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A simple, low-cost, data-logging pendulum built from a computer mouse

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Abstract

Lessons and homework problems involving a pendulum are often a big part of introductory physics classes and laboratory courses from high school to undergraduate levels. Although laboratory equipment for pendulum experiments is commercially available, it is often expensive and may not be affordable for teachers on fixed budgets, particularly in developing countries. We present a low-cost, easy-to-build rotary sensor pendulum using the existing hardware in a ball-type computer mouse. We demonstrate how this apparatus may be used to measure both the frequency and coefficient of damping of a simple physical pendulum. This easily constructed laboratory equipment makes it possible for all students to have hands-on experience with one of the most important simple physical systems.

I. INTRODUCTION

Lessons and homework problems involving a pendulum are often a big part of introductory physics classes and laboratory courses.[1] Typically experiments are limited to using photogates to measure the period of the pendulum. Commercial rotary motion sensors[8] that allow students to collect real-time motion data for a pendulum exist, but often the cost is too great to provide each student in the class with such a sensor, especially in developing countries. In contrast, a new two-button button ball-type mouse can be purchased for under 5 US dollars. Therefore we present a cheap, easy-to-build rotary sensor pendulum using the existing hardware in a computer mouse.

There have been other attempts to use common computer peripherals as data acquisition interfaces. T. J. Bensky in 2001 described the use of a computer joystick to track the motion of a pendulum.[2] We considered using his design when building the data-logging pendulum, but computer joysticks have changed considerably in the past 7 years. Few, if any, models are sold that do not self-center; this is a crucial feature to Bensky's original design. Three papers by Handler, Ochoa, and Kolp feature the use of a computer mouse in tracking motion in a Lenz's Law experiment and in harmonic motion experiments using springs.[3–5] In each case a string was wrapped around the roller in the mouse so that a linear displacement could be measured. Since these experiments, significant changes in mouse hardware in the last $10 - 12$ years make it easier than ever to use a computer mouse to measure angular displacement as well.

At the time that these papers were written, the rollers in the mouse featured a series of electrical contacts that would produce a signal by brushing against a wire as the mouse was moved. This has since been nearly universally replaced by an opto-mechanical mechanism that is much lower in friction. The rollers now have slotted disks, and photogates sense the motion of the disk without any physical contact required. This improved hardware is ideal for tracking the motion of a pendulum because measurement friction is low and can easily be eliminated, and also because the opto-mechanical mechanism that uses a slotted wheel is fundamentally a measure of angular displacement.

There exist computer mice that use a purely optical mechanism to detect translation, namely, a low resolution camera on the underside of the mouse. The camera repeatedly takes pictures of the surface under the mouse and interprets differences between successive

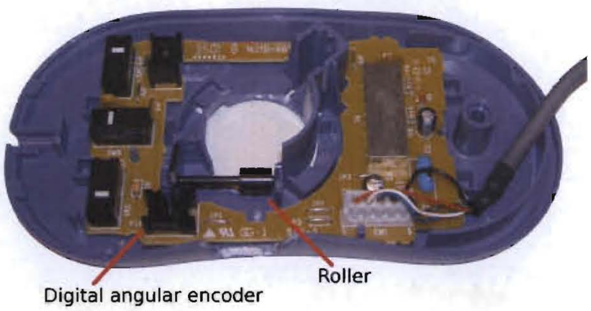

FIG. 1: Interior of a computer mouse. The hole in the center is for the ball, which has been removed. The key components are the digital angular encoder and the associated roller, as indicated. The pendulum will be attached directly to this roller. Color online.

frames as motion. While these mice work the same way to the user, this type of mouse has no mechanical components and is not well suited for this application. It may be possible to adapt an optical mouse for other mechanical experiments, but in this work we specifically take advantage of the hardware present in ball-type mice.

