Using the Sound Card as a Timer

C. E. Aguiar, Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil
M. M. Pereira, Centro Federal de Educação Tecnológica (CEFET-RJ), Nova Iguaçu, Brasil

Experiments in mechanics often involve measuring time intervals much smaller than one second, a task that is hard to perform with handheld stopwatches. This is one of the reasons why photogate timers are so popular in school labs. There is an interesting alternative to stopwatches and photogates, easily available if one has access to a personal computer with sound-recording capability. The idea is simple: a computer sound card can record audio frequencies up to several kilohertz, which means it has a time resolution of a fraction of a millisecond, comparable to that of photogate timers. Many experiments in mechanics can be timed by the sound they produce, and in these situations a direct audio recording may provide accurate measurements of the time intervals of interest. This idea has already been explored in a few cases,[1–5] and here we apply it to an experiment that our students found very enjoyable: measuring the speed of soccer balls they kicked.

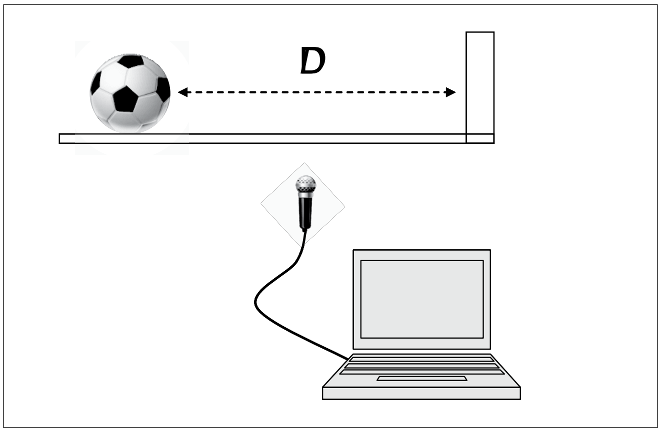

Fig. 1. Setup for measuring the ball speed.

How hard can you kick the ball?

The physics of sports never fails to catch the attention of students (at least for a while). In particular, measurements of their performance in a game can attract a lot of interest. Here we describe a method of measuring how fast they kick a soccer ball. We are interested in the speed of the ball immediately after it is hit, not in the long-term average speed. The later depends on many factors—bounces on the ground, mean height, air drag—that make it difficult to compare different shots. The average speed will not depend so much on these details if we measure it over a short distance from the kick point. In this case the result is a good estimate of the speed the ball gains when hit. But there is a problem now: it is difficult to measure the time it takes for a hard-kicked ball to travel a short distance (2–3 m). Typical times are on the order of a tenth of a second, so that handheld stopwatches cannot be used efficiently. Even photogate timers are not very useful here—they probably demand some reshaping in order to accommodate for the size of the ball and its potentially destructive effects.

The computer sound card provides a simple way to perform the measurement. The setup is shown in Fig. 1. The ball is placed at a known distance D from a wall, and the computer (with a microphone plugged to the sound card) is set on a safe spot roughly equidistant from the ball and the wall. The measurement consists basically of having a student kick the ball (aiming at the wall) while the computer records the sound input. There are many programs that can be used not only to control the recording but also to display and analyze the resulting audio data (the sound editor Audacity[6] is a good and free choice). Figure 2 shows the waveform recorded during a shot. Two distinct sound pulses are seen (and heard), corresponding to the foot hitting the ball and the ball hitting the wall. The start time of each pulse can be accurately determined—to a fraction of a millisecond—by zooming in on the corresponding sector of the waveform (all sound editors have zoom tools). The time of flight of the ball T is the difference between these two times, as shown in Fig. 2. Given the time of flight T and distance D, the speed of the ball is $V = D/T$. For the shot seen in Fig. 2, $D = 2.5$ m and $T = 0.214$ s, so that $V = 42$ km/h. Note that the time interval T is short enough to ensure that V is a good approximation to the instantaneous speed of the ball soon after it is kicked.

It is interesting to have the students perform statistical analyses of the data they collect. The histogram in Fig. 3 shows the distribution of ball speeds in a group of 80 students (62 girls and 18 boys from three different classes of a high school). The mean speed of the balls kicked by them was 38 km/h, with a standard deviation of 12 km/h. The students were encouraged to look for correlations between their shooting performances and personal characteristics like age, gender, height, or mass. Somewhat surprisingly, in most cases no significant correlation was found. Considering age, for example, almost all the students (73 out of 80) were between 15 and 17 years. Over this limited range, age had no influence on the kicking performance. Gender was much more relevant than age: the mean value of the speeds of the balls kicked by boys was 47.0 ± 3.4 km/h (the uncertainty is the standard deviation of the mean), while for girls the mean value was 34.9 ± 1.2 km/h. Concerning body size, the scatter plot in Fig. 4 shows the ball speed versus the height of the student who kicked it (the open data points correspond to girls and the filled ones to boys). The plot suggests that height has only a small influence on the kick outcome. Moreover, most of the

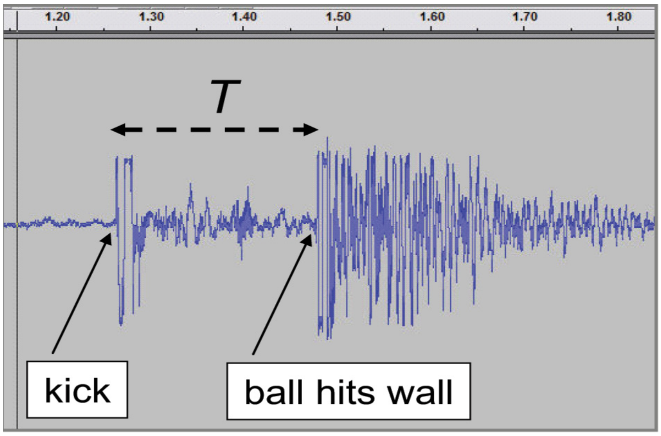

Fig. 2. Waveform recorded in a measurement of the ball speed. The two sound pulses are produced by the foot kicking the ball and by the ball hitting the wall. The time scale at the top is in seconds.

