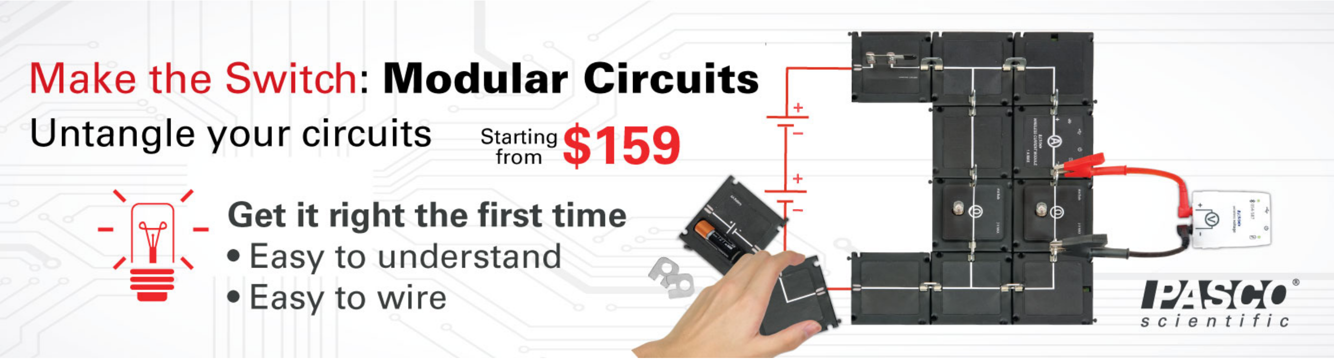
The PASCO Wireless Smart Cart: A Game Changer in the Undergraduate Physics Laboratory

Asif Shakur, and Rainor Connor

Citation: The Physics Teacher **56**, 152 (2018); doi: 10.1119/1.5025290
View online: https://doi.org/10.1119/1.5025290
View Table of Contents: http://aapt.scitation.org/toc/pte/56/3
Published by the American Association of Physics Teachers



The PASCO Wireless Smart Cart: A Game Changer in the Undergraduate Physics Laboratory

Asif Shakur and Rainor Connor, Salisbury University, Salisbury, MD

With the introduction of the Wireless Smart Cart by PASCO scientific in April 2016, we expect a paradigm shift in undergraduate physics laboratory instruction. We have evaluated the feasibility of using the smart cart by carrying out experiments that are usually performed using traditional PASCO equipment. The simplicity, convenience, and cost-saving achieved by replacing a plethora of traditional laboratory sensors, wires, and equipment clutter with the smart cart are reported here.

Fig. 1. The PASCO Wireless Smart Cart.

Features of the PASCO Wireless Smart Cart[1,2]

As the name implies, the PASCO smart cart (Fig. 1) obviates the need for connecting sensors with long wires to a dynamics cart. The cart's onboard sensors wirelessly transmit position, linear velocity, angular velocity, acceleration, and force data directly to a smartphone or computer via Bluetooth®. The smart cart is very inexpensive, and since no cables and connectors, interface boards, sensors, and air tracks are required, there is a tremendous amount of savings in addition to the accuracy of the data collected. The cart is rugged for student use as it is constructed from a durable ABS[3] body with nearly frictionless wheels. The built-in force sensor measures push, pull, and collision forces up to 100 N. The built-in accelerometer and gyroscope measure acceleration and angular velocity along three perpendicular axes. The most innovative part is the built-in wheel encoder for measuring position and velocity on or off a track. The magnetic bumper is used for elastic "collisions" whereas the Velcro® tabs serve to observe inelastic collisions. There is also a spring plunger which is easy to miss because it sits unobtrusively when tucked inside the smart cart. The SPARKvue app for smartphones can be downloaded from the PASCO website free of charge. The smart cart was named a finalist for the prestigious GESS (Global Education Supplies and Solutions) Innovation Product award for 2016.

Inelastic collision

We performed a simple inelastic collision experiment to ascertain the feasibility of using the wireless smart cart in an undergraduate laboratory setting. Two similar smart carts (red and blue) were placed on a 1-m PASCO aluminum track. The free PASCO app SPARKvue was installed on an iPhone. The app paired up with the blue cart via Bluetooth and recognized the unique identification sticker on the cart. We gave the blue cart a gentle push in the direction of the stationary red cart. The two carts collided and stuck together on the Velcro pads. The two carts moved together with a slower speed. Note that we only needed one iPhone to pair up with only one cart (blue) in order to draw meaningful conclusions. The velocity and time data (in addition to position, acceleration, and a raft of other data) were wirelessly transmitted by the smart cart to the iPhone as a CSV file (comma separated values). The data were tabulated in an Excel file, and a graph of velocity vs. time is depicted in Fig. 2.

