# Video Analysis – Inertial and non-inertial reference frames

## Apparatus

Tracker software (free; download from http://www.cabrillo.edu/∼dbrown/tracker/)
video: `two-carts.mov` from http://physics.highpoint.edu/∼atitus/videos/

## Goal

In this experiment, you will measure the motion of two carts: (1) an accelerating fancart and (2) a cart moving with constant velocity. You will then describe the motion of the second cart as viewed from the reference frame of the fancart.

## Introduction

Newton's first law describes the motion of an object (or *system*) if the net force on the object is zero. It basically says that if the forces acting on an object balance (so that there is zero net force on an object), then its velocity will be constant (which may or may not be zero).

Newton's second law describes the relationship between the net force on an object (or *system*) and the object's acceleration.

$$\Sigma \vec{F} = m\vec{a} \tag{1}$$

Applying Newton's second law to one-dimensional motion in the x-direction gives:

$$\Sigma F_x = ma_x \tag{2}$$

$$\tag{3}$$

If Newton's first and second laws are valid, then you are viewing the object from an *inertial* reference frame.

If the net force on an object is zero and yet the object accelerates, then Newton's laws are *not* valid, and you must be viewing the object from a *non-inertial* reference frame.

Another way to say this is if the object is accelerating, then you should be able to identify the force(s) causing the acceleration. If these forces do *not* exist, yet the object accelerates, then Newton's first and second laws are *not* valid, and you are viewing the object from a *non-inertial* reference frame. You have to either invent a force, called a *fictitious force*, to make Newton's laws work in the non-inertial reference frame, or you have to simply recognize that you are in a non-inertial reference frame and not apply Newton's laws.

## Procedure

In this experiment, you will analyze the video of two carts. Both carts are on low-friction, level tracks. (1) Cart 1 has a fan attached to it and (2) Cart 2 has no fan attached. There are no horizontal forces on Cart 2.

1. Download `two-carts.mov` by right-clicking on the link and choosing **Save As...** to save it to your desktop:

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

3. Go to the menu **Video→Import...** and import `two-carts.mov` , as shown in Figure 1.
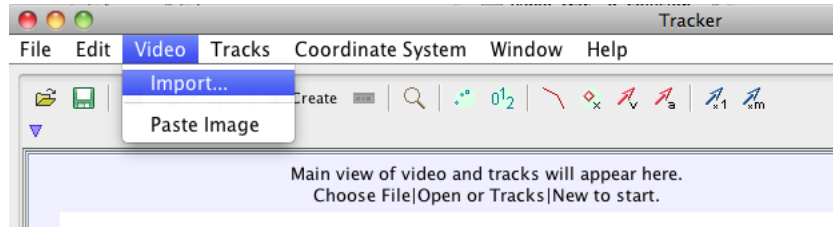
4. Play the video and watch the motion of the two carts.

Figure 1: Video→Import menu

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Describe the motion of Cart 1.

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List all of the forces on Cart 1, and sketch a free-body diagram. In what direction is the net force on Cart 1? Explain your reasoning.

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Describe the motion of Cart 2.

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List all of the forces on Cart 2, and sketch a free-body diagram. In what direction is the net force on Cart 2? Explain your reasoning.

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Are your observations consistent with Newton's first and second laws?

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5. Go to the video control bar and move the left black marker to the right until the video is on frame

001. (See Figure 2) You can also adjust this by clicking on the video settings icon (shown in Figure 3) and setting the start frame at 1.
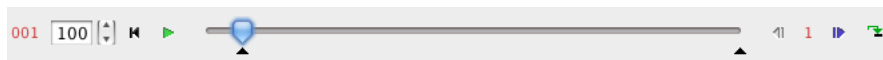


Figure 2: Use the video control bar to set the first frame for analysis to be frame 001.



Figure 3: Video settings icon in the toolbar.

6. There is a 1-m stick in the video. Use this to set the scale (i.e. calibrate distance) for the video.

7. Set the origin of the coordinate system to be at the position of Cart 2. In reality the choice of origin isn't important for measuring velocities and accelerations; but it does determine the intercept on the x vs. t graph for each cart.

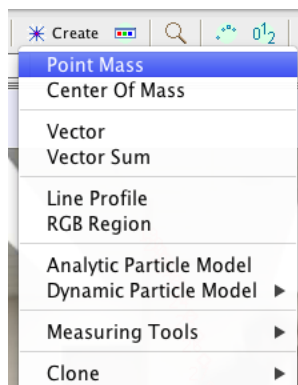8. Click the ☐ Create ☐ button in the toolbar and create a new **Point Mass.**



Figure 4: Create a new point mass and name it cart 1.

9. In the toolbar or in the Track Control pop-up window, click ☐ mass A ☐ , select **Name...**, and change its name to "cart 1".

10. While holding down the Shift key, click on the yellow dot on Cart 1 to mark its position. Continue marking Cart 1 in all subsequent frames in the video.

11. Create a new point mass for Cart 2, change its name to "cart 2," and mark its position in all subsequent frames of the video. (See Figure 5.)

