Two Voyagers Connected to a Single Device via Phyphox:
An Experiment to Determine a Cart's Wheel Radius

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A very nice feature of Voyager is that up to three sensors can be activated for simultaneous data collection. However, certain types of experiments, in the study of collisions between two carts for example, make it desirable to collect acceleration data for both carts. This can of course be done with a pair of Voyagers, each connected to separate devices running the PocketLab app. In this situation, however, it is difficult to start data collection on both Voyagers simultaneously, and it becomes more difficult to view and analyze the combined data.

It would be nice if one could connect two (or more!) Voyagers to the same device—say to an Android device or an iOS device running an app that could display concurrent data collection from both Voyagers. Such a capability is possible by the use of **Phyphox** (**phy**sical **pho**ne e**x**periments), an app developed at the 2nd Institute of Physics of the RWTH Aachen University in Germany. The author of this lesson has been working with a pre-release Android version of this app that supports BLE (Bluetooth Low Energy) technology to transfer data from multiple Voyagers to the Phyphox app. It is important to understand that this capability of Phyphox may not be available to the public until the July 2018 anticipated beta release.

In this lesson, an experiment with a single cart is discussed. Upcoming lessons will consider the collisions between two carts. Many teachers have made use of PocketLab's *VelocityLab* app to study position, velocity, and acceleration by attaching PocketLab to the wheel of a cart. This app is able to compute these parameters because the diameter of the wheel is supplied by the user as input when the app is started. The experiment of this lesson involves the reverse of this process. Students use one Voyager, attached to the top of the cart, to collect position data from the rangefinder. Another Voyager, connected to a wheel, is used to collect angular velocity data. By analyzing the data collected by Phyphox, the student then determines the radius of the cart's wheels. Clearly, this experiment requires the use of two Voyagers, as one cannot collect acceptable rangefinder position data from a Voyager rotating on the cart's wheel.

The experiment of this lesson is in a file named *WheelRadius.phyphox* and will be made available from the author when the Phyphox beta with BLE is released. This file can then be opened in Phyphox and will appear in the Phyphox main screen as shown in Figure 1.

Figure 1

Performing the Experiment

Figure 2 shows a PocketLab HotRod cart with two mounted Voyagers, one on a wheel and the other on the top of the HotRod.
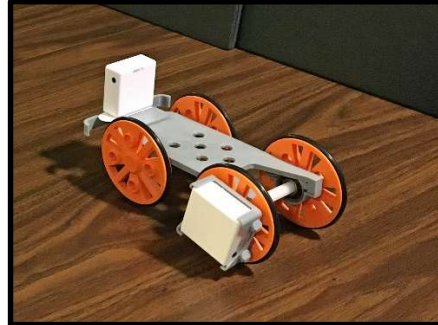