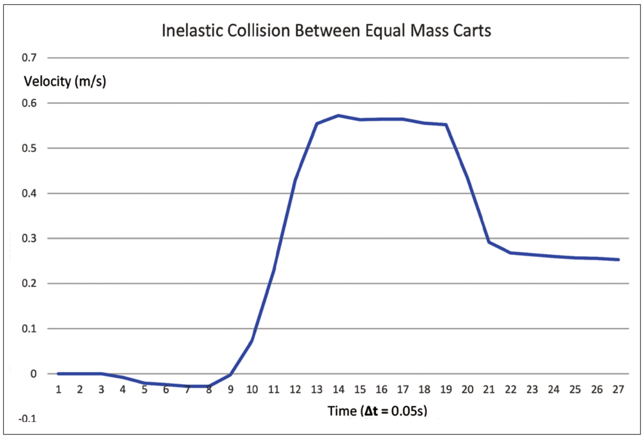


Fig. 2. Inelastic collision between equal mass carts.

The graph in Fig. 2 shows that the blue cart approached the red cart with a speed of approximately 0.56 m/s, and after the collision the two carts proceeded in the same direction with a speed of approximately 0.28 m/s. We know that in an inelastic collision between two equal masses the final speed is expected to be half of the initial speed. The experiment with the wireless smart cart is breathtaking in its simplicity and accuracy. Note that we did not need any other sensors, wires, equipment, and photogates (Fig. 3). No muss, no fuss!

Elastic collision

In order to perform an elastic collision, magnetic bumpers are included with the wireless smart carts. In this case the

DOI: 10.1119/1.5025290

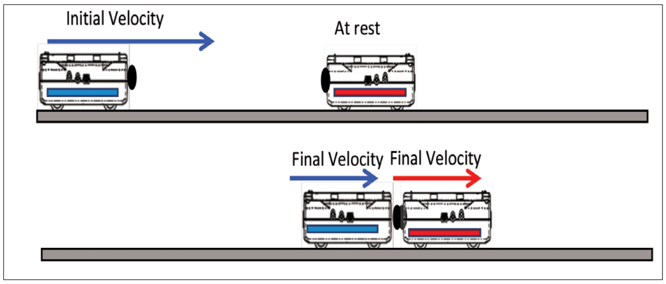


Fig. 3. Inelastic collision between two equal mass smart carts.

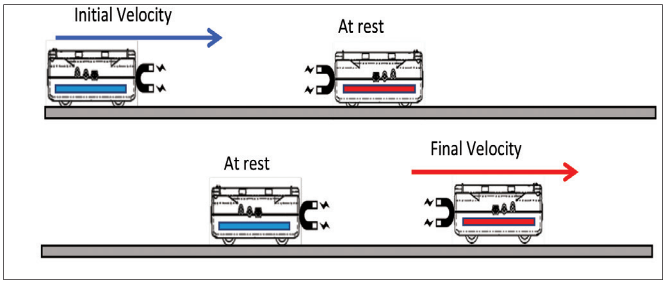


Fig. 4. Elastic collision between equal mass smart carts.

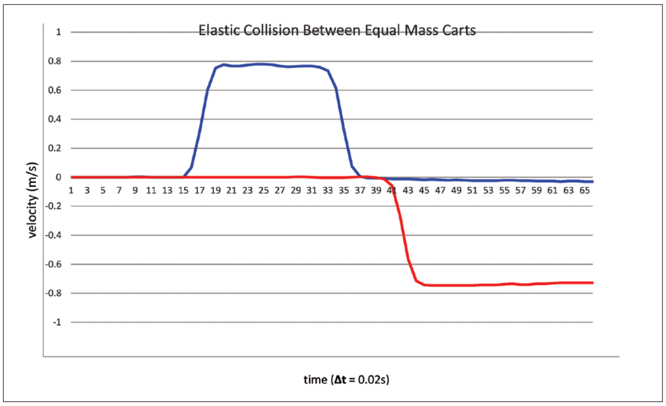
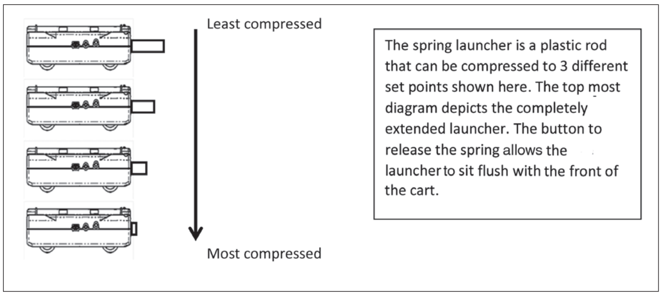


Fig. 5. Velocity vs. time for an elastic collision between equal mass smart carts.

elastic "collision" occurs without any physical contact. We also used a spring launcher in order to impart the same initial velocity for reproducible experiments. The spring plunger is triggered by a push button. In the case of elastic collisions with similar carts, the moving cart came to rest and the stationary cart proceeded in the same direction with a similar velocity (Fig. 4). The graph in Fig. 5 shows the elastic collision between the approaching blue cart and the stationary red cart. Collision experiments were also carried out with carts of dissimilar masses. This is accomplished by placing a slab mass on the tray of the smart cart. Again, the experimental data were consistent with the theoretical prediction.

