Photogate Timing with a Smartphone

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Photogate Timing with a Smartphone

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In a previous article we demonstrated that a simple, passive external circuit incorporating a thermistor, connected to a mobile device through the headset jack, can be used to collect temperature data.[1] The basic approach is to output a sine wave signal to the headset port, through the circuit, and input the resulting signal from the headset microphone. By replacing the thermistor with other variable resistors, the circuit can perform other data measurements. A photoresistor in the circuit will change the amplitude of the returning signal by varying the resistance, depending upon the intensity of light reaching it. The circuit used is shown in Fig. 1 (a discussion of alternative circuits is given in Ref. 2). Two or more photoresistors can be placed in series to form multiple photogates, as shown in Fig. 2. The photoresistors used here have a resistance of about 120 kΩ in the dark and 5 kΩ under lamp light. Ordinary household lamps were used as light sources.

The signal does not drop instantly when the resistor is blocked but rather tapers off to a minimum while blocked. Also, due to hysteresis effects, the dip in the graph when the photoresistor is blocked is slightly asymmetric. To avoid these problems we used a double flag method where the time from the beginning of two separate dips is used for timing purposes.[3] In this method two blockages of the gate are used to make a single velocity measurement. This can be done using a piece of Plexiglas with two tape strips (as shown in Fig. 2) or a card with a notch cut out, placed on the moving object so that two dips are produced at each photoresistor when the object passes and blocks the light to each resistor. The Android app AudioTime+ marks the gate as blocked at the time when the amplitude of the gradual signal drop is 80% of the maximum, unblocked signal. The time interval from the 80% mark at the first dip to the 80% mark at the second dip is the length of time the object takes to pass the photoresistor.

Average velocity at each resistor is calculated from $v_{\text{ave}} = \frac{d}{\Delta T}$, where d is the distance from the leading edge of the first flag (or card) to the leading edge of the second flag (trailing edge of notch). The time Δt from when the card enters the gate until the notch has passed is measured from the app. Figure 3 shows the amplitude of the recorded return signal from a notched card passing a single photoresistor using the Android app AudioTime+.[4] In the figure the time when the signal drops by 80% as the first flag passes the resistor is 1.1318 s and 1.2352 s as the trailing flag passes. The time interval for the card to pass the resistor is given at the bottom right of the screen as 0.1035 s.

Acceleration can be determined from the equation $v^2 - v_0^2 = 2ax$, where v_0 is the average velocity at the first photoresistor, v is the average velocity at the second photoresistor, and x is the distance from the first to second photoresistor. A small error is introduced by assuming the average velocity is equal to the instantaneous velocity at the middle of the card, which is not the case since the card is accelerating. Letting the object move a distance equal to several times the width of the card before entering the first gate reduces the error to an accept-

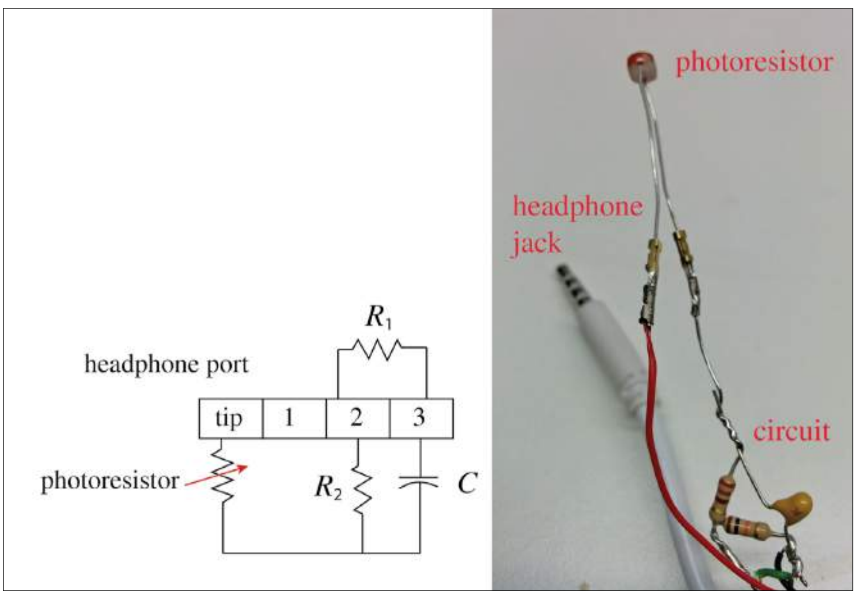

Fig. 1. Circuit used for photogate timing.

