Video Analysis of a Ball on a Rotating Merry-go-round

Apparatus

Tracker software (free; download from http://www.cabrillo.edu/∼dbrown/tracker/)
video: `coriolis-merry-go-round-ball.mov` from http://physics.highpoint.edu/∼atitus/videos/
video: `corioliskraft.mp4` from http://physics.highpoint.edu/∼atitus/videos/

It is assumed that you know how to use the Tracker software.

Goal

In this experiment, you will measure and graph the x-position of a ball as a function of time as it rolls across a rotating merry-go-round. In addition, you will compare the motion of the ball viewed from a stationary camera with the motion of the ball viewed by a camera rotating with the merry-go-round. You will identify the frame of reference in which Newton's First Law correctly describes the motion of the ball.

Introduction

According to Newton's First Law, *if there is no net force (or no forces at all) exerted on an object, then the object will travel in a straight line with constant speed or will remain at rest.* Another way to say it is that if there are no interactions (or no net interaction) between the object and its surroundings, then the object will travel in a straight line with a constant speed or will remain at rest.

Since the object's speed and direction of motion are constant, then the object is said to have a constant velocity. Since velocity is vector, it has both a magnitude and direction. For velocity to be constant, its magnitude and its direction must be constant. (The magnitude of velocity is called speed.) Thus, if the direction of motion changes or if the speed changes, then the object's velocity is not constant.

For an object moving with a constant velocity in the x-direction, its x vs. t graph will like the graph in Figure 1. The slope of the x vs. t graph is the x-velocity v_x.

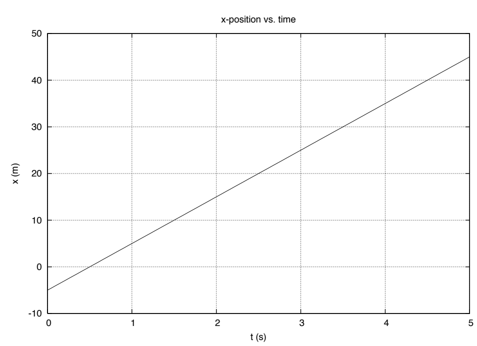

Figure 1: x vs. t for an object moving with constant x-velocity

If an object is moving at an angle with respect to the x axis, then it will have both an x-velocity and a y-velocity. In this case, $\vec{v} = \langle v_x, v_y \rangle$ where v_x is the x-component of the velocity vector and v_y is the y-component of the velocity vector. To measure v_x and v_y, you will need two graphs: (1) x vs. t and (2) y vs. t. The slope of the x vs. t graph is the x-velocity v_x, and the slope of the y vs. t graph is the y-velocity v_y.

However, for an object moving in a straight line, you can always rotate your coordinate system to align with the direction of motion. Then, you only have one variable (x) and you only need one graph (x vs. t).

Procedure

1. Download and view the video `corioliskraft.mp4` .

2. Answer the following questions.

> 1. At one point, the woman and man at the beginning of the video roll a ball directly toward each other. What can the woman and man say about the ball?
>
> (a) The ball travels in a straight line at constant speed (in other words, it travels with constant velocity).
>
> (b) The ball does not have a constant velocity.
>
> 2. What would the woman and man say about the ball based on Newton's First Law?
>
> (a) There is a net force on the ball because its velocity is NOT constant.
>
> (b) The net force on the ball is zero because its velocity is constant.
>
> 3. When analyzing the forces on the ball, the man and woman have to identify those things touching the ball or otherwise interacting with the ball through a distance (like the gravitational force of Earth on the ball). The man and woman can only identify two "things" that interact with the ball while it is rolling between them. What are they? Circle all that apply.
>
> (a) Earth interacts with the ball because it exerts a downward gravitational force on the ball.
>
> (b) The floor exerts a force on the ball because it makes contact with the ball.
>
> (c) The hand exerts a force on the ball even when he/she is not touching the ball.
>
> 4. Earth exerts a downward force on the ball due to gravitational attraction. The floor exerts an upward force on the ball due to contact. Friction is a small effect in this case. Is there anything pushing the ball horizontally while it is rolling?
>
> (a) yes
>
> (b) no
>
> 5. Therefore, is there a net interaction of the ball with its surroundings?
>
> (a) yes
>
> (b) no
>
> 6. What must the man and woman conclude?
>
> (a) Newton's first law is NOT valid. Their observations (i.e. experimental results) are not consistent with Newton's first law.
>
> (b) Newton's first law is valid. Observations (i.e. experimental results) confirm Newton's first law.

3. Download and view the video `coriolis-merry-go-round-ball.mov` .

4. Play the video and observe the motion of the ball. This video contains two parts: (1) the motion of the ball is viewed from above by a stationary camera that is fixed and is thus NOT rotating with the merry-go-round; and (2) the ball is viewed by a camera held by a person sitting on the other side of the merry-go-round.