Figure 2

The first screen that you will see after selecting the Wheel Radius experiment is shown in Figure 3. The top graph indicates that PocketLab Voyager A, mounted to a wheel, will make use of its Z gyroscope. The bottom graph indicates that PocketLab Voyager B, mounted to the top of the cart, will make use of its rangefinder. A message in the center of the screen tells you that it is scanning for Bluetooth devices with the name "PL Voyager" and asks you to pick a device. At this point you should turn on PocketLab A, on the wheel. "PL Voyager" will appear in the message. Click on "PL Voyager" and a message will tell you that Bluetooth is connecting to the device. You will be asked a second time to pick a device—this time turn on the Voyager mounted on top of the HotRod. You can now start data collection with the pulsating start triangle in the upper right corner of the screen. You would then give the HotRod a little push and stop data collection when it comes to rest.
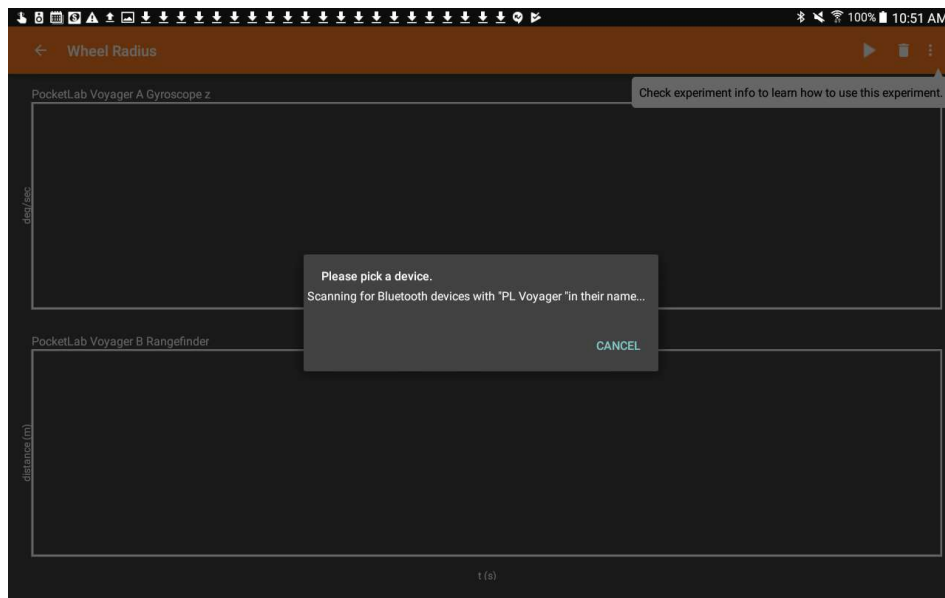

Figure 3

A one-minute YouTube video clarifies the entire process. It is important to remember that gyroscope Voyager A be selected *first*, and rangefinder Voyager B be selected *second*. If they are not selected in the correct order, then the two graphs will be matched to the wrong Voyagers. Figure 4 shows what the graphs may look like after data collection is complete.
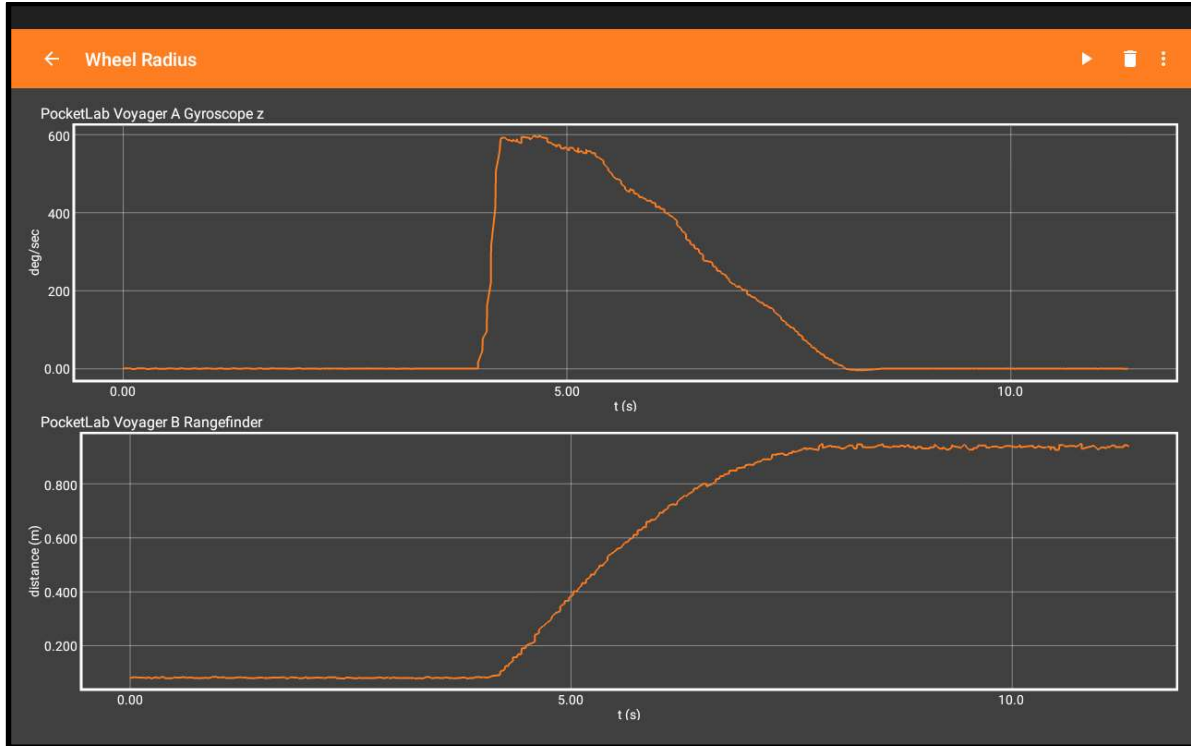

