capture> Movie Capture**. The image from the camera should appear in the Movie Capture window on the computer screen. Click the record button (red circle) near the bottom of the capture window to start recording. To stop recording, press the escape key (or click in the capture window).

In a few seconds, you will be prompted to give the movie a name (no file extension is needed). When you have done this, minimize the movie capture window.

#### Editing and saving a movie with Adobe Premiere:

Your movie should now appear in the Project window. Use the mouse to drag and drop the movie into the left-hand (Source) side of the Monitor window. In the monitor window, move through the frames of the movie using the Forward (▶) and Reverse (◀) keys. Go to the frame in the movie you want to start with and click on the Mark In key ({}). Continue advancing through frames until you come to the frame in the movie you want to end with and press the Mark Out key (}).

Select **File > Export Clip > Movie**. Near the bottom of the window that pops up, check that it says *Make: In to Out as Quick Time , Video: 658x480 at 29.97 fps, Compression: `Planar RGB @ 100%` , and Audio: Disabled*. (If necessary, these can be changed using the Settings button.) Enter a filename (use a filename that contains your initials or other identifying features). Put the file on the Q: drive, in the Physics\P200vid folder. Click **Save**.

#### Instructions for analyzing video images

##### Analyzing data with VideoPoint 2.5:

Open **VideoPoint 2.5**. Close the opening window *About VideoPoint* by clicking on the upper right-hand **x**. A *start-up* window then appears on the screen. Select the **Open Movie** option. In the *new* display window, select the movie that was just created.

In the *Number of Points* window enter the number of objects you wish to analyze (1, in this case) and select **OK**. The screen should now contain a window with the edited movie, a data table window, and a window for the coordinate system.

On the vertical tool bar on the left, click on the icon that looks like a ruler. A *Scale Movie* window appears. Since we're using a meter stick to scale the movie, set the known length as 1 with meters as its unit, then click on **Continue**. Click once directly on one end of the ruler in the video, and click again at the other end of the ruler. This calibrates the coordinate system in the desired unit (meters in this case) instead of in pixels.

Now data can be collected. Notice that the cursor is a circle with crosshairs. Every click made on the screen records a position data point. Place the cursor on the object and click once. This records the first data point. The program automatically advances the movie to the next frame. Click again on the object, being sure to always click on the same part of the object. Do this until the movie is over and all the data is collected. Notice that the *data* window now contains numbers.

To graph the data, find the icon on the left tool bar that resembles a blue graph and click once on it. To graph x data, choose x as the *Vertical Axis* in the *plot series* box. Select position, then add

velocity, and acceleration graphs, and click on **OK**. Repeat with  $y$  as the vertical axis to graph  $y$  data. You may want to use the mouse to drag the margins of the graph to make them bigger.

Note that each graph has a tab with a pink F on the right. Clicking on this tab brings up a dialog box that has options for averaging the data or fitting it with a straight line or a polynomial. For example, to average the  $x$  acceleration data you would click on the pink F tab on the  $a_x$  vs.  $t$  graph, then choose Average from the drop-down menu and click ok. To fit that same data with a straight line, you would choose Linear. Unlike in the LoggerPro software, you can't select only a portion of the data to fit; it fits all the data shown on that graph.

Analyze the video of the tossed ball. Make graphs of position, velocity, and acceleration vs. time for the horizontal ( $x$ ) and also for the vertical ( $y$ ) motion. Adjust the graph scales so the origin (0,0) is on the graph. Use these graphs and the features of the VideoPoint software described above to answer the following questions.

**Question 1.** How does the  $x$  vs.  $t$  graph relate to the  $v_x$  vs.  $t$  graph? How does the  $v_x$  vs.  $t$  graph relate to the  $a_x$  vs.  $t$  graph? Do the same types of relationships hold for the vertical motion?

**Question 2.** From the graphs, was the velocity of the ball in the horizontal ( $x$ ) direction constant? If not, describe how it varies in time. Repeat for the vertical ( $y$ ) direction.

**Question 3.** Use the acceleration graphs to find the average acceleration of the ball in the  $x$  and  $y$  directions, with uncertainty and units. Does your result agree with what you expect? Explain why or why it might not.

$a_x$ :

$a_y$ :

**Question 4.** Since the acceleration is constant for both x and y directions, the velocity components should each be a linear function of time:  $v_x = v_{xi} + a_x t$  (horizontal) and  $v_y = v_{yi} + a_y t$  (vertical). Use VideoPoint to fit a straight line to  $v_x$  vs.  $t$ , and use the equation the computer gives you to determine numerical values for the initial x component of the velocity  $v_{xi}$ , and the acceleration in the x direction  $a_x$ . Repeat for the vertical velocity vs time graph.

$v_{xi}$ :

$a_x$ :

$v_{yi}$ :

$a_y$ :

**Question 5.** Fit the x vs. t graph with a quadratic function of time. Interpret each of the constants in the best-fit equation and determine the initial position, initial velocity, and acceleration. Repeat for the y vs. t graph.

$x_i$ :

$v_{xi}$ :

$a_x$ :

$y_i$ :

$v_{yi}$ :

$a_y$ :

**Question 6.** Do the values you obtained for  $a_x$  and  $a_y$  in questions 4 and 5 agree with those from question 3, within uncertainties?

**Question 7.** Use your results from Question 5 to find the magnitude and direction of the ball's initial velocity.

**Question 8.** From the graphs, what is the acceleration of the projectile when it is at the top of its motion? What is its velocity at that point? Explain how you determined this.

**Question 9.** Create a  $y$  vs.  $x$  graph. (Click on the graph icon, and in the Plot Series window, change the horizontal axis to Pt. S1, then choose  $x$  component and Position. Choose  $y$  component and Position for the vertical axis.) Explain why this graph looks very similar to your  $y$  vs.  $t$  graph. How would you use this graph to find the direction of the velocity of the ball at any point in its trajectory?

### **!Checkpoint 1**

#### **Part II: Application of Projectile Motion**

In this part of the lab, you will first determine the initial velocity of a ball launched vertically from the ball launcher, and then use that initial velocity to predict how far away a ball launched at a different angle from the lab table (greater than  $0$ , less than  $90^\circ$ ) will land.

Note: Use the middle (medium range) launching position. Also, use caution in operating the launcher—keep goggles on any time the launcher is cocked!

Record which launcher you used:

To find the initial velocity, shoot the ball straight up and measure how high it rises. Discuss with your instructor how you plan to do this. Try it several times to see whether the natural variation in the operation of the ball launcher or your ability to measure the height accurately is the main source of uncertainty in the height measurement. When you have made a height measurement, estimate the uncertainty in your measured height.

Height of rise:

Uncertainty:

Use this result to find the initial speed of launch:

Now propagate the uncertainty through the calculation in order to find the uncertainty in the initial speed of launch:

Report the speed with its uncertainty, rounded properly and with units:

Use your result for the initial speed of launch to predict how far away from the launcher the ball will land if it is launched at a different angle between 0 and 90 degrees (you choose the angle, but be sure to record it).

When you have made your prediction, check with your instructor about your prediction and how you plan to measure how far from the launcher the ball will land.

### **! Checkpoint 2**

After you have checked with your instructor, try it out. Make and record several measurements of the distance traveled—a piece of paper taped to the floor where you predict the ball to land will record impacts of the projectile. Then calculate the mean  $\pm$  standard deviation and compare to your calculated value. Is there agreement? If not, what do you think are the most important reasons for the lack of agreement?

### **! Checkpoint 3**