Momentum Conservation in Hover Puck Collisions

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The spark-track air table has been used for many years for standard collision experiments in introductory labs.[1,2] We present an alternative to the air table that uses two inexpensive hover puck toys (battery-powered fans in a round case that float on a smooth surface).[3] Video analysis of a collision between the hover pucks is used to find the total initial and final momentum of the system. We have consistently found good agreement with conservation of momentum in our introductory labs using this system.

Our setup consists of a video recorder placed about 2 meters above a smooth tile floor. We mark the field of view on the floor so students can clearly see the area in which the collision between the hover pucks must occur as seen in Fig. 1. We initially used an inexpensive camcorder to record the motion, though alternative methods for capturing the video have been used.[4,5]

The videos are recorded using the capture feature of the Vernier Logger Pro software.[6] We have our students measure the size of the floor tiles visible in the video in order to set an appropriate scale for the movie. Students then select the location of the center of the hover pucks (marked on the pucks by a clearly visible white dot) on each frame of the video. The data is analyzed by applying a linear fit to the position versus time data of each puck both before and after the collision in the x and y directions. The students weigh each puck to find the mass and then calculate the total initial and final momentum and compare them.

While this approach gives results comparable to those previously obtained with the air table, there is a major systematic effect associated with using the hover pucks in this type of experiment: the fans driving the pucks create a significant thrust on the puck, giving rise to a drift velocity of about 0.1 m/s. To minimize this systematic effect, we have students propel the pucks with a velocity of a few meters per second. Curvature in the position versus time data caused by the acceleration of the pucks by the fan thrust (or an unlevel floor) limits the number of useful data points to a linear approximation immediately before and after the collision. Standard video taken at 30 frames per second usually gives only 3-5 useful data points on either side of the collision.

We present here another video recording technique using high-speed industrial machine vision cameras to capture the collision. The high-speed video (about 60 frames per second) allows us to reduce the systematic effects by reducing the time over which we measure the hover puck velocity before and after the collision.

Machine Vision Camera Setup

We use a black-and-white Guppy F033-B machine vision camera made by Allied Vision Technologies to collect the video of the collision. The camera has a resolution of 656 by 494 pixels and is capable of a frame rate up to 58 frames per second. We use the fastest frame rate to capture the hover puck collision in the greatest detail. We use a Techspec fixed focal-length lens from Edmund Optics (Model NT58-001) with a 12 mm focal length and numerical aperture of F/1.8. The camera is attached via a Firewire cable to a computer running a LabView program. Since the data collection rate is so high (more than 100 Mbit/s), the computer must have a high speed Firewire port to collect the real-time video data.

Fig. 1. The machine-vision camera setup used to capture the video of a collision between two hover pucks. Any video camera could be used in this same configuration.

Video Recording

Although machine vision cameras are compatible with many software packages, we chose to write a LabView program specifically to guide the data collection for our introductory students.[7] We have one computer connected to the camera and dedicated to the data collection. Students record their film using a simple user interface, shown in Fig. 2. The students simply choose a file name for their video, position the hover pucks just outside the tape box, then select a button labeled "Record" to record their collision. After the collision, they click the "Done" button and their video is automatically saved. The software converts the video to the common AVI format which can be read by the Logger Pro software for analysis. We chose to not use video compression in order to have the best possible image of the pucks. Not using compression also leads to very large file sizes: a 3 second video contained about 50 MB of data. Fortunately, new computers and flash drives easily handle larger file sizes and larger amounts of data. We had our students transfer the video using a portable flash drive to their own station's computer for data analysis.

