

LAB02-2: Video Analysis of Projectile Motion

Objective

In this experiment, you will measure and graph the x-position, y-position, x-velocity, and y-velocity of a projectile, in this case a basketball as it moves freely through air. In addition, you will learn how to use video analysis software to measure position as a function of time for any object.

Introduction to Video Analysis

A video is basically a set of images taken at an interval of $1/30$ s between frames. (However, high-speed video has a higher frame rate.) To measure an object's position, you need to:

1. define a coordinate system including an origin and x,y axes.
2. define a scale; in other words define a standard length. For this, it helps to have an object of known length, such as a meterstick, in the video.

For example, consider the object in Fig. 1. To measure its x-position, draw a perpendicular line from the object to the x-axis. To measure its y-position, draw a perpendicular line from the object to the y-axis.

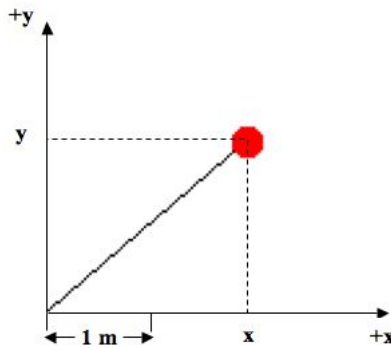


Figure 1: Position of an object depends on the origin and scale of the coordinate system.

Judging by the 1 m scale shown in the image, what is the distance of the object from the origin?

Video analysis software makes it easy to measure position coordinates (both x and y) and time for an object. After defining the scale and the coordinate system, you click on the object. The software shows a dot where you clicked and advances the video to the next frame. The software also measures time because it knows that the video is recorded at 30 frames per second. Thus, whenever you advance the video, time advances $1/30$ s.

Suppose a projectile moves along a parabolic path. Fig. 2 shows an object at intervals of $1/30$ s between the first image A and the last image I.

Suppose that we define $t = 0$ to occur at the first position of the basketball. In Fig. 2, label the time t for each subsequent position of the basketball.

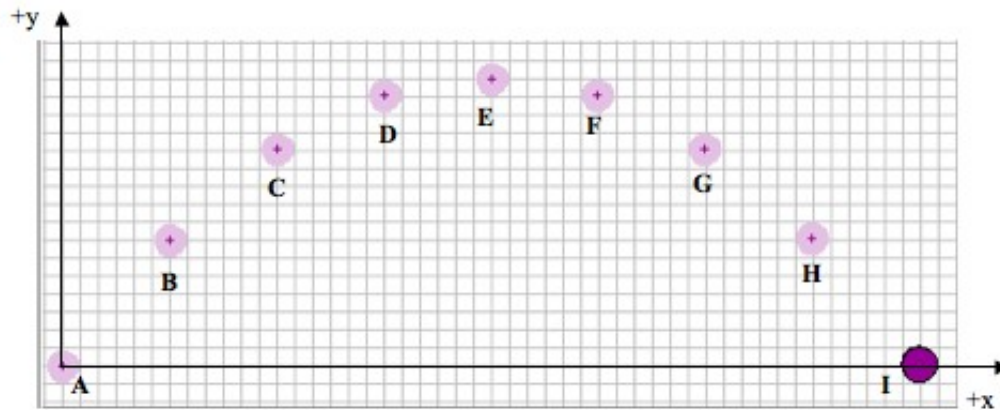


Figure 2: Position of a projectile at equal time intervals of $1/30$ s.

Measure the x-position of the basketball from A to I and sketch a circle on the x-axis at the x-coordinate of each image in Fig. 2. Remember to draw a perpendicular line between the object and the x-axis to sketch these circles. An example is shown in Fig. 3. Make a data table below showing x-position (x) and time (t) for the object.

On the figure above, also show the object on the y-axis at each instant of time. Sketch a line from the object perpendicular to the y-axis and sketch circle at that position.

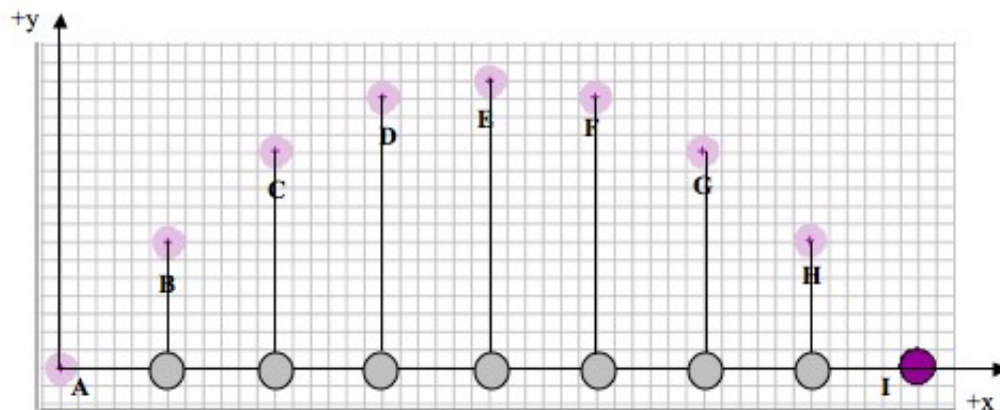


Figure 3: x-positions of the projectile.

