Investigation 2
Motion in 1-dimension

Motion of a Fancart on a track

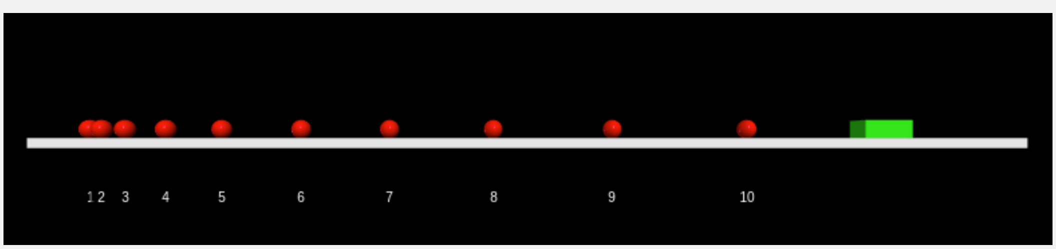
In physics, we study the motion of objects using the field of kinematics, which relates an object's *position* (x), *velocity* (v), and *acceleration* (a) as follows:

$$v = \frac{dx}{dt} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \qquad \text{and} \qquad a = \frac{dv}{dt} = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t}$$

As you have seen in your physics text, for constant acceleration, these become the familiar kinematic equations:

$$\begin{aligned} x_f &= x_i + v_i t + \frac{1}{2} a t^2 \\ v_f &= v_i + a t \\ v_f^2 &= v_i^2 + 2a\left(x_f - x_i\right) \end{aligned}$$

We will be using these equations to help us understand the motion of a fancart.



The green box represents the fancart, while the red dots indicate the position of the cart at different times.

Investigation 2 — Part 1

Background information: Position, Velocity, and Linear Regression

1.1 Motion captured by an ultrasonic motion detector

An ultrasonic motion detector works by measuring the position of an object using sound waves. This process is shown, schematically in Figure 2.1. A short pulse, or click is emitted by the motion detector. The pulse then travels through the air to an object and bounces off of that object and returns to the detector. The distance that the object is away from the detector is proportional to the time that it takes for the reflected pulse to be detected. (That is, a longer detection time implies a longer distance). A pulse is emitted every 0.05 s, and the measurements are taken repeatedly. This will produce a table of time and position values that are automatically plotted by the data-collection software, LoggerPro.

The time that elapses between the pulse being emitted and detected, Δt, is used to determine the distance that the object is away from the detector.

$$d = \frac{c_s \Delta t}{2} \tag{2.1}$$

Here, c_s is the speed of sound. However, the speed of sound is not a universal constant. It depends on many factors including temparature, humidity, and air pressure. Rather than engaging in a calculation of the speed of sound, we can simply *calibrate* our motion detector. *Calibration* is the act of verifying the measurement of one device by using another device of known accuracy. In this case, you should devise a method for checking the measurements that your ultrasonic motion detector is making using a device which measures lengths.

1.2 Calculating velocity from position-time data

As we discussed previously, the motion sensor measures the object's position repeatedly for multiple times. So we will get a bunch of time values, $(t_1, t_2, t_3, \ldots)$, and a bunch of position values, $(x_1, x_2, x_3, \ldots)$. When we want to pick one of these measurements, it is common to use t_i and x_i respectively.

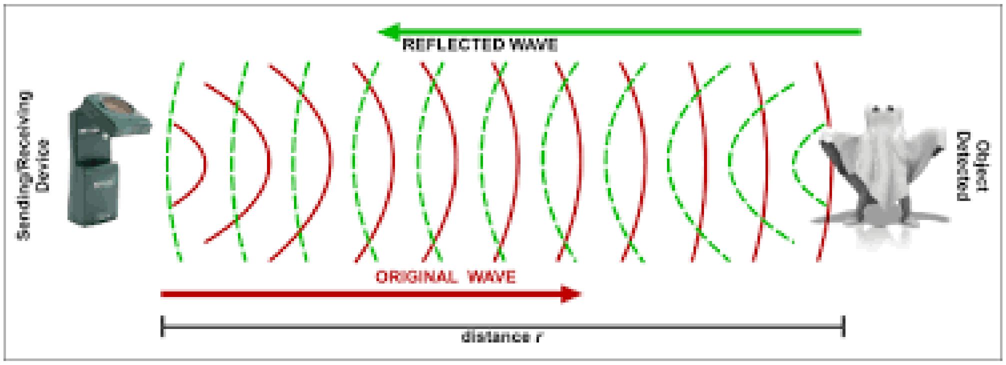


Figure 2.1: Image taken from: `http://www.deserthighlandspr.com/images/ultrasonic_device_example.png`.