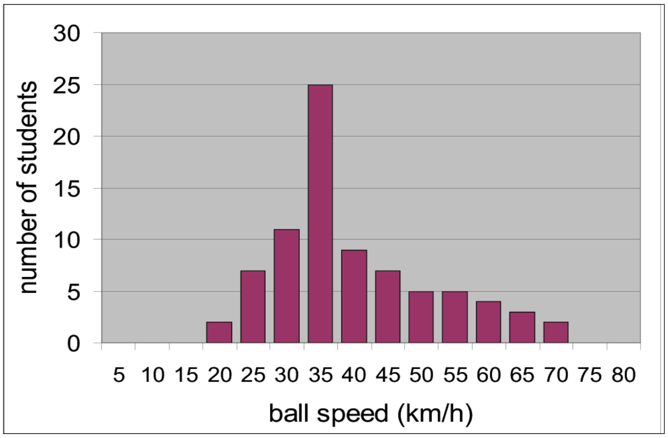

Fig. 3. Speed distribution of the kicked balls. The sample corresponds to 80 high school students, each taking one shot.

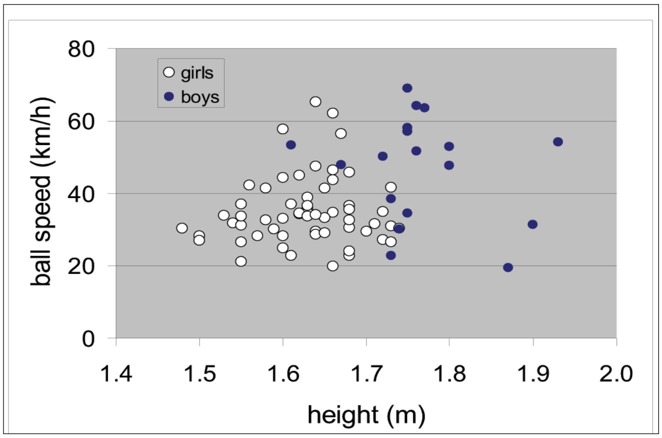

Fig. 4. Ball speed vs height of the student who kicked it. Open and filled data points correspond to girls and boys, respectively.

effect appears to be related to gender, as the boys in this group tend to be taller than the girls. If one considers only the boys, or only the girls, then no correlation between height and ball speed is found.

Comments

The measurement was quite easy to perform even with relatively large groups of students. We used a number of small laptops (netbooks), which allowed teams of three to four students to share a computer for data taking and analysis. As the experiment is better executed in a gymnasium or in open space, portable computers are a good choice whenever possible. If these are not available (or not in sufficient number), one can do the sound recording with an mp3 recorder/player—a gadget that students frequently carry with them—and later transfer the audio files to a computer for analysis.

The time-of-flight measurement with the sound card is very accurate, so that the error in the calculated speed comes mostly from uncertainties in the distance traveled by the ball. For most kicks the ball doesn't head straight to the wall, and the length *D* shown in Fig. 1 is really a lower bound to the traveled distance. To minimize this uncertainty, it is useful to draw a target area on the wall and accept only shots that hit this region. If the target area is sufficiently small, it is possible to keep the distance uncertainty within acceptable limits. It is also a good idea to keep the microphone at similar distances from the ball and the target area, as this cancels out the time delays related to sound propagation from the kick and hit points to the recording location.

Measurements of the ball speed are a good starting point for many interesting discussions on the physics of soccer kicks. One could, for example, investigate if air drag is important at the typical speeds found in the experiment, or try to estimate how fast the foot must move in order to impart such speeds to the ball. Several topics that can be explored in this manner are found in Refs. 7-9.

As a final comment, we note that it is possible to use the sound card as a timing device in mechanics experiments even when no sound is produced. Examples of how this is done are in Refs. 10 and 11.

Acknowledgments

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Carlos Eduardo Aguiar *is associate professor of physics at Universidade Federal do Rio de Janeiro, Brasil. His main professional interests are nuclear physics and physics education.*
Instituto de Física, Universidade Federal do Rio de Janeiro, C.P. 68528, Rio de Janeiro, 21941-972, RJ, Brasil; carlos@if.ufrj.br

Marta Maximo Pereira *teaches physics at Centro Federal de Educação Tecnológica (CEFET-RJ), Nova Iguaçu, Brasil. She is a graduate student at the Universidade Federal do Rio de Janeiro specializing in physics education.*
Centro Federal de Educação Tecnológica, Nova Iguaçu, 26041-271, RJ, Brasil; martamaximo@yahoo.com