5. Open the *Tracker* software on your computer.

6. Use the menu **Video→Import...** to import your video, as shown in Figure 2.

7. Zoom in on the video until it is large enough to comfortably see the ball.

8. Set the origin of the coordinate system to be at the center of the merry-go-round. Do your best to estimate the center because this can be a significant source of error in the measurements. It turns

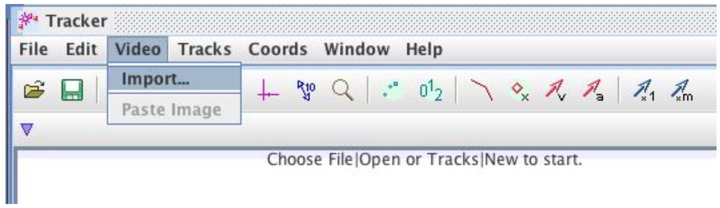

Figure 2: Video→Import menu

out that if you advance the video 6 frames (so that it is on the 7th frame), the support bars will be aligned with the horizontal and vertical axis, and the center of the merry-go-round can be easily found by aligning the coordinate system with the support bars.

9. To calibrate the scale, click the ruler icon and stretch the ruler across the diameter of the merry-go-round. Do your best to make ruler go through the center of the merry-go-round. We will assume that the diameter is 2 m. (Note that we do not have an exact scale, so our results are completely based on this assumption. As a result, we do not know the accuracy of our measurements.)

10. Create a new mass (by clicking the $\boxed{\text{Create}}$ button in the toolbar). While holding down the shift key, mark the ball. Continue marking until the last frame before it is caught.

    Note that the ball has both a v_x and a v_y since in our coordinate system, it travels to the right (+x direction) and downward (–y direction). It is more convenient, however, if we align our coordinate system with the direction of motion of the ball.

11. Move the origin of the coordinate system to the first mark of the ball. Rotate the x-axis of the coordinate system so that it is nearly aligned with the marks. You may have to adjust the origin as well so that it is not exactly on the first mark. You may notice that the last couple marks start to veer from the straight line, but the other marks are very close to being in a straight line. Do your best to align the coordinate system with these marks, as shown in Figure 3.

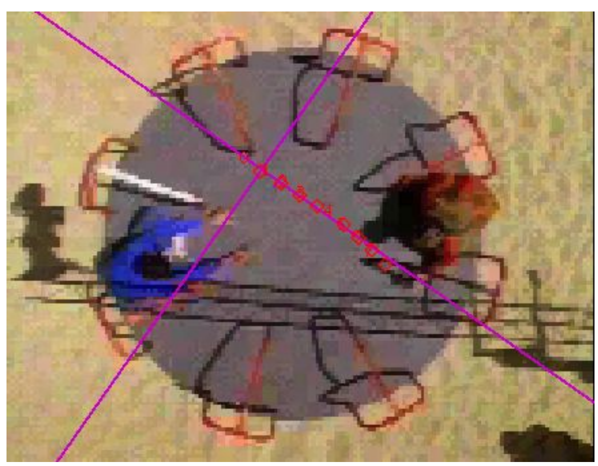

Figure 3: Align the x-axis with the direction of motion of the ball.

With the coordinate system defined in this way, what should be v_y for the ball (theoretically)?

12. Graph x vs. t. Analyze the graph and find the best-fit curve for the graph. Write down the curve fit, and use the curve fit to measure the x-velocity v_x of the ball.

13. Graph y vs. t. If you adjust the scale on the vertical axis to effectively zoom out on the graph, you'll notice that y is nearly constant, so v_y is nearly zero as expected.

Analysis

1. Use your curve fit to answer the following questions.

From the graph, do you conclude that v_x is constant or not constant? Explain your answer.

From your best-fit curve, what is the x-velocity v_x of the ball?

The only two forces on the ball are the downward gravitational force by Earth and the upward contact force by the merry-go-round. These forces cancel (since the ball doesn't fly upward out of the plane of the video). Thus, what is the net force on the ball?

Based on your measurements of the x-velocity of the ball and your observations about the forces on the ball, what can you say about Newton's first law?

(a) Newton's first law is NOT valid. Our measurement of v_x and our observation of the net force on the ball is not consistent with Newton's first law.

(b) Newton's first law is valid. Experimental measurements of v_x and our observation of the net force on the ball confirms Newton's first law.

2. Watch the motion of the ball as viewed by a person on the merry-go-round. This is the later part of the video.

What do you notice about the path of the ball in this reference frame?

(a) The ball travels in a straight line at constant speed (in other words, it travels with constant velocity).

(b) The ball does not have a constant velocity because it travels along a curved path, so its direction changes.

In this rotating reference frame, what can you say about Newton's first law?

(a) Newton's first law is NOT valid. The ball does NOT travel in a straight line which indicates that there is a horizontal force of some kind acting on the ball. Yet, no horizontal interaction exists. So, Newton's first law is not consistent with our observations in this reference frame.

(b) Newton's first law is valid. The ball does not travel in a straight line, so something is pushing the ball horizontally. We can't see anything pushing it, but it must be there in order to make Newton's first law valid.

3. An inertial reference frame is defined as a reference frame in which Newton's first law is valid.

Which of these reference frames is an inertial frame?

(a) The "stationary" frame where the camera is fixed above the merry-go-round and does not rotate.

(b) The "rotating" reference frame where the camera is mounted on the merry-go-round and rotates with the merry-go-round.