PocketLab Voyager: A Study of Rolling Resistance

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Rolling resistance is a force that opposes the motion when an object rolls along a surface. There are many examples of objects experiencing rolling resistance: car or bicycle tires on pavement, skateboard wheels on a half pipe ramp, steel wheels on a railroad track, ball bearings in a pulley, bowling balls on a bowling lane, and carts rolling on a dynamics track, just to mention a few. Many factors can affect the magnitude of the forces associated with rolling resistance. These include the wheel substance, the surface on which it is rolling, pressure created by the load it may be carrying, bearings holding the wheel to its axle, surface adhesion, and wheel diameter.

In this experiment a coasting cart on a flat surface gradually slows down and stops due to rolling resistance. Two very different surfaces are compared—a carpeted floor and a wood floor. In the case of a carpet, the primary factor affecting rolling resistance is deformation of the carpet as the cart rolls. Not all of the energy needed to deform the carpet is recovered when the pressure from the cart is removed. In other words, the effect is non-elastic. The purpose of this experiment is three-fold: (1) to determine the force of rolling resistance, (2) to determine the coefficient of rolling resistance between the cart the surface on which it rolls, and (3) to gain a practical understanding of the *meaning* of this coefficient.

Figure 1 shows the free-body diagram of the cart as it slows down from rolling resistance. The normal and gravitational forces are equal in magnitude as the cart rolls on the level plane of the surface. From Newton's second law, the net force, *ma*, is therefore equal to the force of rolling resistance. The coefficient of *rolling resistance* is defined by the equation shown in the diagram as the *ratio of the force of rolling resistance to the normal force*. The coefficient of rolling resistance is, therefore, a *dimensionless quantity* that can be thought of as *the force per unit weight required to keep it moving at a constant speed on a level surface, assuming negligible air resistance*.

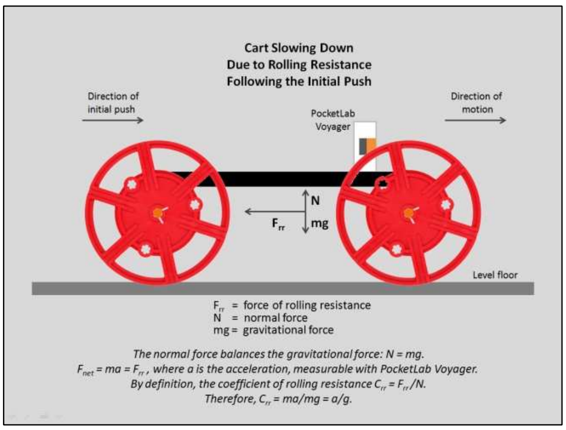

Figure 1

Figure 2 shows a snapshot of the case where Voyager has been taped to a cart with its range finder selected. In the snapshot the card has come to a rest on the carpet after being given an initial push toward the wall. Therefore, range finder distances on the superimposed graph represent how far Voyager is from the wall. Readings were taken at a rate of 25 per second. A movie is also included with this lesson for those interested in viewing it.

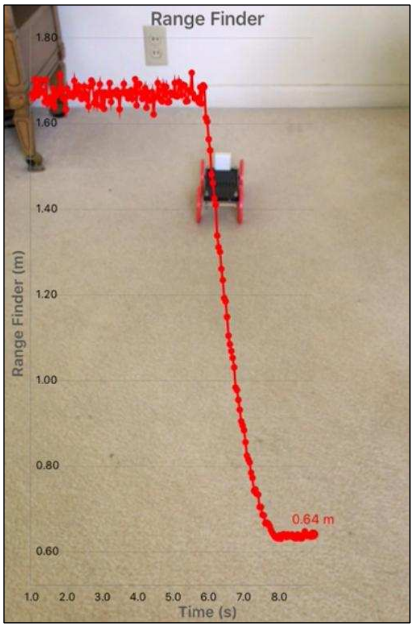

Figure 2

Data Analysis

Figure 3 shows a graph of distance from the wall vs. time. The data was obtained in Excel from the csv file created from the PocketLab app. The main region of interest is from about 6 to 8 seconds, during which the cart was slowing down due to rolling resistance.

