Acceleration of a Tossed Basketball

Purpose

The purpose of this experiment is to investigate acceleration by studying different parts of the motion of a basketball tossed vertically in the air. A sonic ranger position sensor is used to measure the position of the ball and its velocity and acceleration are obtained by numerical differentiation.

Background

Position, Velocity, and Acceleration

Acceleration is defined as the rate of change of an object's velocity. If the velocity v of an object is known as a function of time then the acceleration can be obtained by taking its derivative, which is also equal to the slope of the tangent to the curve on a graph of velocity versus time.

$$a = \frac{dv}{dt}$$

Likewise, velocity is the rate of change of an object's position, x. Velocity is calculated as the derivative of position and is equivalent to the slope of a graph of position versus time.

$$v = \frac{dx}{dt}$$

Thus acceleration is the second derivative of position. Acceleration can be inferred from a graph of position versus time by looking at the concavity of the graph. If position is concave up then the acceleration is positive, if concave down then acceleration is negative.

$$a = \frac{d^2x}{dt^2}$$

When making measurements in the laboratory we don't generally know the position or velocity as specific functions of time. Instead we make measurements of the position at discrete, regularly spaced intervals of time and we obtain a waveform representation of the position. This waveform can be numerically differentiated to find the velocity at a given point by calculating the change in position divided by the change in time using

$$v_i = \frac{\Delta x}{\Delta t} = \frac{x_{i+1} - x_{i-1}}{t_{i+1} - t_{i-1}}$$

If the time interval between measurements is small enough then the average velocity over this time interval is nearly the same as the instantaneous velocity defined by the derivative.

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

In the same manner, the velocity waveform can be numerically differentiated to obtain acceleration. The *Physics Lab Assistant* software used in this experiment can be configured to automatically calculate velocity (and acceleration) in this manner by taking numerical derivatives of the position waveform.

Newton's Second Law: Forces and Acceleration

Newton's Second Law is a relationship describes the acceleration of an object in terms of the net (total) force on the object and the object's mass. Specifically, it says that the acceleration of an object is directly proportional to the net force on it and inversely proportional to its mass.

$$a = \frac{F_{net}}{m}$$

In this experiment we will not be measuring forces but we can still use Newton's Second Law to qualitatively understand the forces that must be present during different parts of the ball's motion.

For example, when you toss the basketball vertically upward the velocity of the ball goes from zero to some large upward value. Thus, the acceleration, which is the rate of change of velocity, must be upward as well. Newton's Second Law then requires that the net force on the ball must be in the upward direction during the toss. The forces on the ball can be considered to be the force exerted by your hand during the throwing motion and the weight of the ball. For the net force to be upward, the force exerted by your hand must have been greater than the force exerted by gravity.

However, when the ball leaves your hand, the only force acting on the ball is the gravitational force exerted by the Earth. We will assume that other forces that could be present, such as air resistance, are small enough that they can be ignored. In this case we would expect a downward acceleration for the ball while the ball is in flight.

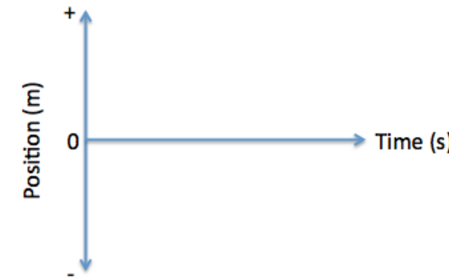
Acceleration of a Tossed Basketball

Pre-Lab Questions

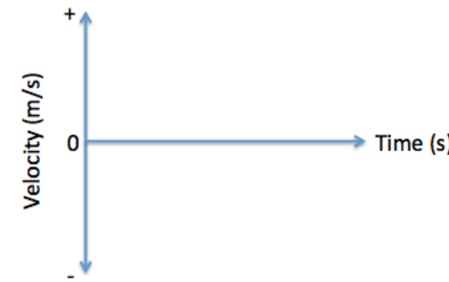
1. One goal in this experiment is to determine the acceleration of a basketball that has been tossed vertically in the air as it is rising upward, at its highest point, and while coming down. Please state as specifically as you can your predictions of the magnitude and direction of the acceleration of the basketball at these times.