Figure 4

In order to export the data, all you need to do is click the ellipsis in the upper right corner of the screen and select *Export Data* from the drop-down menu. You can then choose the desired data format (Excel, CSV) and pick a method for sharing the data (Google Drive, Dropbox, Email, etc.) See Figure 5.
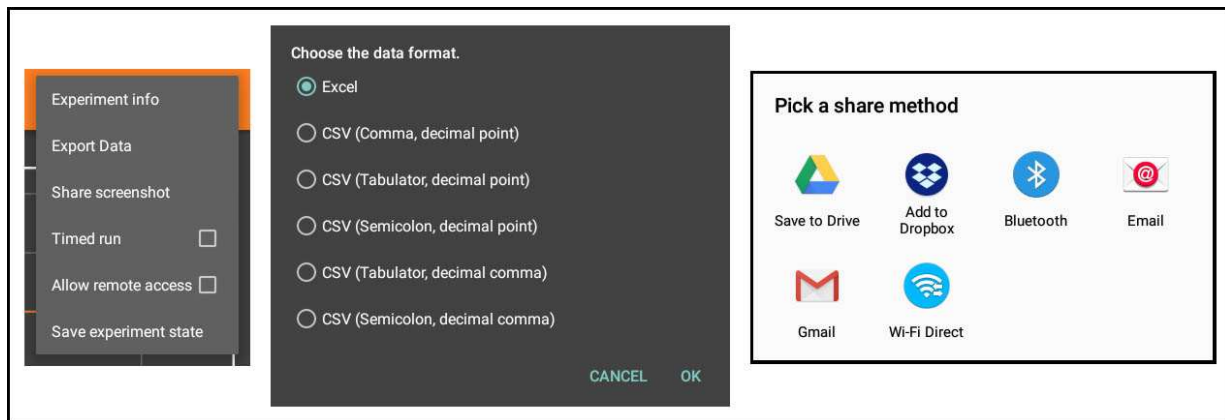

Figure 5

Analysis

There are certainly a number of ways to approach the analysis of the z-gyroscope and rangefinder data from this experiment. The author elected to export the data from Phyphox as an Excel file, and then initially constructed the two graphs shown in Figure 6. The z-gyro graph shows that the push lasted about 0.2 s, *i.e.*, from 0.8 s to 1 s.
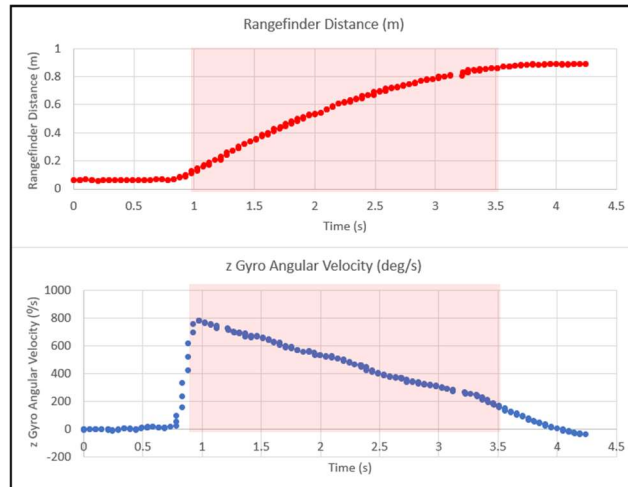

