Finding the average speed of a light-emitting toy car with a smartphone light sensor

To cite this article: Serkan Kapucu 2017 Phys. Educ. 52 045001

View the article online for updates and enhancements.

Related content
- Finding the acceleration and speed of a light-emitting object on an inclined plane with a smartphone light sensor
  Serkan Kapucu
- Determining the efficiency of optical sources using a smartphone’s ambient light sensor
  J A Sans, J Gea-Pinal, M H Gimenez et al.
- Studying rotational dynamics with a smartphone—accelerometer versus gyroscope
  Mats Bräskén and Ray Põnn

Recent citations
- A simple experiment to measure the maximum coefficient of static friction with a smartphone
  Serkan Kapucu
- Finding the acceleration and speed of a light-emitting object on an inclined plane with a smartphone light sensor
  Serkan Kapucu
Finding the average speed of a light-emitting toy car with a smartphone light sensor

Serkan Kapucu

Abstract
This study aims to demonstrate how the average speed of a light-emitting toy car may be determined using a smartphone’s light sensor. The freely available Android smartphone application, ‘AndroSensor’, was used for the experiment. The classroom experiment combines complementary physics knowledge of optics and kinematics to find the average speed of a moving object. The speed of the toy car is found by determining the distance between the light-emitting toy car and the smartphone, and the time taken to travel these distances. To ensure that the average speed of the toy car calculated with the help of the AndroSensor was correct, the average speed was also calculated by analyzing video-recordings of the toy car. The resulting speeds found with these different methods were in good agreement with each other. Hence, it can be concluded that reliable measurements of the average speed of light-emitting objects can be determined with the help of the light sensor of an Android smartphone.

1. Introduction
Smartphones are often used in physics classrooms at present [1, 2], where some researchers, particularly as physics educators, have performed studies using various sensors on these devices to find the values of physical quantities [3–8]. In kinematics, the acceleration of objects was detected using the acceleration sensors of these devices [3, 4]. Moreover, in optics, their light sensors were used to better understand the properties of light [5, 6], while the speed of sound was also measured with smartphone applications [7, 8].

In this study, instead of concentrating only on optics, or on kinematics, both fields of knowledge are taken into consideration to find the average speed of a light-emitting toy car. It is, in fact, very easy to measure the average speed of an object if it has a constant speed. The average speed of an object is equal to the ratio of the distance travelled by an object, to the elapsed time taken to travel this distance [9]. With this basic knowledge of kinematics as well as concepts in optics, such as illumination, the average speed of light-emitting objects can be found. In this regard, this study aims to find the average speed of a light-emitting toy car using the light sensor of an Android smartphone.

2. Theoretical background
Android smartphones are equipped with internal sensors capable of detecting light, magnetic fields, sounds, and their own acceleration. One of the freely available Android applications, ‘AndroSensor’ [10], can display what these
sensors measure (see figure 1). As this study focuses on the light sensor of the Android smartphone, we should first know some terms about photometry. Two fundamental terms in photometry—illuminance and luminous intensity—are sufficient to understand the displayed value for light provided by the AndroSensor application. Illuminance is the luminous flux per unit area. Its symbol is $E_v$, and its unit is the lux. Luminous intensity also refers to the luminous flux per unit solid angle, and is represented by the symbol, $I_v$, and its unit of measurement is the candela [11]. The relationship between illuminance and luminous intensity for a point light source is given by, $E_v = \frac{I_v}{d^2}$ [12]. When we look at the AndroSensor application’s display (figure 1), we only see one value for light. The application only displays the illuminance values ($E_v$), measured in lux. Also, although this smartphone application can display the illuminance values from a light-emitting object that moves toward the smartphone, it cannot display the speed of the objects, as in radar detectors. However, if we know the illuminance and the luminous intensity of the light-emitting object that is moving toward the smartphone, we can calculate the distance between the object and the smartphone using the formula, $E_v = \frac{I_v}{d^2}$. When the coming lights from light source are perpendicular to light sensor. We can then use this distance in the calculations to determine the average speed of the moving object. The formula, $V = \frac{\Delta X}{\Delta t}$, gives the average speed of an object in meters per second (m s$^{-1}$). In this formula, $\Delta X$ is the total distance travelled and measured in meters, and $\Delta t$ is the total time taken to travel this distance, measured in seconds [9].

