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Marcello Campione ; Antonino Pietropaolo ; Gianlorenzo Bussetti

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Probing the Optical Properties of Planar Light Sources Using Smartphone Sensor Devices

Marcello Campione, University of Milano–Bicocca, Milan, Italy
Antonino Pietropaolo, ENEA, Frascati, Italy
Gianlorenzo Bussetti, Politecnico di Milano, Milan, Italy

Smartphones are widespread devices among secondary school and university students, and they also offer a series of sensors integrated in a portable device, which are demonstrated to allow for a prompt and accurate measurement of some physical quantities.[1] For example, the smartphone light sensor was used to test Malus's law,[2] to monitor the circular motion of a light-emitting object,[3] to measure the Brewster angle,[4] to perform turbidity measurements of sugar solutions[5] and transmittance measurements to verify the Lambert–Beer law,[6–8] and to characterize point-like sources[9] and linear sources.[10] In the present work, we describe an at-home laboratory experiment that allows characterization of the emission properties of liquid crystal displays (LCDs)—representing very well-defined planar emitters with tunable intensity, color, and shape—by determining their luminance level and a parameter accounting for the angular intensity distribution of the light source. This experiment represents a direct application of photometry principles at the basis of the quantification of the *brightness* of light-emitting screens as well as astronomical extended objects such as galaxies and nebulae.

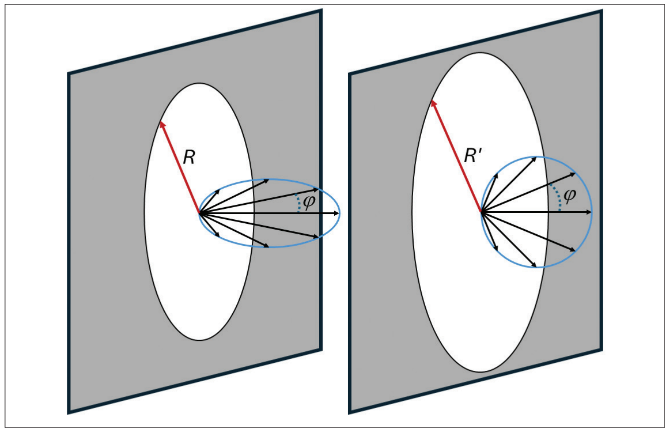

Fig. 1. Radiation patterns of two luminous disks with equal illuminance trend as a function of the distance. The one on the left (non-Lambertian) has a smaller radius *R* and a preferential emission direction; the one on the right shows a larger radius *R*′ (>*R*) and a Lambertian emission pattern.

Theoretical concepts

Illuminance (E) represents the luminous flux (ϕ) per unit surface (lumens per square meter $=$ lm/m^2 $=$ lux, abbreviated lx) collected at a point, and it is a quantity that can be evaluated by means of smartphone light sensors. The inverse-square decay law of illuminance of a point light source with distance d, Eq. (1), is a common notion of basic optics theory, which is readily demonstrated to be a direct consequence of the propagation of spherical wave fronts with a center at the point light source.

$$E = \frac{\phi}{4\pi d^2} \cdot \qquad (1)$$

Planar emitters can be approximated as a dense array of point sources uniformly distributed over the surface. Therefore, the illuminance dependence as a function of the distance from the emitter plane can be evaluated by an integration over the whole surface. For circular surfaces (disk with radius R) with a Lambertian emission pattern, the illuminance decay with distance from the center of the disk follows the relation[11,12]

$$E^D = \pi L\left[\frac{R^2}{(d^2+R^2)}\right], \qquad (2)$$

where L represents the luminance [nits (nt) or candelas per square meter (cd/m^2) (the SI unit); 1 nt $=$ 1 cd/m^2 $=$ 1 lm $\cdot$ sr^{-1} $\cdot$ m^{-2}], which is the appropriate quantity to characterize planar light emitters, as luminous flux (lumens) is provided to quantify the emission characteristics of small spherical light emitters (lamps, LEDs, flashlights, etc.) and linear emitters (fluorescent tubes, neon lights, etc.). In a Lambertian emitter, L is the same in all directions and in all points of the surface. This means that the emitted luminous intensity I of a point follows the Lambert law: $I(\varphi) = I(0)\cos(\varphi)$, where φ is the angle between the surface normal and the direction of observation (Fig. 1). Equation (2) is obtained by integrating the illuminance at the detector position given by a concentric ring of radius r over the interval 0–R.[11,12]

Fig. 2. Picture of the experimental setup.

