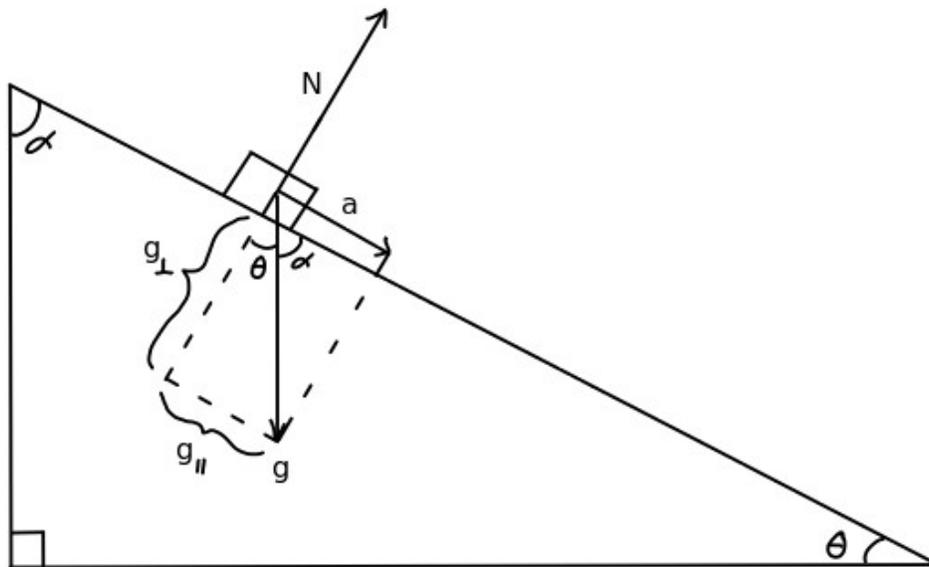

Uniformly Accelerated Motion in 2D

Introduction

An object undergoing uniformly accelerated motion in 2 dimensions has the same kinematic equation as motion in 1 dimension, with the exception that the motion is split into vector components. Since this lab utilizes a cart moving on an incline track, we will use this as an example.



As you can see from the illustration, acceleration equals the parallel component of gravity and the normal force must equal the perpendicular component of gravity (otherwise the cart would not stay on the track). Utilizing trigonometric principles, the law of similar triangles and Newton's 2nd law, we find that:

x-component	y-component
$\Sigma \vec{F}_x = m\vec{a}$ $mg \sin(\theta) = m\vec{a}$	$\Sigma \vec{F}_y = 0$ $\vec{N} - mg \cos(\theta) = 0$
$\vec{a} = g \sin(\theta)$	$\vec{N} = mg \cos(\theta)$

Thus, acceleration does not depend on mass, it only depends on the angle of inclination (θ). Furthermore, acceleration is *constant* once the angle of inclination is set, since gravity is constant and always points in the same direction. This means that acceleration always has the same direction and magnitude for movement both up and down the incline.

Note that it is velocity that changes. When the cart is pushed up the incline, the velocity vector points in the opposite direction to the acceleration vector; this is why the cart will slow down, stop ($v = 0$) and change direction (which will change the sign of the velocity vector). When the cart moves down the incline, the velocity vector now points in the same direction as acceleration and velocity will increase from zero until it reaches the bottom.

Goal

To study motion with constant acceleration in 2 dimensions for a cart moving up and down an inclined track and how the angle of inclination affects acceleration.

Equipment

Cart	Motion Sensor
Track	Protractor/Angle Indicator

Lab Notes

In this lab, you will push the cart up the inclined track. The motion sensor will track the cart's position as it moves up and down the track which will be logged by the computer program Capstone. Capstone will also calculate the velocity and acceleration of the cart such that all 3 graphs will be created and viewable in real time as the motion occurs. These 3 graphs will be similar but not identical to 1D motion. Thus, you will have a parabolic position vs time graph, and linear graphs for both velocity and acceleration.

To Obtain Good Data

Things that can cause noise in the position and velocity graphs include debris in the track or on the wheels, motion sensor settings and interference, thus:

1. Always clean cart wheels and track before starting the run.
2. Do NOT allow the cart to strike the motion sensor. Ensure that when you push the cart up the incline, the cart does not come any closer than 20cm away from the motion sensor.
3. Adjust the motion sensor as necessary. You may need to make multiple adjustments and runs before you get smooth graphs. If you have difficulty, contact your TA.
4. Remember that the acceleration graph will be noisy and may or may not have a small slope (jerk) due to error.

Reminder: Motion Sensor Settings

The motion sensor has a toggle switch on it such that one can adjust to wide or narrow beam, and typically, wide beam works the best for this experiment. In addition, the eye is elevation adjustable with marked settings. The greatest interference occurs when the eye is at 0, or perpendicular to the motion of the cart. For best results, adjust the eye slightly off 0, either clockwise or counter-clockwise.