	Magnitude	Direction
Rising		
Peak		
Falling		

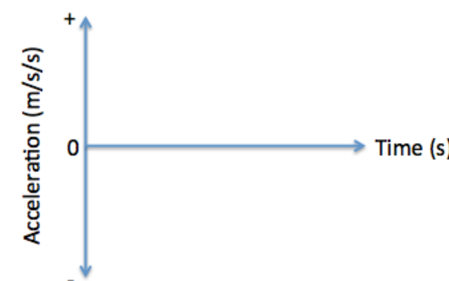
2. Suppose you toss a basketball vertically upward, allow it to rise to its highest point, and then catch it near the same point where you released it. Sketch a plot showing your prediction of the position of the basketball as a function of time from the instant it leaves your hand until just before you catch it. Take the positive direction to be vertically upward.



3. Describe how you could calculate the velocity of the basketball from the position data. Sketch a plot showing your prediction of the velocity of the basketball while in flight. Pay attention to the zero velocity level and positive and negative directions on the velocity axis. Make sure important points on the time axis for the velocity graph line up with corresponding instants of time on the position graph above it.

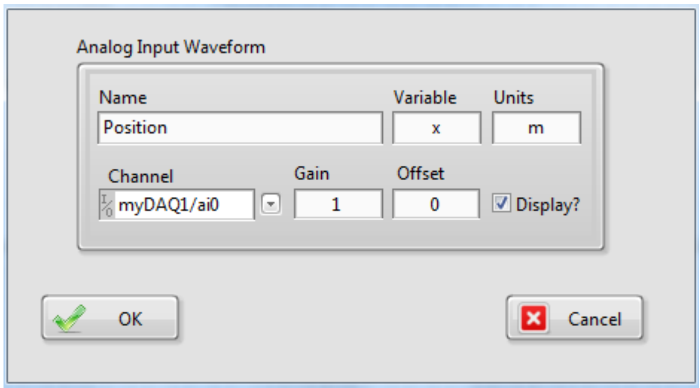


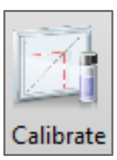
4. Describe how you could calculate the acceleration of the basketball from the velocity data. Sketch a plot showing your prediction of the acceleration of the basketball while in flight. Again, be sure to pay attention to the zero and positive and negative directions on your acceleration axis and to align important points in time with the previous two graphs.



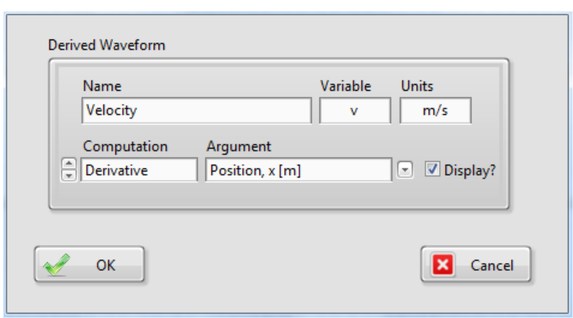
In-Lab Procedure

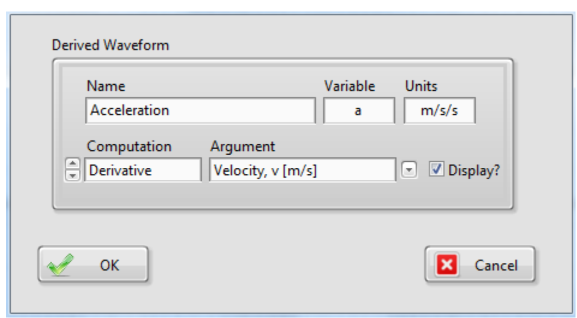
1. Arrange the iWorx MDN-100 position sensor so that it can monitor the position of the basketball during its vertical motion. You can either mount the sensor so that it is below the basketball looking upward or above the basketball looking downward. The downward looking arrangement has the advantage that you can also bounce the basketball on the ground and to study the acceleration that occurs during the bounce.
2. Connect the myDAQ (or ELVIS workstation) to the computer with the USB cable and connect the position sensor to the myDAQ (or to the ELVIS workstation). Be sure to record in your lab notebook the analog input channel you use and recall that if using the myDAQ that CH1 connects to physical channel myDAQ1/ai0 and CH2 connects to myDAQ1/ai1.
3. Open the *Physics Lab Assistant* software. Create a Position waveform using Add button on the Analog Input Waveforms tab. Be sure to associate this waveform with the same physical channel that you connected the position sensor to previously.