The pre-lab activity for this week involves analyzing the motion of a cart over successively shorter time intervals. We will observe that the position vs. time graph has a (nearly) linear shape as the time interval we are considering gets shorter. This is actually a fundamental idea in Calculus – all functions are linear on a "short enough" interval. In physics, this means that we can treat all motion as constant velocity during short time intervals. So the velocity at the i^{th} instant can be calculated using:

$$v_i = \frac{x_{i+1} - x_{i-1}}{t_{i+1} - t_{i-1}} \tag{2.2}$$

where the position and time values are for the subsequent and previous instants respectively.

1.3 Using Linear Regression to Find Acceleration

What happens when we are using the motion detector to analyze the motion of something that is accelerating? The velocity given by Eq. (2.2) will be different for each time interval you measure. If the acceleration is constant, the kinematic equation for velocity vs. time is an equation for a line, and we can use a technique called *linear regression* to determine that properties of the line, such as the initial velocity and the acceleration, from our experimental data points. Linear regression is explained in detail in Appendix B. Please review this section before the pre-lab. You should be familiar with using Excel with the `Data Analysis Toolpack` to obtain a linear regression, R^2 value, and standard errors of the fit parameters (all covered in Appendix B).

Investigation 2 — Part 2

Pre-Lab: Motion of a cart

The goal of this activity is to measure the acceleration of, and calculate the net force on, a cart rolling down a ramp. We will do this using a motion sensor and a low-friction cart.

2.1 Connecting the motion detector to your computer

We will be using Vernier hardware to automate measurements and record them on our computer. These are shown in Figure 2.2. Using this hardware has multiple benefits. First, the motion sensor can collect data more quickly than we can. Second, the data can be easily sent to your spreadsheet. This reduces mistakes (not *errors*) due to transcribing numbers incorrectly (i.e., writing them down or entering them in your calculator). Finally, this practice matches modern lab sciences. Most data is collected by computer and the struggle that we have is not *getting* data, but *analyzing* the data that we have. Some data sets have trillions of events to analyze.[1] The hardware and software that we will be using to collect position vs. time data are listed below.

Ultrasonic Motion Sensor: This is pictured in Figure 2.2(a). Sometimes, we will call it a "motion sensor" or a "motion detector".

LabQuest2 interface: This is pictured in Figure 2.2(b). While it can be used without a computer, we will connect it to our computers via USB. Different sensors may be plugged into the ports which are shaped somewhat like an ethernet port or phone jack.

LoggerPro software: This is the proprietary software created by Vernier to facilitate and manage the collection of data by the computer.

In order to collect your position vs. time data, you need to ensure that your hardware is in working order. You can do this by plugging the cable with the white clips on it into both the motion sensor and the LabQuest2 interface. Next you need to ensure that the LabQuest2 interface is connected to the computer via USB. Next, you need to open the file `sonicRanger.cmbl` on your computer. (Your TA can help you locate the `sonicRanger.cmbl` file if you have difficulty finding it.) LoggerPro will open, and automatically detect the

[1] See, for example the Wikipedia page on Big Data: `https://en.wikipedia.org/wiki/Big_data`.

(a) (b)

Figure 2.2: (a) Vernier motion sensor and (b) LabQuest2 interface. Images from `http://www.vernier.com`.

ultrasonic motion detector. In order to collect data, you click the green button on the right side of the toolbar. Data collection will stop when you click the red button or after 5 seconds, whichever comes first. Try it out by collecting some data and moving your hand in front of the motion sensor. See what happens, and make sense of the output that you see on your screen. A few things that you should pay attention to:

1. What are the units of the position measurement? Does the length being measured make sense? (For example, if it were measuring a position of 10 m, would you believe the measurement?)
2. Is the position measured always changing whenever your hand is moving? If not, when is the position not changing?
3. What other factors do you need to take care of in order to ensure an accurate measurement?

Don't forget to clear your data before you continue.

2.2 Collecting data

As you have read in your physics text, an object moving on a ramp moves with constant acceleration. So we will measure the position vs. time for a cart on a ramp, and use that to determine the acceleration of the cart, as well as the net force on the cart. At each of your stations, in addition to a motion sensor, you should have a track, some blocks that you can use to incline the track, and a cart. Use these to set up a ramp and align your motion sensor.

In order to ensure that you are getting accurate measurements, you must *calibrate* the motion sensor. You can do this by holding the cart stationary and verifying the measurement using another device (e.g., a meter stick). In order to properly calibrate the motion sensor you need to verify position measurements for a range of positions on the track. Check at least three locations:

1. At the top of the track
2. In the middle of the track
3. At the bottom of the track

Resolve any discrepancies between the two measurement devices before you go on.