Spring launcher

Kinetic and potential energy transformation experiments were performed by triggering the spring plunger, which sits inside the smart cart (Fig. 6). The first order of business was to calculate the spring constant k. Several different masses ranging from 100 g to 700 g were placed on the extended spring plunger and the distance of compression was recorded. It was established that the spring compresses 1.2 +/- 0.1 cm. for mass increments of 200 g. We used Hooke's law:



The spring launcher is a plastic rod that can be compressed to 3 different set points shown here. The top most diagram depicts the completely extended launcher. The button to release the spring allows the launcher to sit flush with the front of the cart.

Fig. 6. Spring launcher at the front of the PASCO Wireless Smart Cart.

Table I. Launch speed of the smart cart for three plunger positions.

Plunger Compression x +/- 0.001 m	Measured Cart Speed v +/- 0.01 m/s	Calculated Cart Speed v(m/s) +/- 0.04 m/s
0.015	0.36	0.38
0.030	0.82	0.76
0.045	1.16	1.10

$$F = -kx,$$

where x is the compression of the plunger spring, and concluded that

$$k = 163 \text{ N/m}.$$

We also measured the compression of the three-position spring plunger for the three positions or notches (Table I). Conservation of energy gives potential energy of the spring equals the kinetic energy of the cart:

$$½\, kx^2 = ½\, mv^2$$

$$v = x\,(k/m)^{1/2}.$$

The mass of the smart cart m is 250 g or 0.25 kg.

Note that the speed of the smart cart v is linearly related to the compression x of the spring. This is a nuanced point often missed by the beginning students of physics and engineering!

Rolling down an inclined plane

We wanted to verify that the speed data being transmitted by the smart cart's wheel encoder are accurate. In other words, we wanted to rule out the presence of any systematic errors. To test this we measured the speed of the cart at the bottom of an inclined track (Fig. 7) and compared it to values calculated using the equation $v = (2gh)^{1/2}$.

The cart was rolling smoothly on very light wheels, which provides some justification for treating it as a sliding object with no friction. When the height of the smart cart on the inclined plane was 0.25 m, the speed at the bottom was measured to be 2.1 m/s. The calculated value for the speed is 2.2 m/s. Considering the small error in our setup of the inclined plane's height, the existence of a negligible amount of rolling friction, and a small amount of kinetic energy of rotation tied up in the light wheels of the cart, we believe the smart cart's wheel encoders are very smart indeed.

Magnetic damping

The magnetic damping accessory is available from PASCO but is not included with the smart cart kit. Damped motion

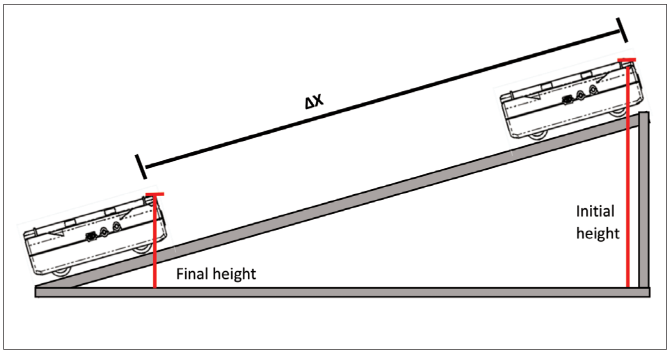


Fig. 7. Smart cart rolling down an inclined PASCO track.

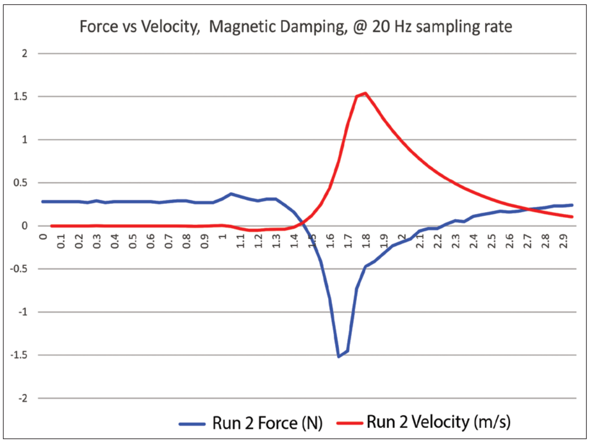


Fig. 8. The smart cart experiences magnetic braking.