Equation (2) correctly converges to Eq. (1) for $d \gg R$, and to a constant value in the limit $d \ll R$. In particular, $E^D = \pi L$ for $d = 0$. The product πL is defined as the luminous exitance

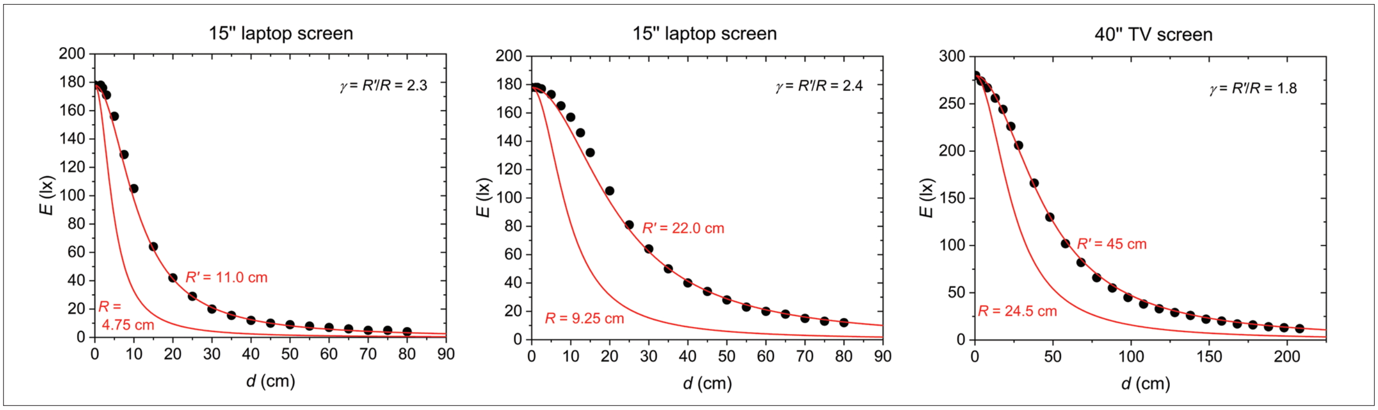

Fig. 3. Data points (black dots) collected with the smartphone sensor (uncertainties for distance and illuminance are well within the symbol size) and curves (red lines) calculated with Eq. (2). The real used disk radius (*R*) and that of the virtual Lambertian source (*R*′) are reported together with the γ parameter.

of the screen (lm/m^2). The fundamental characteristic of Eq. (2) is that it reflects a decay behavior with distance similar to that of Eq. (1). In proximity to the source, it saturates to a value that can immediately provide the luminance level of the planar emitting device. Hence, by placing the smartphone sensor close in front of the luminous surface, one can extract the L value just dividing the measured illuminance by π.

Here, we give evidence that for LCDs the illuminance decay rate as a function of the distance is substantially lower than that calculated by Eq. (2). This can be the consequence of a directionality of the source emission pattern (luminance higher along the forward direction). Under these circumstances, the used planar emitter cannot be considered a Lambertian source. Nonetheless, the decay law expressed in Eq. (2) can be restored if a virtual Lambertian source of radius $R' > R$ is considered as a model system instead of our non-Lambertian source of radius R (Fig. 1). In view of comparing different sources, we propose to evaluate a dimensionless parameter ($\gamma = R'/R$) to quantify the emission directionality.

Procedure and experimental results

We adopted the light sensor installed in a Redmi 10C and we used the luxmeter function available in the Physics Toolbox Suite (Vieyra Software) to visualize the illuminance measured by the instrument. To produce a luminous disk (planar emitter), we visualized on a 15-in. laptop LCD (see Fig. 2) and on a 40-in. TV screen an image (jpeg format) of a white disk on a black background, setting the brightness level to maximum. The disk radius was set to 4.75 ± 0.05 cm and 9.25 ± 0.05 cm on the laptop screen and 24.5 ± 0.05 cm on the TV screen, as measured with a meter stick. After orientating the smartphone plane parallel to source plane, the sensor was placed in the center of the luminous disk, while the source–sensor distance was varied and measured with a meter stick (Fig. 2). For short distances, direct reading of the illuminance on the smartphone display might be prevented by the size of the source screen. In this case, data can be stored by the use of the "record" function of the software, and then shared, e.g., via Bluetooth. The uncertainty on the measured distances was estimated to be ±0.5 cm, whereas the uncertainty of the illuminance was 2–5 lx, resulting from repeated measurements at the same distance.

