§ 1 Introduction

In this laboratory you will observe the motion of two thrown objects, and you will compute the velocity and acceleration, from the observed position.

§ 2 Recording the motions

Procedure 2.a
Find something that is about the size of a tennis ball and roughly spherical. It should be at least as heavy as a tennis ball. We will refer to this as the "ball" for the rest of this document. Loosely crumply up a piece of paper into a ball about the size of a tennis ball. We will refer to this as the "paper" for the rest of this document. Put your camera on the trip so that the long direction of the image is vertical. Set up the camera facing a closed door, so that you can see all of the door from the floor to the ceiling. Make sure that the door looks like a rectangle in the image. Measure and record the distance L from the camera to the door. Measure the width W and height H of the door. If the paper or ball are not clearly visible against the door, choose a paper or ball of a different color so it contrasts with the door. Turn on as many lights as you can, this will make the image sharper.

Any large rectangle can be used instead of a door as long as the sides of the rectangle are vertical.

Procedure 2.b
Play catch with someone, you at one edge of the closed door and your partner at the other edge of the door. So that the ball travels in a plane parallel to the door, with the ball always a distance D from the door. Throw the ball in a high arc, so that the ball nearly reaches the top of the door. You can view this example video. It might be helpful to place something tall on the floor at a distance of D from the door, sit on the floor and toss the ball over this object to your partner. Practice with both the ball and ball of paper so that you can keep them a distance D from the door as they travel to your partner. Record the distance D. While viewing the video it will not be easy to tell if the path of the ball was a constant distance from the door. So shout out when it this happens so that when you view the video later you will know which tosses to use.

Procedure 2.c
Turn on the video camera and record tosses of the ball back and forth. Do the same with the ball of paper. You can make just one video with all the tosses, this will make the calibration easier, since you will only have to calibrate once. Make sure to record at least two tosses in each direction (left going and right going) that stays a distance D from the door. For the ball of paper get at least one toss in each direction.

§ 3 Process the data

Procedure 3.a
Import the video to Tracker and track the four good tosses. If the sides of the door are not parallel in the image you will need to use the perspective correcting feature of Tracker, instructions and a helpful program [MSwin, macOS] are available on the class website. Use the height of the door H to calibrate Tracker. Make sure that the y-axis in Tracker is aligned with the vertical edges of the door. Save the data files as `paperR.txt` for the ball of paper that is going to the right, and `paperL.txt` for the ball of paper that is going to the left. Similarly use file names `ballR1.txt`, `ballR2.txt`,`ballL1.txt` and `ballL2.txt` for the right and left going tosses with the ball.

Procedure 3.b
Get the program `Lab1p4` [MSwin, macOS] from the class website. Run `Lab1p4` with each of your six data files. Once in the program be sure to set the value of distance L between the camera and the door, and the distance D form the door to the object. The program will produce some graphs and a pdfs of those graphs. The pdfs will be placed in the same directory as the data files.

§ 4 Interpretation

▷ QUESTION 1

The program graphs x versus t and y versus t. It also fits a quadratic function of time

$$y_{\text{fit}} = c_0 + c_1 t + \tfrac{1}{2} c_2 t^2$$

to y with the three constants c_0, c_1 and c_2. The program also fits a linear function of time

$$x_{\text{fit}} = b_0 + b_1 t$$

to x.

(a) Which trajectories are well fit by a polynomial functions? Which are not fit well by a polynomial?

(b) For the trajectories that **are** well fit by the polynomial use the definition of the of velocity

$$v_x = \frac{dx}{dt} \quad \text{and} \quad v_y = \frac{dy}{dt}$$

to compute the velocities from the polynomial function. For the same trajectories use the definition of acceleration

$$a_x = \frac{d^2x}{dt^2} \quad \text{and} \quad a_y = \frac{d^2y}{dt^2}$$

to compute the acceleration from the polynomial function. Graph the velocity versus time for all of the trajectories that are fit well by a polynomial on the same axes. Do the same for the acceleration versus time. Do the different trajectories have anything in common in the graphs? Are the velocity and acceleration what you expected?

▷ QUESTION 2

For the trajectories that were not very well fit by a polynomial, the program also tries to fits the vertical positions by a more complicated function than a polynomial. This more complicated function is relevant in cases where the resistance of the air on the object is significant compared with the gravitational force on the object. This fitting is shown in the third graph. For the trajectories that are not fit well by the polynomial does this more complicated function do a better job of fitting the vertical motion? The velocity and acceleration are graphed for you for this more complicated function. Are the velocity and acceleration graphs very different from the velocity and acceleration graphs for the trajectories where the data was well fit by a polynomial? How are the graphs the same, how are they different?