(magnetic braking) occurs because of the eddy currents generated in the nonmagnetic but electrically conducting aluminum track. Lenz's law dictates that the motion of the cart will be resisted by a magnetic force proportional to the velocity of the cart. This force is measured by the force sensor at the front of the cart. The magnetic damping accessory was attached to the front of the cart and the cart was pushed. The Sparkvue app recorded the data from all the sensors onboard. The graph of force vs. velocity is instantly displayed on the smartphone. We exported the data by sending ourselves an email. Then we plotted the graph in Excel. This graph is shown in Fig. 8. Note that the velocity of the smart cart decreases exponentially because the magnetic force is a resistive force and is proportional to the velocity.

Angular velocity

One of the best kept secrets about the smart cart is that it can measure the angular velocity of a rotating smart cart. We spun the smart cart on an old-fashioned three-speed turntable with speeds of 33 rpm, 45 rpm, and 78 rpm (revolutions per minute). We were taken aback when the smart cart angular velocity data plateaued around 45 rpm and failed to increase as we cranked up the angular velocity to 78 rpm! That's when we remembered the maxim that when all else fails, read the manual.[4] The smart cart reference guide clearly states that the maximum angular velocity that the gyroscope can measure is 245 dps (degrees per second). Since 78 rpm equals 468 dps, it is well beyond the range of the smart cart's gyroscope. It must be noted that the gyroscope within the iPhone can easily measure 78 rpm. This is known from publications about rotating an iPhone to verify the conservation of angular momentum.[5-7] Fortunately, the PASCO SPARKvue app can also make use of the internal sensors of the iPhone and Android devices to allow for these experiments to take place using the same software familiar to students.

Conclusions

The PASCO Wireless Smart Cart is a robust, reliable, and innovative educational piece of equipment. The price of the cart is $159. This cost can easily be recouped by eliminating all other sensors, wires, photogates, dynamics carts, and the like in the traditional physics laboratory. The convenience and simplicity of not getting tangled up in the clutter of all those wires cannot be overstated. We expect the smart cart to usher a paradigm shift in undergraduate physics laboratory instruction.

Acknowledgments

Dr. Mark Muller, chair of the physics department, provided unwavering support and encouragement. Dr. Joe Howard, associate chair of the physics department, encouraged us to revitalize the physics laboratories. Benjamin Valliant, a junior, assisted with the magnetic braking experiment.

References

1. PASCO Wireless Smart Cart, https://www.PASCO.com/prodCompare/smart-cart/index.cfm.
2. "PASCO Scientific's New Smart Cart Provides an All-In-One Wireless Solution to Make the Classroom Study of Forces and Motion Easy and Affordable," PACSO scientific, https://www.PASCO.com/about/news/press-releases/PASCO-introduces-the-smart-cart.cfm.
3. Acrylonitrile butadiene styrene, Wikipedia, https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene.
4. PASCO Wireless Smart Cart Manual, https://www.PASCO.com/file_downloads/Downloads_Manuals/Wireless-Smart-Cart-Manual-ME-1240-1.pdf.
5. A. Shakur and T. Sinatra, "Angular momentum," *Phys. Teach.* **51**, 564–565 (Dec. 2013).
6. Martín Monteiro, Cecilia Cabeza, Arturo C. Marti, Patrik Vogt, and Jochen Kuhn, "Angular velocity and centripetal acceleration relationship," *Phys. Teach.* **52**, 312 (May 2014).
7. Martín Monteiro, Cecilia Cabeza, and Arturo C. Marti, "Rotational energy in a physical pendulum," *Phys. Teach.* **52**, 180 (March 2014).

Asif Shakur *is a professor of physics at Salisbury University. He passionately believes that the smartphone and smart cart combination will revolutionize the undergraduate physics laboratory. His other interests include chess, digital and analog electronics, assembly language programming and computer interfacing, and* Bell's Theorem and Quantum Realism *(Springer 2012).*
AMSHAKUR@salisbury.edu

Rainor Connor *graduated from Salisbury University in 2016 with a Bachelor of Science in physics. Since his graduation he has joined CREE Inc., an innovative lighting and component company based in Durham, NC. Rainor's interests range from artful crafts such as glassblowing and painting, to more scientific hobbies like stargazing and robotics. As of 2018, Rainor has been getting ready to attend graduate studies to further his career in the physical sciences.*