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.

Introduction

Lessons and homework problems involving a pendulum are often a big part of introductory physics classes and laboratory courses [3]. Typically, experiments are limited to using photogates to measure the period of the pendulum. Commercial rotary motion sensors 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 ball-type mouse can be purchased for under 5 US dollars and surplus used units are often available at little or no cost. Therefore, we present a low-cost, 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. In 2001 Bensky described the use of a computer joystick to track the motion of a pendulum [1]. We considered using his design when building a data-logging pendulum, but computer joysticks have changed considerably in the past eight years. Few, if any, models are sold that do not self-centre; this is a crucial feature to Bensky’s original design. Three papers by Ochoa et al feature the use of a computer mouse in tracking motion in a Lenz’s law experiment and in harmonic motion experiments using springs [5–7]. In each case a string was wrapped around the roller...
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Figure 1. Interior of a computer mouse. The hole in the centre 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. The second roller (to detect translation orthogonal to the first roller) has been removed.

Figure 2. The assembled pendulum mouse in action.

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 (approximately the diameter of the dowel). We remove the cover of the mouse and locate the best digital angular encoder (with roller) to use for a pendulum (see figure 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 by cutting back the plastic near the roller. With additional hardware it is possible to mount the brackets of the roller from either side to allow for full 360° motion of the pendulum. Measurement friction may be reduced or eliminated using different mounts for the roller.

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, but a small plastic rod would work equally well. Since no glue is used, rods of varying lengths can be easily substituted during experiments. Figure 2 shows the completed experimental apparatus.

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

We plug the mouse into the universal serial bus (USB) port of a computer. The resolution of the apparatus is limited by the number and spacing of the slots in the disc 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 $360^\circ \pm 1^\circ$ gave a change in the position of the cursor of $194 \pm 1$ pixels. This results in a conversion factor of $0.0324 \text{ radians/pixel}$. A custom computer program is used to measure the motion of the cursor in pixels. We find that the apparatus has a resolution of $0.0324 \text{ radians}$, 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

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

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 $\beta$ 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 equation of motion reduces to

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

We can write the solution as follows:

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

where $\delta = \frac{3\beta}{2ml}$ is the decay constant and $\omega = \sqrt{\frac{3g}{2l} - \delta^2}$ is the frequency of free oscillations [4]. $A$ and $\phi$ are determined using the initial conditions. Figure 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 photo-gates. This is a simple example of a high school or undergraduate level laboratory experiment that uses the apparatus but it is well suited to more advanced teaching applications such as exploring the driven physical pendulum or coupling between pendula.

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 $0.63 \text{ s}$ 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 laboratory 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 laboratory equipment. The ease of construction allows the building of the pendulum...
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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. The source code for free data-logging software to record the motion of the pendulum can be obtained in the online version of the journal at stacks.iop.org/physed/44/488. LA-UR 09-00439.

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A variation of this design was successfully used to explore synchronization between real and virtual pendula experimentally [2].

Vadas Gintautas completed a PhD in physics at the University of Illinois at Urbana-Champaign, USA in 2008. He is currently a postdoc at Los Alamos National Laboratory, USA. Besides physics education, his research interests are nonlinear dynamics and computational neuroscience.

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