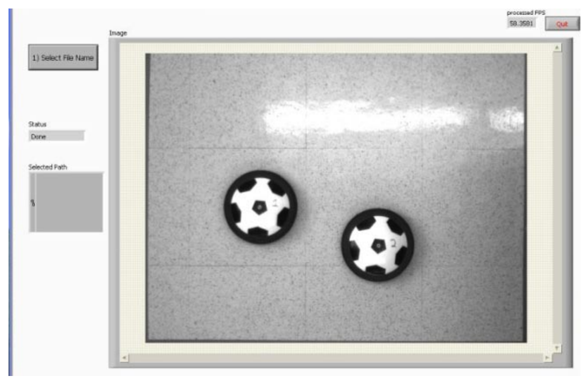

Fig. 2. A screen shot of the LabView program used to collect the video data.

Data Analysis

The students then process the video of the collision using the Logger Pro software as in the simpler arrangement using the camcorder. A sample graph of the analysis of one of the pucks is shown in Fig. 3. Since the video was taken at about 60 frames per second, we have the students utilize only a fraction of a second of the film, typically about 20 frames. Sample results of the initial and final momentum collected using the high-speed camera are given in Table 1.

Momentum	kg m (95% CI)
P_x initial	0.5065 ± 0.0096
P_x final	0.4938 ± 0.0033
P_y initial	0.4164 ± 0.0099
P_y final	0.4223 ± 0.0040

Table 1: Sample student data using the high-speed camera.

The results were collected from approximately 15 student groups during the course of the semester. All groups found that momentum was conserved within the uncertainties of the experiment.

In summary, we have implemented a new conservation of momentum experiment involving the video analysis of a collision of two hover pucks. While an ordinary camcorder could be used, a high-speed machine vision camera collects the data at a fast enough rate so that the systematic drift of the hover pucks is minimal. Measurements of the initial and final momentum of the system indicate that momentum is conserved for these collisions. The software package available from National Instruments for acquiring data from the camera (NI-IMAQ) was used to capture and save the data for analysis. This package also contains a large number of simple utilities useful for both collecting and processing video data and is capable of much more sophisticated real-time analysis which could be used in upper-level labs.

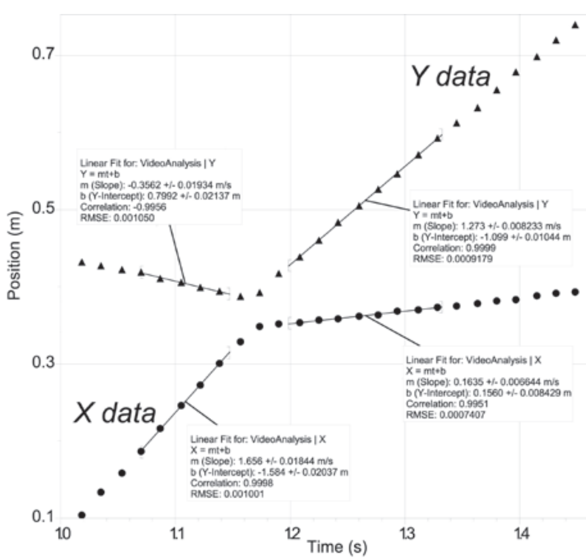

Fig. 3. Sample data collected from the video analysis for a single hover puck. The *x*-position data are given as solid circles, the *y*-position data are triangles.

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[1] M. Zebarth, "Daedalon air table: An evaluation," *Phys. Teach.* **18**, 660 (1980).

[2] D. Kagan, "Why Is There No Vertex in Air-Table Collisions?", *Phys. Teach.* **38**, 414-415 (October 2000).

[3] Available from Pasco, part number SE-7335B.

[4] E. Wyrembeck, "Video Analysis with a Web Camera," *Phys. Teach.* **47**, 29-29 (January 2009).

[5] D. Chen, "Digital Camera as a Data Collector," *Phys. Teach.* **47**, 54 (January 2009).

[6] Vernier Software and Technology, http://www.vernier.com

[7] See EPAPS Document No. [XX] for a copy of the LabView code. LabView 8.5 and the NI-IMAQ package are required to run the software. For more information on EPAPS, see http://www.aip.org/pubservs/epaps.html.