By examining the x-coordinate of the object, is the x-motion characterized by uniform motion or constant acceleration? Give a reason for your answer.

Sketch a graph of x vs. t for the projectile and write an equation for x as a function of time.

In Fig. 2, mark the y-position of the projectile by drawing horizontal lines from the object to the y-axis and drawing a circle at that point on the y-axis. Is the y-motion characterized by uniform motion or constant acceleration? Give a reason for your answer.

Sketch a graph of y vs. t for the projectile and write an equation for y as a function of time.

Experiment

1. Open our course web site, and click the link to videos. Right-click on the link to 02-2-basketball.mov and save it to your desktop.
2. Open the Logger Pro software on your computer.
3. Use Insert→Movie... to import your video.

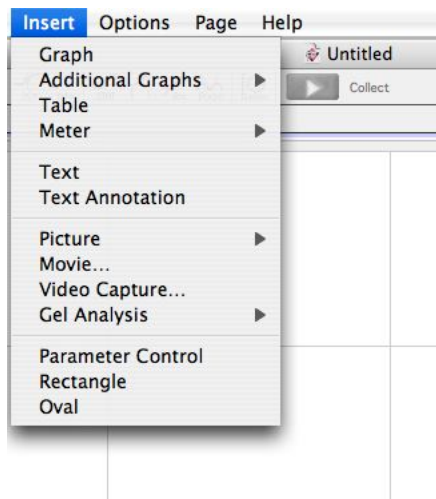


Figure 4: Insert movie menu

4. To expand the video, click once on the video, grab the corner of the video window, and expand.
5. At this point, it's nice to lay out the video, data table, and graph so that you can clearly see everything. Go to Page→Auto Arrange... to organize the screen, as shown in Fig. 5.
(You can always make the video larger or smaller and auto arrange the page in order to clearly see the data, graph, and video at the same time.)
6. Note the video controls at the bottom of the video pane, shown in Fig. 6. Go ahead and play the video, step it forward, backward, etc. in order to learn how the video controls work.
7. Navigate to the first frame of the video by stepping the video forward until the ball has clearly left the player's hand. This will be first frame in our analysis of the motion of the basketball.
8. You now need to define the origin of the coordinate system. Click the icon in the bottom right corner of the video pane (the icon with three red dots shown in Figure 7) in order to expand the sidebar used for video analysis.
9. In the sidebar of the video pane, click the icon in Fig. 8 to show the coordinate system (you can hover the mouse over each icon to see what they do).

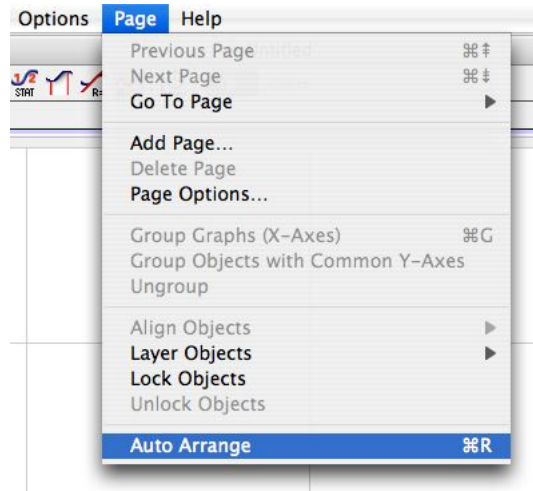


Figure 5: Auto arrange to clean up the panes in the window.