Considering the two formulas, $E_v = \frac{I_v}{d^2}$, and $V = \frac{\Delta X}{\Delta t}$, we see that we can calculate the speed of the object moving toward the smartphone if we know the luminous intensity, $I_v$, of the light source. Using the $E_v$ value that the AndroSensor displays, we can then easily calculate the distance, $d$ (the distance between the toy car and the smartphone). When the light-emitting toy car moves toward the smartphone, the measured $E_v$ values will change continuously. However, the $I_v$ value remains constant, as it depends only on the light source. This value is typically indicated in the documentation, or device specifications, provided with the light source, however, in this study, this value was measured with the AndroSensor smartphone application for a more reliable measurement. Furthermore, the final remaining value needed to calculate the speed, $\Delta t$, is also known, as the AndroSensor takes measurements every 0.500 s and records them with MS Excel. We can thus calculate the average speed of the moving car with these known values.

3. Experiment

The experiment required the following objects: a light-emitting toy car, a measuring tape marked to 1.00 m (or equivalently, a meter stick), an LED flashlight, an Android smartphone, electrical tape, a dumbbell, and some laths and boxes. The remote-controlled toy car had a four-wheel drive system and could operate at constant speed. To ensure that the car moved in a straight line, some thick laths were fixed to the floor with tape to keep the car on a uniform path. The LED flashlight was
Finding the average speed of a light-emitting toy car with a smartphone light sensor

attached to the car with some tape, and used as a light source with sufficient luminosity for the experiment. The Android smartphone acted as my light sensor and detected the illuminance provided by the toy car. To prevent the toy car from crashing into the smartphone, I used a dumbbell as a stopping obstacle. Some small boxes were used to combine the experimental materials with each other. A typical setup for the experimental materials is shown in figure 2.

Before beginning the experiment, to ensure the Android smartphone only detected light from the LED flashlight in its illuminance measurement (so that only light with a known luminous intensity is measured), the lights of antenna and head-lights of the toy car were taped over. To ensure an accurate measurement, it was also important to position the LED flashlight so that the emitted light was perpendicular to the light sensor of the smartphone. My LED flashlight was positioned to be as close to perpendicular to the smartphone’s light sensor as was possible.

Additionally, the luminous intensity value of the LED flashlight is required to be able to measure the speed of the toy car. In order to measure this value, I used the smartphone’s AndroSensor application. However, since this application only displays the illuminance value, the luminous intensity was therefore calculated using the formula $I_v = E_vd^2$. Though the AndroSensor measured the illuminance value every 0.500 s, unfortunately these values were slightly different from each other. This might be due to the sensitivity of the smartphone light.

Finally, in the experiment, the light-emitting toy car and the LED flashlight were operated in darkness. The toy car travelled a distance of 5.20 m along a straight route at constant speed, and the AndroSensor application measured the illuminance values throughout the motion of the toy car. The final experimental design of this study is depicted in figure 4.

For an alternate means of analysis, the motion of the car was video-taped to determine another average speed, so that its average speed could be determined from the video analysis. The recording was analyzed with Windows Movie Maker operating in slow motion, and the time taken to travel a 1.00 m distance marked by two dark electrical bands (see figure 4) was measured from this video analysis. The alternate average speed of the toy car was found by dividing this 1.00 m distance by the measured time.