## Analysis

1. Fit a function to the graph of x vs. t for Cart 1. What is x(t)?

2. Fit a function to the graph of $v_x$ vs. t for Cart 1. What is $v_x(t)$?

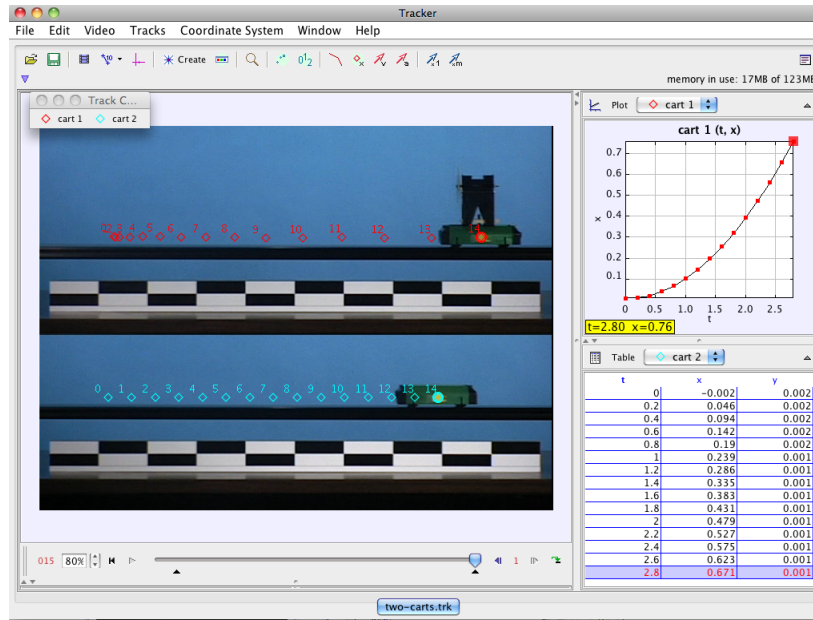3. What is the initial velocity of Cart 1? What is the acceleration of Cart 1?

Figure 5: Trails for the two carts.

4. Fit a function to the graph of x vs. t for Cart 2. What is x(t)?

5. What is the velocity of Cart 2?

6. What is the acceleration of Cart 2?

7. Do Newton's laws explain the motion of each cart? Sketch free-body diagrams for each cart and explain your answer.

8. Is the "ground" (i.e. the video camera) an inertial reference frame?

9. At what time (i.e. clock reading) does Cart 1 pass Cart 2? **Answer this question algebraically.**

10. Now measure the clock reading on the video when Cart 1 passes Cart 2. Compare your measured value with the calculated result.

> Now imagine that these are cars and you are riding in Cart 1 that is accelerating to the right, as measured by a person on the ground. Describe the motion of Cart 2 from your reference frame (i.e. the reference frame of Cart 1).

11. **Answer all of the following questions from the reference frame of Cart 1.** Note that these are all predictions. You will make the measurements later.

    (a) What is the initial velocity of Cart 2 (at $t = 0$)? Be sure to consider both direction and magnitude.

    (b) Before you pass Cart 2, will Cart 2 appear to speed up or slow down?

    (c) What is the acceleration of Cart 2 (in your reference frame)?

(d) Sketch a graph of $x$ vs. $t$ for Cart 2 in your reference frame.

(e) Sketch a graph of $v_x$ vs. $t$ for Cart 2 in your reference frame.

12. Now, go to **Coordinate System→Reference Frame** and select "cart 1" as shown in Figure 6. Answer the following questions.
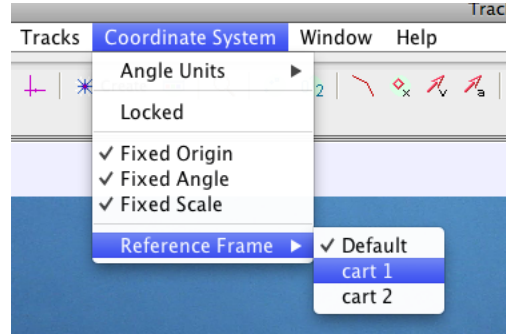


Figure 6: Change the reference frame to Cart 1.

(a) View the $x$ vs. $t$ graph for Cart 2. How is it similar or different to what you predicted?

(b) View the $v_x$ vs. $t$ graph for Cart 2. How is it similar or different to what you predicted?

(c) What is the initial velocity of Cart 2?

(d) What is the acceleration of Cart 2?

(e) Do Newton's first and second laws describe Cart 2 in your reference frame? Explain your answer.

(f) Is Cart 1 an inertial reference frame? Explain your answer.

Now imagine that these are cars and you are riding in Cart 2 that has a constant velocity to the right, as measured by a person on the ground. Describe the motion of Cart 1 from your reference frame (i.e. the reference frame of Cart 2).

13. **Answer all of the following questions from the reference frame of Cart 2.** Note that these are all predictions. You will make the measurements later.

(a) What is the initial velocity of Cart 1 (at $t = 0$)? Be sure to consider both direction and magnitude.

(b) Before you pass Cart 1, will Cart 1 appear to speed up or slow down?

(c) What is the acceleration of Cart 1 (in your reference frame)?

(d) Sketch a graph of $x$ vs. $t$ for Cart 1 in your reference frame.

(e) Sketch a graph of $v_x$ vs. $t$ for Cart 1 in your reference frame.

14. Now, go to **Coordinate System→Reference Frame** and select "cart 2" to change the reference frame to Cart 2. Answer the following questions.

(a) View the $x$ vs. $t$ graph for Cart 1. How is it similar or different to what you predicted?

(b) View the $v_x$ vs. $t$ graph for Cart 1. How is it similar or different to what you predicted?

(c) What is the initial velocity of Cart 1?

(d) What is the acceleration of Cart 1?

(e) Do Newton's first and second laws describe Cart 1 in your reference frame? Explain your answer.

(f) Is Cart 1 an inertial reference frame? Explain your answer.