Next, you should collect some position vs. time data. Take a few runs until you get a nice smooth curve. Once you have good data, export it into Excel. You can do this by selecting `File` → `Export As` → `CSV...` and then choosing a location to save the raw data. This file will then open directly in Excel, although once you open it, you should save it in the default Excel format with an extension `xlsx`. ***If you do not convert your file to the*** `xlsx` ***format, you will lose all of the plots that you make, as well as the formulas you used to make any subsequent calculations.***

2.3 Analyzing data

Once your data has been saved in the appropriate file format, you should calculate velocities using the method that we developed in Part 1.2 of this investigation. When calculating each velocity value, you should use cell references. *If you have never done this before, check with an instructor, and get help!*

Now that you have x vs. t and v vs. t data, make graphs of these data. Carry out a linear regression on the v vs. t data. Show the line of best fit on the v vs. t graph, and interpret the fit parameters. Appendix B.1 should help you interpret the regression. Use Figure B.1(a) as a model for the plots you create.

Finally, use your data to calculate the net force on the cart. If you need to measure any other properties, do so now.

Before you leave

As a group:

1. Create a plot of position vs. time for your cart.
2. Create a plot of velocity vs. time for your cart. Include your line of best fit on the graph.
3. Report the acceleration of your cart with both ***uncertainty*** and ***units***.
4. Report the net force on your cart with both ***uncertainty*** and ***units***.

Type up your results and plots as a group and submit them on Blackboard. ***Before you submit, everyone must sign up for a group on Blackboard in order to get credit for the assignment.***

Investigation 2 — Part 3

Argumentation Question: Does the force that the fan exerts depend on the mass of the cart?

This portion of the investigation is designed to last for two weeks. During the first week, your goals are to:

- Develop a proposal to measure the argumentation question.
- Get your proposal approved by the TA.
- Begin collecting and analyzing data. (Ideally, your data will be fully collected and analysis can happen during the week.)

During the second week of this investigation the main activity is the argumentation session. As such, you will need to:

- Finish data collection and analysis.
- Prepare your group's whiteboard for an argumentation session.
- Discuss the findings from the argumentation session.

Based on your previous experience, your task is to design and carry out a procedure for measuring the force that a fan is exerting on a cart, and determine if that force changes when the mass of the cart changes. However, before you begin taking measurements, you must create a proposal as a group. The proposal form is found on page 25. Be as specific as possible as you develop your proposal. In the *"How will you collect your data?"* box, you should pay attention to the following questions:

- What quantities will you need to measure directly?
- How will you measure each quantity?
- What safeguards will you put in place to reduce your uncertainty?
- How many different cart masses will you determine the force for?

In the *“How will you analyze your data?”* box, you should pay attention to the following questions:

- How will you calculate the fan’s force on the cart? (Include intermediate steps.)
- How will you use your data to determine if the forces are the same or different?

3.1 Lab Report

Does the force that the fan exerts depend on the mass of the cart?

Once you have completed your work, you will prepare an investigation report that consists of three sections. Your report should answer these questions in 2 pages of text. This report must be typed (12 pt font and 1-inch margins) and any diagrams, figures, or tables should be embedded into the document.

Generally, you need one page for the first two sections and the second page for third section.

3.1.1 Section 1 (About $\frac{1}{2}$ page)

What concept were you investigating and how does it relate to the guiding question?

- Discuss position and time and how they relate to velocity and acceleration.
- Specifically discuss how these concepts relate to the force that the fan exerts on the cart.

3.1.2 Section 2 (About $\frac{1}{2}$ page)

How did you go about your work and why? This is *not* the details of your procedure, but a discussion and justification of the process.

- Describe the methods for measuring the position vs. time data and any calculations that are made.
- Discuss what you did to reduce error/ensure consistent measurements.

3.1.3 Section 3 (A little more than 1 page)

What is your argument? This third section is where you not only present your data, but also use the values you obtain as evidence in your reasoning. Statements like, "See data table for values," are *not* acceptable.

- State your claim.
- Use your measurements to support your claim.
- Include any figures that you created, along with the line of best fit to your data.
- Include a data table with the values that you measured for the fan's force.
- Discuss the limitations of your measurements and conclusions.
- Compare with other groups. Discuss reasons for differences.

Don't make your figures so large that they take up a massive amount of space, but also don't make them so small that they are difficult to read.

3.1.4 Section 4 (about $\frac{1}{4}$ page, final report only)

In your final report include a short statement explaining your response to the peer reviews. If you changed something in your final report as a result of the peer reviews, describe what you changed. If you disagree with a suggestion given by a reviewer, state why. **Note**: Include this section in your final report only, not in your draft report you submit for peer review.

In addition to your lab report, also upload your Excel file with your data and analysis to Blackboard with your final report.

Name: ______________________ Date: ______________

Instructor: ______________________ Section/Group: ______________

3.2 Lab Investigation 2 Proposal

The Guiding Question...

⇓

What data will you collect?

⇓

How will you collect your data?

⇓

How will you analyze your data?

I approve this investigation ______________ Date: ______________