Figure 6: Video controls used to play and step the video



Figure 7: Icon used to expand the sidebar of the video pane



Figure 8: Icon used to set the coordinate system

10. Click and drag on the video to place the origin of the coordinate system at the location where you would like to define (0,0), as shown in Figure 9. For this video, you can place the origin at any point you choose.
11. Now, you must calibrate distances measured in the video. In the sidebar, click on the icon shown in Figure 10 to set the scale for the video.
12. Click and drag to draw a green line across the stick shown near the floor on the video. Enter the length of the stick which is 2 m long. (See Figure 11.)
13. You are ready to add markers to the video to mark the position of the basketball. First, let's not show the coordinate system and scale. It's too distracting. So, click each of the two icons in the lower right corner of the video pane, shown in Fig. 12. These icons are used to hide or show the coordinate system and scale.
14. To add markers, first click on the icon with the red dot and cross hairs, shown in Fig. 13. You will now be in an editing mode to add points.
15. In this case, we will mark the center of the basketball. Click on the center of the basketball. You

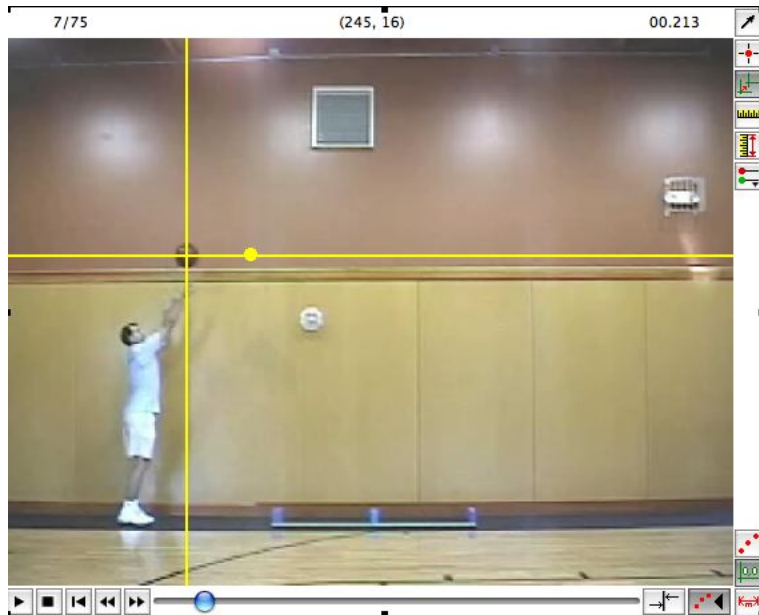


Figure 9: Click and drag to set the origin of the coordinate system



Figure 10: Icon used to set the scale.

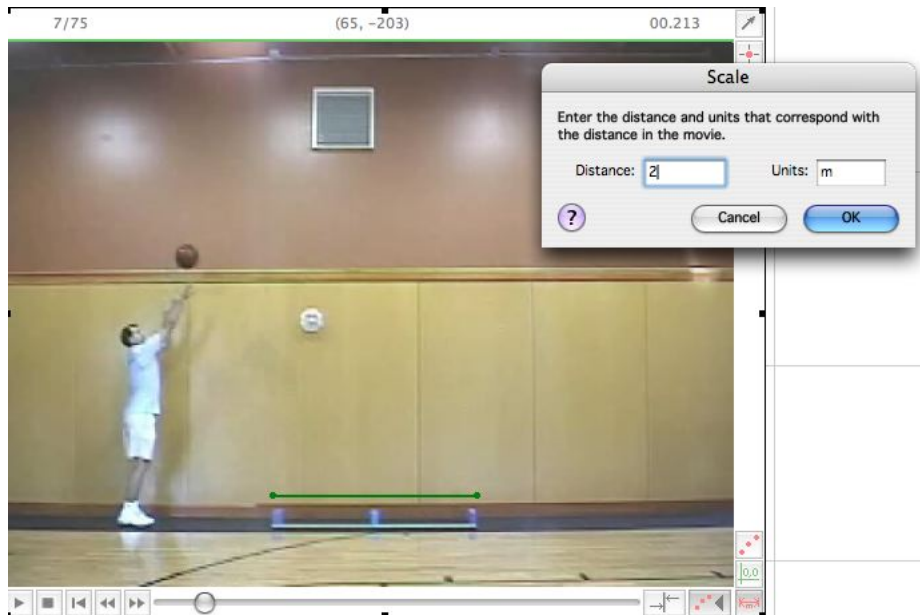


Figure 11: Calibrate the scale for the video.

should notice that a marker appears at the position of the basketball where you clicked and that the video advances one frame.



Figure 12: Use these icons to show or hide the coordinate system and scale.



Figure 13: Icon toggle the editing mode for marking positions in the video.

16. Again click on the same part of the basketball to mark its next position. Again, the video will advance.
17. Continue marking the basketball. After marking the basketball while it is in the air, your video should look like the picture shown in Fig. 14.