4. Select the Position waveform in the Analog Input Waveforms table and use the Calibrate button to perform a two-point calibration of the sensor. For best results use two points that cover the extremes of the expected motion and then check the calibration somewhere in the middle of this range. Recall that you shouldn't place anything closer than ?? cm to the front of the position sensor.
5. Create Velocity and Acceleration waveforms using the Add button on the Derived Waveforms tab. Be sure to enter the correct relationship to compute these waveforms from previously defined waveforms.



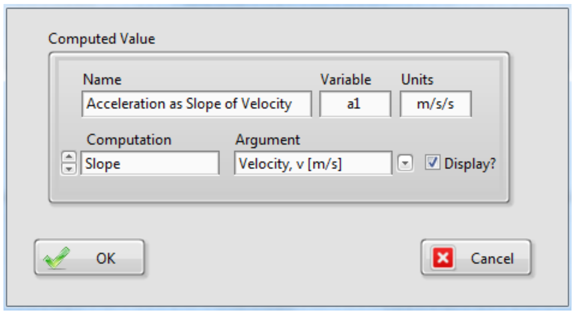


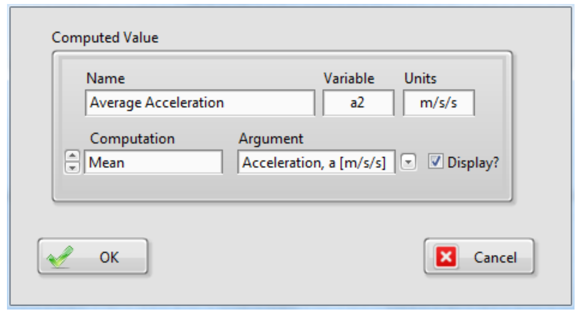
6. Use the Save button under the Experiment Setup area at the top of the screen to save these waveform definitions and calibration to a file. This file can be used to restart the experiment without having to re-define the waveforms and recalibrate in the event you have to start over.

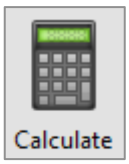
7. Using the Acquire button, collect a set of position versus time data while tossing the basketball in a vertical path above (or below) the sensor. It may take a few practice trials to perfect your technique and get a good set of data. You want to keep the basketball in the vertical view of the sensor and obtain a very smooth trace of position versus time.