II. BUILDING THE PENDULUM

The following parts and tools are needed: a ball-type computer mouse, a wooden or plastic dowel, a small screwdriver (used to open the mouse casing), a pair of small clippers (used to cut back the mouse casing), and a small drill bit. We remove the cover of the mouse and locate the best angular encoder to use for a pendulum (see Fig. 1). We cut away enough of the cover to allow access to the encoder, then replace the cover to provide support to the assembly. In this case we allow for moderate amplitude (180°) motion of the pendulum. With additional hardware it is possible to mount the brackets of the roller from either side of the pendulum to allow for full 360° motion. If the pendulum is not mounted to the roller but the other way around, measurement friction can be eliminated.

A small drill bit turned by hand will make a hole in the roller. A rod with the same diameter as the drill bit will fit into this hole and will function as the pendulum. We used a thin wooden dowel,[9] but a small plastic rod would work equally well. Since no glue is used, rods of varying lengths can be easily substituted for an experiment. Fig. 2 shows the completed experimental apparatus.

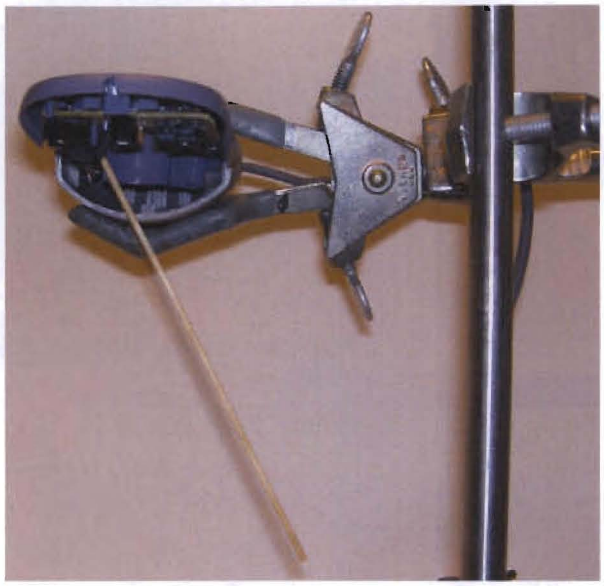

FIG. 2: The assembled pendulum-mouse in action. Color online.

III. CALIBRATION AND USE

We plug the mouse into the Universal Serial Bus (USB) port of a computer.[10] The resolution of the apparatus is limited by the number and spacing of the slots in the disk of the angular encoder. Therefore, it is possible to calibrate the motion of the cursor to angular displacement units. One calibration method is to determine the motion in pixels of one or more full turns of the roller. For the apparatus we built, a rotation of 360 ± 1 degrees gave a change in the position of the cursor of 194 ± 1 pixels. This results in a conversion factor of 0.0324 radians per pixel. This program tracks the motion of the cursor in pixels;[11] therefore the apparatus has a resolution of 0.0324 radians, which corresponds to a fractional uncertainty of 0.52% out of a full turn.

The standard equation of motion of a pendulum with damping is

$$Ia = -\frac{mgl}{2}\sin x - \beta v, \tag{1}$$

where $I = \frac{1}{3}ml^2$ is the moment of inertia. Here m and l refer to the mass and length of the rod, respectively, while g is acceleration due to gravity and β controls the strength of the damping term. Also, x, v, and a are the angle measured down from the vertical, the angular velocity, and the angular acceleration, respectively. In the small angle approximation, the