4. Results
I first needed to determine the luminous intensity of the LED flashlight. However, as already mentioned, the Android smartphone application AndroSensor only displays the illuminance values and the luminous intensity was therefore calculated using the formula $I_v = E_vd^2$. Though the AndroSensor measured the illuminance value every 0.500 s, unfortunately these values were slightly different from each other. This might be due to the sensitivity of the smartphone light.
sensor. Though, as these values were close to each other, it was decided to record the values every 0.500 s for 1.00 min, and to calculate their average illuminance value. The illuminance values recorded by the AndroSensor were between 55.0–63.0 lux. Considering an uncertainty analysis (see [13, 14]) the average illuminance value of the 120 recordings taken in 1 min was found to be 58.7 ± 0.1 lux. Putting this value and the distance of 1.00 ± 0.02 m into the formula, $I = E_d^2 / v$, the luminous intensity of the LED flashlight was found to be 58.7 ± 2.4 candela. To be able to measure the average speed of the toy car, the distance travelled in a certain time was needed. Theoretically, the distance was calculated using the formula, $d = \sqrt{\frac{I}{E_v}}$, and this distance inserted into the formula $V = \frac{\Delta X}{\Delta t}$ to calculate the average speed. In the experiment, it was expected that the toy car would travel the same distance in every 0.500 s time-step, due to its constant velocity. However, this expectation could not be met. Sensitivity of the smartphone’s light sensor, and some experimental errors might have caused these unexpected results. However, some distance values taken in equal times were close to each other. In addition, in order to increase the reliability of the experimental results, the experiment was repeated three times. Therefore, three different measurements were obtained as provided in table 1.

In the first measurement the toy car was 1.98 ± 0.04 m away from the smartphone when its illuminance was 15.0 lux, and 0.226 ± 0.005 m away from the smartphone when its illuminance was 1154.0 lux. Therefore, for the first measurement, the total distance travelled between these two values was found to be $\Delta X_1 = 1.75 ± 0.04$ m. Since the elapsed time (4.00 s) for travelling this distance was also known, the average speed of the toy car using the formula of $V = \frac{\Delta X}{\Delta t}$ was
Finding the average speed of a light-emitting toy car with a smartphone light sensor

Table 1. Measured illuminance and position values of the toy car.