8. Select the Waveforms tab to change the main display to show three graphs of Position, Velocity, and Acceleration. Identify the regions of time where the ball is rising, when it is at the top of its trajectory, and when it is falling? Use the vertical zoom cursor to simultaneously zoom all three graphs to the time the ball is in the air.
9. In your lab notebook, make note of the shape (linear, quadratic, exponential, constant, etc.) of the position versus time graph. Does your prediction from the pre-lab agree with the measurements you have made in lab?
10. Notice that the velocity is generally a bit noisier than the position and the acceleration is noisier than the velocity. This is a normal consequence that results from numerically differentiating real data. Since velocity is the derivative of position, it is equal to the slope of the position versus time. Small bumps in the position waveform result in larger spikes in the velocity. Keeping this in mind, study the velocity and make note of what happens to the velocity of the ball as it is rising, when at the peak, and when falling. Be sure that you are not looking at regions of time where the ball is in contact with your hand. What is the shape of the velocity versus time graph during the time the ball is in flight? Does it agree with your pre-lab prediction?
11. Study the acceleration and make note of what happens to the acceleration of the ball as it is rising, when at the peak, and when falling. What is the shape of the acceleration versus time graph during the time when the ball is in the air (not being touched by your hand)? Does it agree with your pre-lab prediction?
12. Using the cursor tools, extend the region of time that you focus on to include the time when you are throwing the basketball at the beginning and when you are catching it at the end. Investigate the acceleration of the basketball during the throwing and catching regions. How does the acceleration in these moments of time compare to the acceleration when the ball is free and in the air?
13. Create a set of graphs that you can use in your report that show the position, velocity, and acceleration as a function of time. Zoom in on the data so that these graphs include only the throwing, rising, at top, falling, and catching portions of the ball's motion. You can create these graphs either by exporting the waveform graphs directly to Microsoft Word, or by exporting the waveform data as a tab-delimited text file, an Excel file, or an Igor Pro text file and then creating the graphs in your favorite graphing software.
14. If you have arranged your motion sensor in a downward looking configuration you can optionally repeat the experiment without catching the ball on the way down. Attempt to get a trial where the ball bounces back vertically in the path of the motion sensor then study the acceleration the ball experiences as it bounces from the floor. How does this acceleration compare (both in magnitude and in direction) to the acceleration when in free fall?
15. Finally, perform multiple trials of the throw and catch to get an experimental measure of the acceleration due to gravity and compare to the published value of 9.80 m/s^2. To do this, create a new calculation for average acceleration using the Add button on the Calculated Values tab. You can compute the average acceleration either from the slope of the velocity waveform or from

the average of the acceleration waveform (or create two calculations and use both).