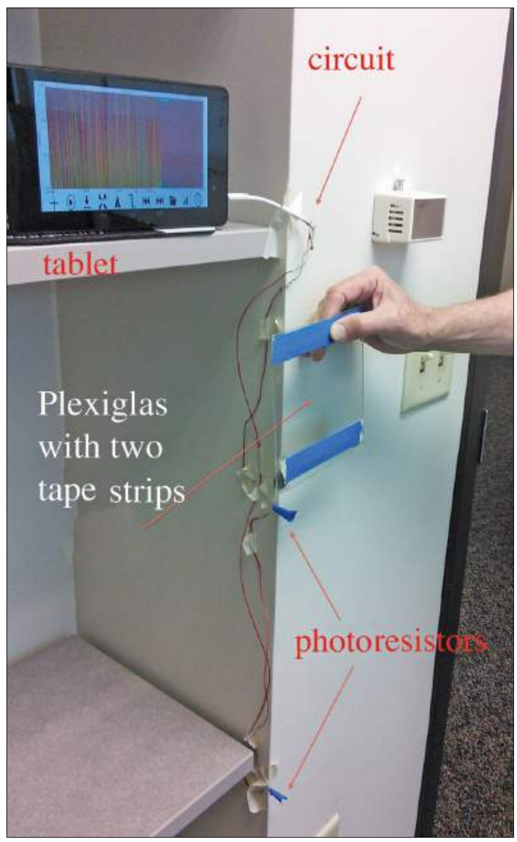

Fig. 2. Two photoresistors connected to a tablet.

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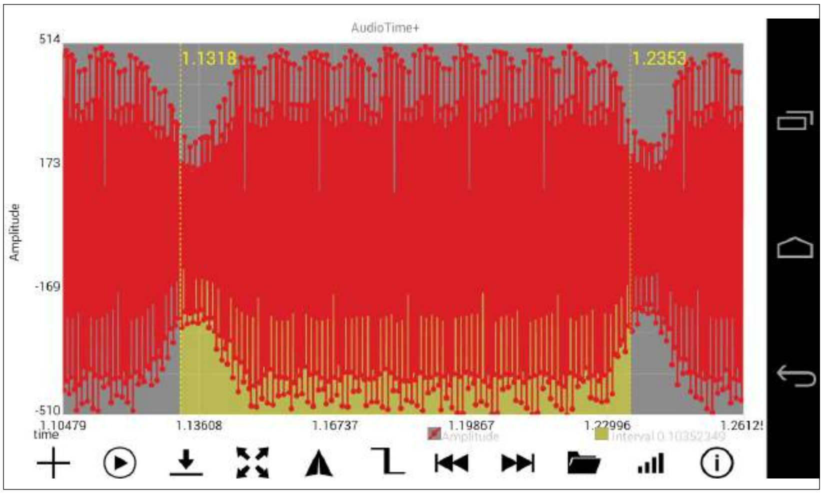

Fig. 3. A 4000-Hz frequency source is output through the headset port circuit and recorded from the microphone input. In this screen shot from the AudioTime+ app, the photoresistor is read as blocked for 0.1035 s between seconds 1.1318 s and 1.2353 s. The leading edge to leading edge distance of the notched card was 9.0 cm, giving an average speed of 0.87 m/s while the object was passing the resistor. Apparent irregularities in the amplitude of the signal are due to screen resolution; the screen does not have the pixel resolution for the number of data points being represented.

able level (see Ref. 5 for details). Alternatively, by measuring the time t from the center time of blocking the first gate to the center of blocking the second, acceleration can be calculated from $v = v_0 + at$.

We used two photoresistors and a toy car with a notched card attached to measure acceleration down an incline plane. For an incline of 9.5° the acceleration of a frictionless sliding object would be $g \sin(\theta) = 1.6$ m/s^2. The notch on the car was cut out so that the leading edge to leading edge of the two flags was 9.0 cm. A consistent acceleration of 1.3 m/s^2 over several trials was measured with AudioTime+ phone app acting as timer. The error is attributable to friction and rotational inertia in the wheels of the toy car. We also measured the acceleration of gravity using a free falling Plexiglas square with two tape strips, 11.9 cm apart. An average acceleration of 9.9 m/s^2 was measured over five trials.

Photogates are very portable, inexpensive, and can be used in many different settings. For example, a single photoresistor can be used to measure the rotational motion of a wheel. This can be done by placing a small card with a known width on the wheel and arranging the photogate to be blocked by the card as the wheel rotates. Both constant angular speed and angular acceleration can be measured from the length of time of the amplitude dips in the output signal. Due to the portability and simplicity of the measurement apparatus, this works for a mounted wheel in a science lab or the wheel of a moving object such as a student's bicycle.

As a final example, a photoresistor/phone combination attached to an object (bicycle, car, runner) moving past a series of openings of known spacing (openings in a picket fence, telephone poles, etc.) could be used to measure speed and acceleration. Because the apparatus is mobile, the exploration of the movement of many objects outside the ordinary classroom laboratory becomes possible.

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