<table>
<thead>
<tr>
<th>Light(1) (lux)</th>
<th>X1 (m)</th>
<th>Light(2) (lux)</th>
<th>X2 (m)</th>
<th>Light(3) (lux)</th>
<th>X3 (m)</th>
<th>Δt (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0</td>
<td>1.98 ± 0.04</td>
<td>16.0</td>
<td>1.92 ± 0.04</td>
<td>14.0</td>
<td>2.05 ± 0.04</td>
<td>0.500</td>
</tr>
<tr>
<td>20.0</td>
<td>1.71 ± 0.04</td>
<td>21.0</td>
<td>1.67 ± 0.03</td>
<td>17.0</td>
<td>1.86 ± 0.04</td>
<td>0.500</td>
</tr>
<tr>
<td>27.0</td>
<td>1.47 ± 0.03</td>
<td>27.0</td>
<td>1.47 ± 0.03</td>
<td>24.0</td>
<td>1.56 ± 0.03</td>
<td>0.500</td>
</tr>
<tr>
<td>38.0</td>
<td>1.24 ± 0.02</td>
<td>39.0</td>
<td>1.23 ± 0.02</td>
<td>35.0</td>
<td>1.30 ± 0.03</td>
<td>0.500</td>
</tr>
<tr>
<td>52.0</td>
<td>1.06 ± 0.02</td>
<td>63.0</td>
<td>0.96 ± 0.02</td>
<td>43.0</td>
<td>1.17 ± 0.02</td>
<td>0.500</td>
</tr>
<tr>
<td>79.0</td>
<td>0.86 ± 0.02</td>
<td>78.0</td>
<td>0.868 ± 0.02</td>
<td>77.0</td>
<td>0.873 ± 0.02</td>
<td>0.500</td>
</tr>
<tr>
<td>153.0</td>
<td>0.619 ± 0.01</td>
<td>150.0</td>
<td>0.626 ± 0.01</td>
<td>109.0</td>
<td>0.734 ± 0.02</td>
<td>0.500</td>
</tr>
<tr>
<td>259.0</td>
<td>0.476 ± 0.010</td>
<td>312.0</td>
<td>0.434 ± 0.009</td>
<td>281.0</td>
<td>0.457 ± 0.009</td>
<td>0.500</td>
</tr>
<tr>
<td>1154.0</td>
<td>0.226 ± 0.005</td>
<td>1665.0</td>
<td>0.188 ± 0.004</td>
<td>613.0</td>
<td>0.309 ± 0.006</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Calculated. Putting the values ΔX and Δt into this formula the average speed of the toy car in the first measurement was found to be \( V_1 = 0.438 ± 0.010 \) m s\(^{-1}\). When these calculations were repeated for the other measurements, the total distance travelled for the second and third measurements were found to be \( \Delta X_2 = 1.73 ± 0.04 \) m, and \( \Delta X_3 = 1.74 ± 0.04 \) m, respectively. The average speeds for these measurements \( V_2 \) and \( V_3 \) were also determined to be \( 0.432 ± 0.010 \) m s\(^{-1}\) and \( 0.435 ± 0.010 \) m s\(^{-1}\), respectively. As a test control on whether these values were similar to the average speed of the toy car found in another alternate method, video analysis was performed with Windows Movie Maker. Viewing the toy car in slow motion, the elapsed time for it to travel a distance of one meter was determined. In the three measurements, the elapsed times, \( \Delta t'_1, \Delta t'_2, \) and \( \Delta t'_3 \) taken to travel 1.00 ± 0.02 m were found to be 2.34 s, 2.36 s, and 2.30 s, respectively. The average speeds (\( V = \frac{\Delta x}{\Delta t} \)) were calculated by dividing the distance (1.00 ± 0.02 m) by the elapsed times identified by the video analysis. The resulting speeds, \( V'_1, V'_2, \) and \( V'_3 \) were found to be \( 0.427 ± 0.005 \) m s\(^{-1}\), \( 0.424 ± 0.005 \) m s\(^{-1}\), and \( 0.435 ± 0.005 \) m s\(^{-1}\), respectively. These speed values were very close to those speed values found with the help of the smartphone application AndroSensor.

5. Conclusions

This study demonstrated that the average speed of a light-emitting toy car can be calculated using the light sensor of a smartphone. When the average speeds obtained from video analysis and the AndroSensor were compared, the average speeds were very close to each other. When we consider the average speed obtained from video analysis as being close to the toy car actual/theoretical speed, this result implies that the light sensor of a smartphone can be used for reliable average speed measurements of light-emitting objects. As a limitation of this experiment, we first need to know the luminous intensity of these objects in order to calculate their speed. For example, in this study, the luminous intensity of the LED flashlight was calculated by placing it one meter away from the smartphone. Moreover, reflections of light from the floor might affect the lux values identified by AndroSensor while the light-emitting toy car was travelling. If this experiment were performed in dark floors, more reliable results could be reached.

When we consider the widespread use of smartphones in physics classrooms \([2]\), this experiment could be used to increase the students’ interest in kinematics and optics. In particular, using a smartphone as a radar-like device should increase students’ interest in physics. This experiment is also very easy to carry out in physics classrooms, as all the tools and materials used in the experiment are readily available and are low in cost.

References

[1] Countryman C L 2014 Familiarizing students with the basics of a smartphone’s internal sensors Phys. Teach. 52 557–9


Serkan Kapucu has a PhD degree in physics education. He is currently an assistant professor at Ağrı İbrahim Çeçen University. His research areas include epistemological beliefs, conceptions of learning, teaching beliefs and attitudes. Moreover, he tries to develop a variety of physics activities using smartphones.