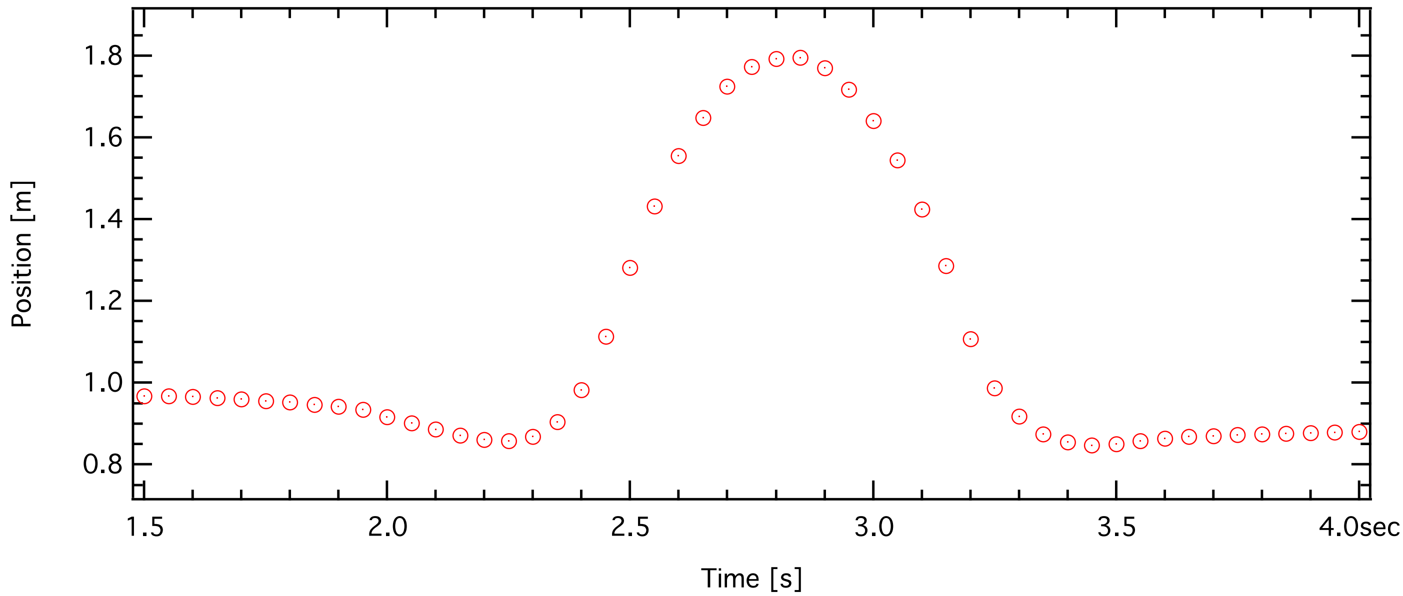


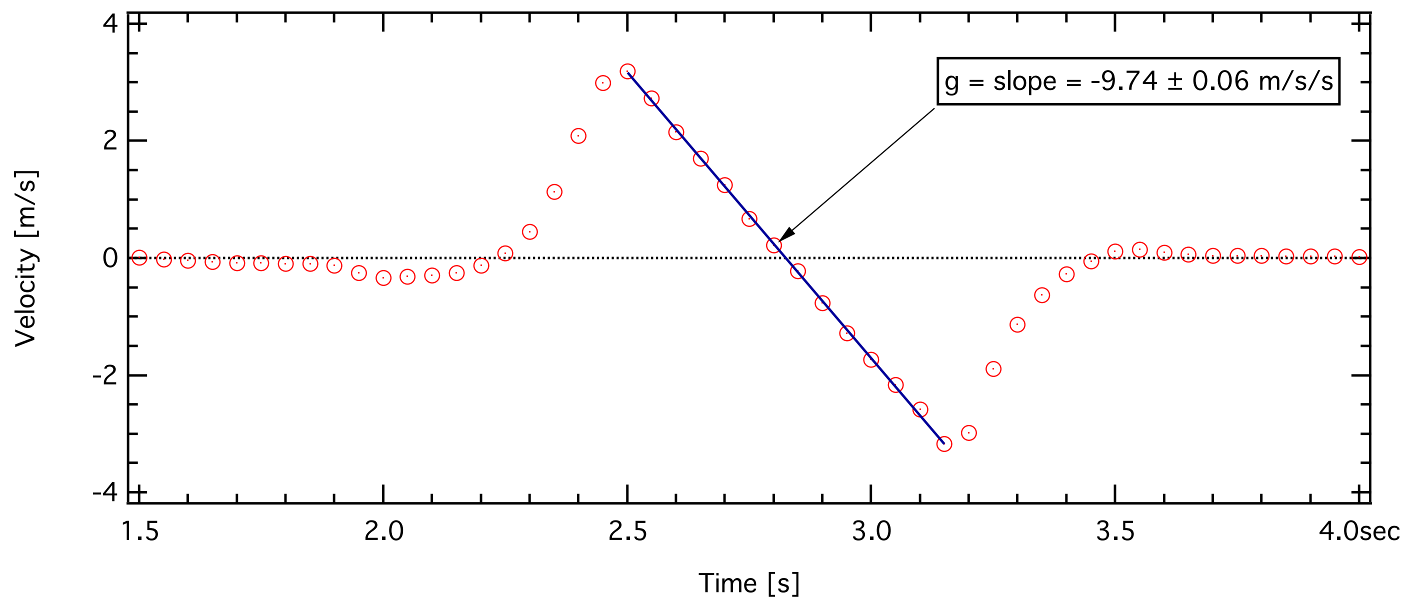


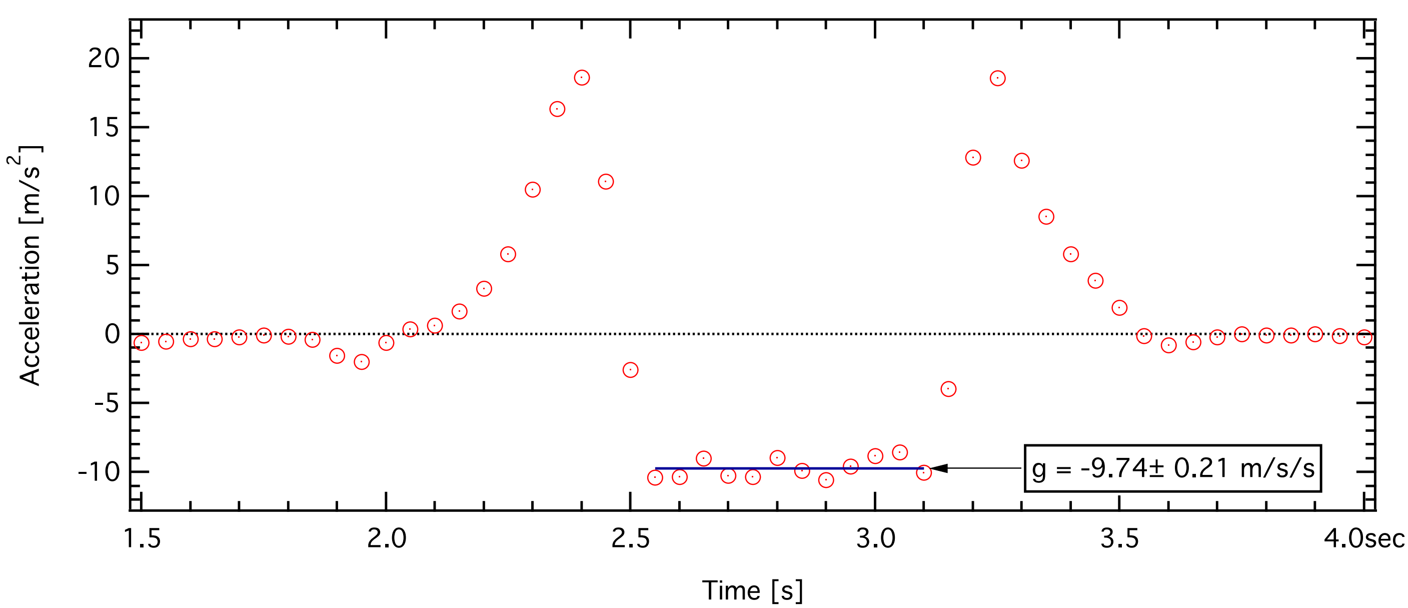
To use this feature you should collect a good set of data, zoom the waveform graph in on the region when the ball is in the air, and then press the Calculate button. A new calculation from the selected data will be entered into the Calculations tab on the main display. You should repeat this a minimum of five times to get multiple values of the acceleration due to gravity. Compute the average and standard error of your results and compare this to the published value of the acceleration due to gravity.

Post-Lab

1. You should have created a set of graphs that show the position, velocity, and acceleration of the basketball that span the intervals when the ball is tossed upward, when it is rising, when it is at its peak, when it is falling, and when it is being caught. Be sure to annotate your graph with labels that identify these five intervals. Briefly discuss the graphs in each of these intervals being sure to describe the shape of each graph (linear, concave up, concave down, constant, etc.) and what these shapes indicate about the acceleration in the interval and thus the net force in the interval. Be sure you specifically mention the magnitude and direction of the acceleration that you found in the intervals when the ball is rising, when at the peak, and when falling. Do your results agree with your pre-lab predictions?
2. If you collected measurements when the ball was bouncing then also discuss the acceleration that you measured during the bounce in the same manner.
3. You should have collected a table where you repeatedly measured the average acceleration of the basketball during the time when it was in free fall (when not in contact with your hand). Compute the average and standard error of these measurements and compare your result to the standard value of the acceleration due to gravity in your laboratory (use g = 9.81 m/s^2 unless told a different value by your instructor) by computing a percent difference. If your result differs significantly from the standard value can you identify any sources of systematic error that could have attributed to this difference?


Position [m]
1.8
1.6
1.4
1.2
1.0
0.8
1.5
2.0
2.5
3.0
3.5
4.0sec
Time [s]


Velocity [m/s]
g = slope = -9.74 ± 0.06 m/s/s
4
2
0
-2
-4
1.5
2.0
2.5
3.0
3.5
4.0sec
Time [s]


Acceleration [m/s^2]
g = -9.74± 0.21 m/s/s
20
15
10
5
0
-5
-10
1.5
2.0
2.5
3.0
3.5
4.0sec
Time [s]