Figure 6

During the regions highlighted in red on the graphs from 1 s to 3.5 s, the cart was slowing down due to a variety of frictional forces. It is these red regions that are of interest for further investigation, so the data for these regions was used to construct a new pair of graphs, as shown in Figure 7. Copying just this data to new graphs allows for easy trendline analysis of these regions in Excel.
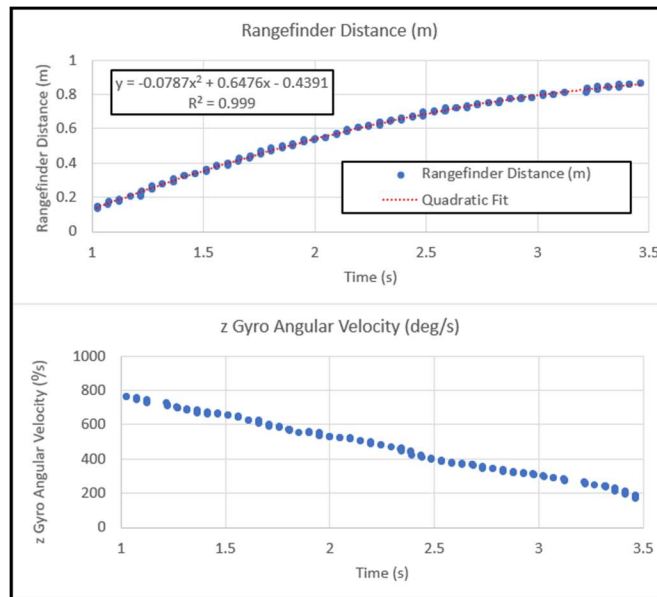

Figure 7

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We know that $v = \omega r$, where v is the linear velocity of the HotRod, ω is the angular velocity of the wheels, and r is the wheel radius. We can therefore compute the radius by finding the value of the ratio v/ω.

To compute the linear velocity v at any point in time, one could compute $\Delta d/\Delta t$ for consecutive pairs of points in the rangefinder distance data. The problem with doing this is that the resultant velocity data is extremely noisy, almost to the point of being useless. The author found that a better approach was to do a quadratic fit $y = Ax^2 + Bx + C$ to the rangefinder data of Figure 7. Then compute the derivative $2Ax + B$ of this quadratic to obtain an equation for velocity. The quadratic fit is shown by the dotted red line on the rangefinder graph, and the quadratic equation is also shown. From this equation, we can obtain the linear velocity v at any point in time as $v = 2(-0.0787)t + 0.6476$. A new column is added to the spreadsheet calculating v for the time range of the graph.

Another new column is added to the spreadsheet that converts angular velocity ω from °/s to radians/s. A final column is added to the spreadsheet calculating the ratio $v/\omega = r$. Then the average of the values in this final column is calculated. The author obtained a value for r of 0.0349 m = 34.9 mm. Direct measurement of the wheel by a ruler gives a radius of 34 mm. This, in turn, tells us that we have a percent error of about 2.6%. See Figure 8.
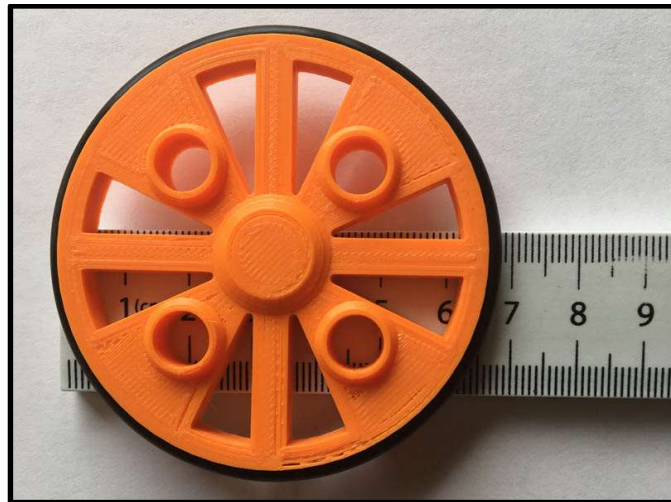

Figure 8