Safety

1. Do NOT allow the cart to strike the motion sensor.
 2. Have one group member catch the cart before it reaches the bottom; when the cart hits the bumper, it has a tendency to jump off the track.
 3. Keep the angle of inclination low ($<15^\circ$), high angles increase the likelihood of the cart jumping the track as it is pushed.
 4. Keep all breakable electronic devices away from the track, and ensure the lab computer equipment is at a safe distance from the track, in the event that the cart jumps the track.
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Setup

1. Log in, open Capstone, then click 'Hardware Setup':



2. Click the Digital Channel 1 button on the interface picture and add 'Motion Sensor'. Set the frequency to 20 hz.

3. Click the 'Data Summary' tab:



1. Click 'Position' to highlight, then click the Gear icon to the right of it.
2. Click 'Numerical Format' and change the 'Number of Decimal Places' to 3, then click 'Ok'.
3. Repeat for 'Velocity' and 'Acceleration'.



4. Click 'Graph' on the right hand pane and drag it into the center of the workspace. You can do this again to show 2 graphs side by side, or open new pages for the other graphs (recommended).



5. For one graph, click 'Select Measurement' on the y-axis and choose 'Position'. You should now have a Position vs. Time graph.
 6. For the 2nd graph, click 'Select Measurement' on the y-axis and choose 'Velocity'. You should now have a Velocity vs. Time graph.
 7. For the 3rd graph, click 'Select Measurement' on the y-axis and choose 'Acceleration'. You should now have an Acceleration vs. Time graph.
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Procedure

1. Using a protractor or the angle indicator on the side of the track, set the angle of inclination between $3\text{-}5^\circ$. Read and record the actual angle in the table for run #1. The motion sensor must be at the top of the incline.
 2. After cleaning the track, cart wheels, and adjusting the photo eye, place the fan cart at the bottom of the incline. Practice pushing the cart up the track. Ensure it comes no closer than 20cm from the motion sensor. Do NOT allow the cart to strike the sensor.
 3. When you are comfortable with the force required to move the cart at this angle, click 'Record'.
 4. Push the cart up the track, allow it to come back down, and stop recording just before it reaches the bottom.
 5. Check the position and velocity graphs for smoothness.
 6. If necessary, adjust photo eye and repeat procedure to obtain smooth graphs.
 7. Go to velocity vs. time and highlight only the points corresponding to the linear portion of the graph.
 8. Click the drop down arrow next to the 'fit' button  and choose 'Linear' to apply a linear fit to your data.
 9. Record the slope in the table for run #1.
 10. Go to acceleration vs. time and highlight only the points corresponding to the linear portion of the graph.
 11. Click the drop down arrow next to the 'statistics' button  and choose 'Mean' to find the mean value of the acceleration.
 12. Record the mean in the table for run #1.
 13. Calculate the theoretical acceleration for this angle of inclination.
 14. Calculate the %Errors for the slope and mean, as well as %Difference between slope and mean.
 15. Adjust the angle of inclination of the track to between $5\text{-}7^\circ$ and repeat entire procedure.
 16. Adjust the angle of inclination of the track to between $7\text{-}9^\circ$ and repeat entire procedure.
 17. Choose the run with the smoothest graphs and export the data to excel for re-creation.
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Data

Item	Run #1	Run #2	Run #3
Angle of Track			
Acceleration (Slope)			
Acceleration (Mean)			
Acceleration (Theoretical)			
% Error (Slope)			
% Error (Mean)			
% Difference			

Analysis

- Using Microsoft Excel or similar graphing program, re-create the 3 graphs. Use the trendline function to fit each graph and include the equation & r-value. Don't forget to include Titles and Axes Labels with units.
- What happens to the acceleration of a cart as it moves up and down the inclined plane?
- Observing your Position vs Time graph:
 - Why does the position begin at a maximum and decrease as the cart moves up the incline?
 - Where is the cart when the position is at its minimum value?
- Observing your Velocity vs Time graph:
 - In graph quadrant I, what direction is the cart traveling?
 - In graph quadrant I, is velocity increasing or decreasing?

- (c) When velocity is zero, where is the cart?
 - (d) In graph quadrant IV, what direction is the cart traveling?
 - (e) In graph quadrant IV, is velocity increasing or decreasing?
5. Observing your Acceleration vs Time graph, does this graph indicate uniformly accelerated motion? Why or why not?
- 6.
- (a) How did acceleration change when the track became steeper?
 - (b) Use the acceleration equation to explain why this occurs.
7. What could account for the %Difference between the slope and mean accelerations?
8. Account for and explain the sources of error that could cause the %Error.