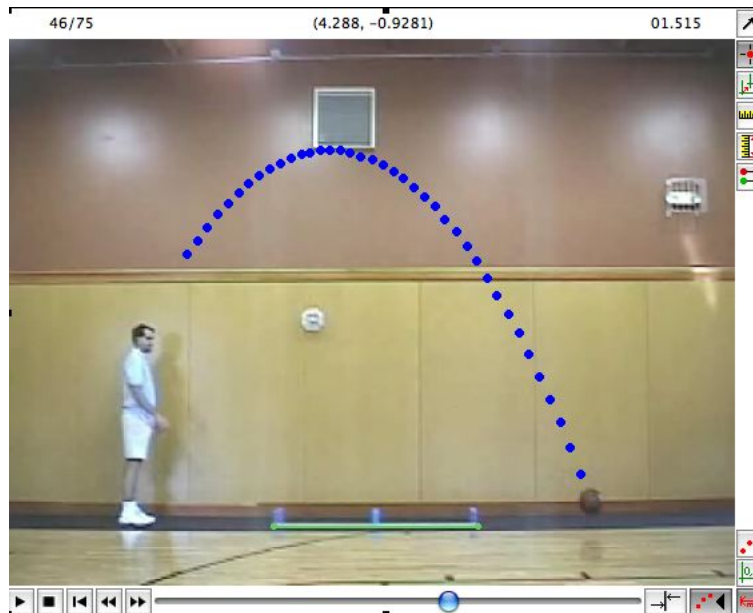


Figure 14: Marks showing the basketball's position for successive frames of video

You are finished collecting data. Now, we will analyze the data.

Analysis

1. Click the graph to bring it to the front.
2. By default, it will show both the x and y coordinates of the basketball.
3. Let's change what is being plotted. First, click the label on the vertical axis. By default, both X and Y are shown. When you click this label, you will have a menu that you can select what is being plotted. Select Y for right now.
4. In a similar way, click the label of the horizontal axes and select X.

What do you notice about this graph of Y vs. X? Sketch it below.

When you plot y vs. x, you are plotting *the path of the object*.

5. Now change the vertical axis to X and the horizontal axis to time.

What function describes this graph of x vs. t? (i.e. linear, quadratic, square root, sinusoidal, etc.)

6. Go to Analyze→Curve Fit and fit a linear function to x(t).

Record the function and the values of the constants for your curve fit. Write the function for x(t). From this function, determine the x-velocity of the basketball.

How would you characterize the x-motion of a projectile, uniform motion or motion with a constant (non-zero) net force?

7. Change the vertical axis label to Y to view the Y vs. time graph. Using the same procedure as before.

What function appears to best describe y(t)?

8. Fit a quadratic to y(t).

Record the function and the values of the constants for your curve fit. Write the function for $y(t)$. Based on this curve fit alone, determine the y-acceleration of the basketball?

How would you characterize the x-motion of a projectile, uniform motion or motion with a constant (non-zero) net force?

9. Change the vertical axis to Y-Velocity to plot v_y vs. time.
10. Select the linear portion of the curve and fit a straight line to the data. Remember to not include the first two and last two data points in your fit.

Record the parameters of the curve fit and the function for $v_y(t)$. Using this function determine the y-acceleration of the basketball.

11. You found that the x-velocity of the basketball is constant.

What do you expect the x-velocity vs. time graph to look like?

12. Change the vertical axis to X Velocity. Note that the data appears to be all over the place. That's because by default, the graph is "zoomed in" on the data.
13. Go to **Analyze**→**Autoscale**→**Autoscale from 0**
14. The data appears to be along a horizontal line, though there is sufficient scattering in the data due to uncertainty in the measurements.
15. Using your mouse highlight the data by drawing a window around the data points.

16. In the toolbar, click on the **STAT** button. Logger Pro will compute and display the average value of the data.

Record the average value of v_x (called the mean) and the standard deviation. How does this compare to the slope of the x vs. t graph?

Application

1. What is the velocity (x and y components) of the basketball at the first instant that it leaves the player's hand? You should get this from your curve fits and/or graphs and/or data. Express this as a vector and sketch it.

2. What is the position (x and y components) of the basketball at the first instant that it leaves the player's hand? You should get this from your curve fits and/or graphs and/or data.

3. The mass of the basketball is about 0.62 kg. What is the net force on the basketball while it is in the air?

4. Using theory, calculate the position and velocity of the basketball at $t = 0.5s$.

5. Compare your theoretical calculation in the previous question with the position and velocity measured in the experiment at or near $t = 0.5$. How do they compare?

6. Using theory, calculate the time (clock reading) when the ball hits the ground.

7. Compare your answer to the previous question to what you measure in the experiment.