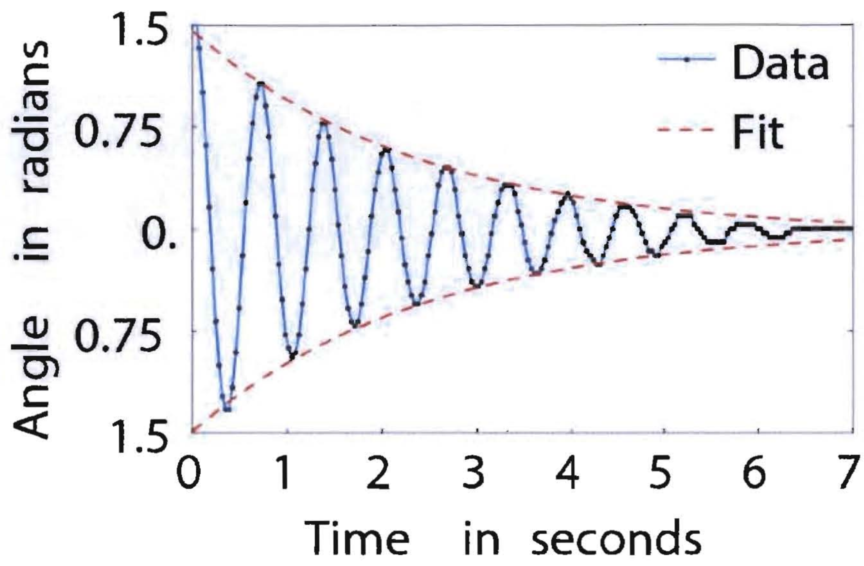

FIG. 3: Position-vs-time data for the pendulum. The dots show the actual data from the pendulum, with a thin solid line added to guide the eye. The dashed line shows a fit of the data to an exponential decay envelope. Color online.

equation of motion reduces to

$$a = -\frac{3g}{2l}x - \frac{3\beta}{ml^2}v. \tag{2}$$

We can write the solution as follows:

$$x(t) = Ae^{-\delta t}\cos(\omega t_{\phi}), \tag{3}$$

where $\delta = \frac{3\beta}{2ml^2}$ is the decay constant and $\omega = \sqrt{\frac{3g}{2l} - \delta^2}$ is the frequency of free oscillations.[6]

A and ϕ are determined using the initial conditions. Fig. 3 shows a plot of position versus time data for the pendulum when released from rest). The dashed line shows a fit of the turning points to an exponential decay envelope. For the pendulum, we obtain $\delta = 0.415$ with $R^2 = 0.997$ for the fit. This simple investigation is quite easy to do using the data from this apparatus, but next to impossible using only photogates.

IV. CONCLUSION

The mouse-pendulum is a low cost solution to the need for an experimental pendulum that provides real-time angular displacement data. The small- amplitude period of the pendulum (approximately 0.63s for the apparatus we built) depends only on the length of the rod and can be easily adjusted for various experiments. This apparatus is ideal for undergraduate and even high school lab classes. Furthermore, the low cost makes it possible for teachers with very limited budgets and those in developing countries to provide each student in the class with a useful piece of lab equipment. The ease of construction allows building the pendulum to be a good classroom exercise, during which practical experimental considerations (such as how to minimize friction) may be discussed. This design is robust for serious experimental work as well.[12] Photographs detailing the construction of the apparatus described in this paper, as well as source code to data logging software to record the motion of the pendulum can be obtained online.[13]

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1 Paul Gluck. Versatile physical pendulum. *Physics Teacher*, 42:226, 2004.

2 T.J. Bensky. Measuring g with a joystick pendulum. *Physics Teacher*, 39:88, 2001.

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4 O. Romulo Ochoa and N. Franklin Kolp. The computer mouse as a data acquisition interface: Application to harmonic oscillators,. *American Journal of Physics*, 65:1115, 1997.

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6 E. H. Graf. Computerized physical pendulum for classroom demonstrations. *Physics Teacher*, 43:244, 2005.

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8 Vernier order number RMS-BTD; PASCO model number PS-2120

9 This pendulum has a length of 14.7cm, a diameter of 2.2mm and a mass of 0.38g.

10 In general, most operating systems will accept input from two mice plugged in simultaneously (via the USB port) so the pendulum need not interfere with normal operation of the computer. This was tested for Windows XP, Linux, and OS X. We turn OFF the hardware acceleration

for the mouse to ensure that the displacement does not depend on the angular velocity of the roller. Detailed instructions are available online.

11 It is somewhat more difficult but quite possible to write a computer program that uses the data coming from the mouse itself. The resolution of this data is limited only by the resolution of the optical angular encoder within the mouse.

12 A variation of this design was used to explore synchronization between real and virtual pendula experimentally.[7]

13 `http://vadasg.googlepages.com/`