Illuminance measurements were performed under dark conditions, i.e., with background illuminance lower than 2 lx. The results are reported in Fig. 3. The saturation value of illuminance (luminous exitance) is 178 ± 5 lm/m^2 for the laptop screen and 280 ± 5 lm/m^2 for the TV screen. These data give a luminance of 56.7 ± 1.6 nt for the laptop screen and 89.2 ± 1.6 nt for the TV screen. These results fall well within the expected luminance values of related screens, ranging from a few tens to hundreds of nits, depending on the achievable brightness level adopted. For indoor use, nit levels below 200 are sufficient, whereas under sunlight illumination, brightness may overcome 500 nt to ensure adequate visibility. In the case of screens equipped with high dynamic range (HDR), nit levels must overcome 1000 to ensure full optimization of the screen performance. The curves calculated with Eq. (2) by setting the actual radius of the displayed disk systematically underestimate the decay trend of the illuminance. A good interpolation of the experimental data is achieved by setting a radius 2.3–2.4 (1.8) times greater for the laptop (TV) screen (see calculated γ values in Fig. 3). We interpret this difference in terms of a preferential forward emission of the LCD source (Fig. 1), in good agreement with the characteristics described in the literature.[13]

Conclusions

LCDs represent useful and versatile models of planar emitters that are suitable to be characterized by a smartphone light sensor. We showed a simple methodology that allows one to obtain an estimate of the average luminance of the screen and the determination of the preferential forward emission degree (γ parameter). We suggest a possible extension of this experimental activity by investigating the decay law on extended sources having different color, brightness, and emitter shape.

References

1. M. Monteiro and A. C. Martí, "Resource Letter MDS-1: Mobile devices and sensors for physics teaching," *Am. J. Phys.* **90**, 328–343 (2022).
2. M. Monteiro, C. Stari, C. Cabeza, and A. C. Martí, "The polar-

ization of light and Malus' law using smartphones," *Phys. Teach.* **55**, 264–266 (2017).
3. S. Kapucu, "Discovering quantities of circular motion of a light-emitting toy train using a smartphone light sensor," *Phys. Teach.* **57**, 480–482 (2019).
4. C.-M. Chiang and H.-Y. Cheng, "Use smartphones to measure Brewster's angle," *Phys. Teach.* **57**, 118–119 (2019).
5. N. Tongjan and C. Sirisathitkul, "Accuracy and precision of smartphones in measurements of illuminance and liquid turbidity," *Rev. Cuba. Fis.* **37**, 131 (2020).
6. P. Onorato, L. M. Gratton, M. Polesello, A. Salmoiraghi, and S. Oss, "The Beer Lambert law measurement made easy," *Phys. Educ.* **53**, 035033 (2018).
7. K. Malisorn et al., "Demonstration of light absorption and light scattering using smartphones," *Phys. Educ.* **55**, 015012 (2020).
8. P. Onorato, T. Rosi, E. Tufino, C. Caprara, and M. Malgieri, "Using smartphone cameras and ambient light sensors in distance learning: The attenuation law as experimental determination of gamma correction," *Phys. Educ.* **56**, 045007 (2021).
9. J. A. Sans et al., "Determining the efficiency of optical sources using a smartphone's ambient light sensor," *Eur. J. Phys.* **38**, 025301 (2017).
10. I. Salinas, M. H. Giménez, J. A. Monsoriu, and J. C. Castro-Palacio, "Characterization of linear light sources with the smartphone's ambient light sensor," *Phys. Teach.* **56**, 562–563 (2018).
11. V. Ivchenko, "Extended versus point light source: Where does the difference in the illuminance exist?" *Rev. Mex. Fis. E* **18**, 127–130 (2021).
12. R. M. Bunch, *Optical Systems Design Detection Essentials* (IOP Publishing, 2021).
13. I. Moreno and C. Sun, "Modeling the radiation pattern of LEDs," *Opt. Express* **16**, 1808 (2008).

Marcello Campione *is an associate professor of experimental physics of matter at the University of Milano–Bicocca. He has a keen interest in physics and chemistry of nanomaterials and nanominerals.*
marcello.campione@unimib.it

Antonino Pietropaolo *is a researcher at the ENEA Research Center in Frascati. He is devoted to the study of neutron detectors and the use of neutrons for condensed matter physics and for the production of medical radioisotopes.*

Gianlorenzo Bussetti *is an associate professor of experimental physics of matter at the Politecnico di Milano. He has a strong interest in the physics of surfaces and organic semiconductor materials.*

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