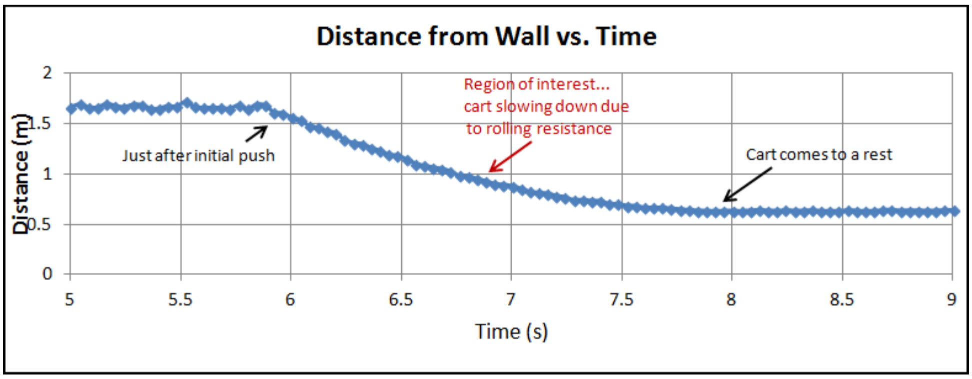

Figure 3

This region of interest was plotted on another Excel chart all by itself so that some regressions could be investigated using the "Add Trendline" feature of Excel. This chart is shown in Figure 4. The best fit was obtained from a polynomial order 2 trend/regression type, i.e. a *quadratic* fit, as shown in the chart. This is not surprising, as the curve does have a parabolic shape.

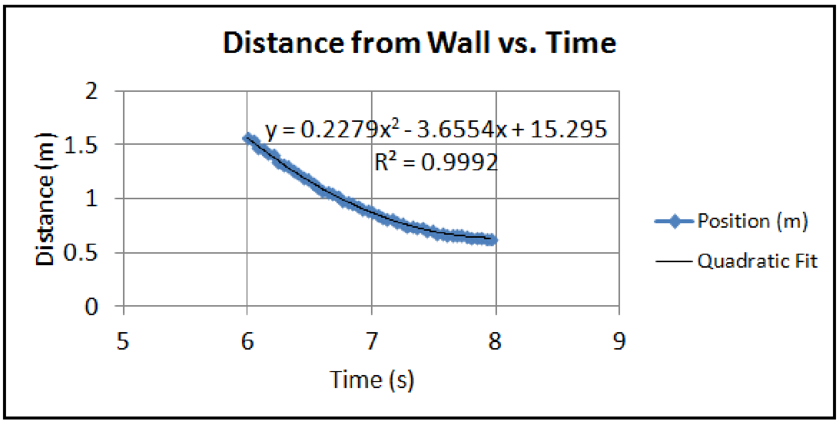

Figure 4

The graph is of the form $y = Ax^2 + Bx + C$, where y is distance in meters and x is time in seconds. There are a number of ways that the rate of deceleration could be determined. Probably the quickest and easiest makes use of physics principles and some elementary differential calculus. Since velocity is the first time derivative of the distance, then velocity would be given by $v = 2Ax + B$. Since acceleration is the time derivative of velocity, $a = 2A$. From Figure 4, we see that A = 0.2279; therefore, the rate of deceleration is $2A$ = 0.456 m/s^2.

We are now ready to address the three objectives of our experiment:

1. The mass m of Voyager plus cart is 0.137 kg. Therefore, the force of rolling resistance F_{rr} is given by ma = (0.137 kg)(0.456 m/s^2) = 0.0625 N.
2. The coefficient of rolling resistance C_{rr} is given by a/g = (0.456 m/s^2) / (9.8 m/s^2) = 0.0465, a dimensionless quantity.
3. Since the coefficient of rolling resistance is defined by $C_{rr} = F_{rr}/N$, it is the force per unit weight required to keep the cart moving at a constant speed on a level surface. When this experiment was done with the cart rolling on a wood floor, the coefficient of rolling resistance turned out to be 0.00757. Therefore, since , 0.0465/0.00757 = 6.14, it requires about 6 times more force per unit weight to keep the cart moving at a constant speed on the carpet than on the wood floor.