Notes on practical photometry for image sensor and vision sensor developers

T. Delbruck, Inst. of Neuroinformatics, UNI-ETH Zurich (tobi@ini.phys.ethz.ch)

rewritten 2006 from 1997 notes. Last modified 11/13/2006 9:25:49 AM.

Source URL site for this document: http://www.ini.unizh.ch/~tobi/anaprose/recep/index.php

Using a photographic spotmeter

A technical light meter like the one that used to be made by Tektronix (J17) is good for precise lab work because they come with illuminance, luminance and irradiance heads. Tektronix has stopped making this meter but you may still be able to buy one.

However, a photographic spotmeter can also be useful for calibration of imager exposure levels and certainly for measuring image contrasts. A photographic meter will only measure visible light, not energy. To use it, you have to figure out photometric units and how they relate to each other. The spotmeter uses photographic EV units (Exposure Value), which is a log2 scale. The log2 comes from photography and aperture stops, where 1 full stop is a factor of 2 exposure. Relation between EV and luminance L in nits (1 nit=1 cd/m^2) is

$$L = 2^{EV-3}$$

when you set ASA=100 on the spotmeter. Therefore if you read EV=3, you have a luminance of 1 nit. What are nits you ask?

Photometry units

The basic photometric quantity is a lumen (**lm**), which is a certain quantity of visible photons per second. Depending on the spectrum of the light, for a given number of lumens, there could be a few highly visible photons (yellow-green), or tons of barely visible photons (say blue, or deep red). To get lumens from photons, you multiply photons at each wavelength by their relative visibility and add them all up, finally multiplying by a magic scale factor at the end. The scale factor is 680lumens per watt for yellow-green photons (555nm). You get less lumens per watt away from this peak. For “white” light, defined as distributed like sunlight over energy over the visible range, scale is 250 lumens per watt, or 4mW/lumen. Incandescent 60W bulbs put out around 600 lumens; they only make 10 lm/W because most watts make invisible infrared photons. Useful relations between lumens and watts (from Al Rose) are

$$\text{lux} \approx 4\ \text{mW/m}^2 \approx 10^4 \frac{\text{photons}}{\text{um}^2\ \text{sec}}\ \text{("white" sunlight, average wavelength 555 nm)}$$

Illuminance, **lux**, is lm/m^2.

Next we have luminous intensity, measuring flux from a point source, lumens per solid angle. Luminous intensity is called candela (**cd**), and is lumen/steradian. There is 4π **steradian** solid angle per sphere. A uniformly radiating 1 lumen source spreads the lumen over 4π steradians, hence produces 1/4π candela.

Next we have luminance, measuring flux from an extended surface. It’s the thing corresponding to object brightness. Luminance is called **nit**, and equals lumen per steradian per sq m of surface; a nit is the same as the more commonly used **cd/m^2**. If a surface is a diffuse reflector, it looks equally bright at all angles; it emits a constant luminous intensity in all directions, a constant rate of photons per unit solid angle from your viewpoint. This constancy of brightness with viewpoint means actual luminance (lumens per steradian per sq m surface) drops off as cos(theta) away from the surface perpendicular, but luminous intensity (lumen per steradian) is constant. Integrating total lumens emitted over a hemisphere from a square meter illuminated by a lumen, tells you that you need factor of 1/π to get total lumens emitted to come out to the lumen you shined on.

For a perfect diffuse reflector, the relation between luminance L (nit=cd/m^2=lm/steradian/m^2 surface) and incident illuminance I (lux=lm/m^2) is

$$L\ (\text{nit}) = I\ (\text{lux}) \frac{\cos(\theta)}{\pi}$$

Note the cos(θ) goes away if you use projected surface area, luminance is then lumen per steradian per projected m^2. A perfect white reflector illuminated with 1 lux has 0.34 nit luminance; conversely, a surface with 1 nit luminance is equivalent to a perfect diffuser illuminated by 3.14 lux.

A test using the Tektronix J17 illuminance and luminance heads with a piece of white paper under office fluorescent illumination showed the following: illuminance=535 nit, luminance=119 nit giving a ratio of 4.5 rather than the ideal 3.14. This can probably be attributed to imperfect non-Lambertian paper reflectance.

Relation between scene illumination and image illumination

Say we measure a certain scene luminance or illuminance. What is the imager illumination? This relation is geometrical and is shown in Fig. 1. Suppose 1 lux illuminates a 1 m^2 white diffuse reflector, imaged through aperture *f*. 1 lumen reflected is spread into hemisphere of 2π steradian, lens intercepts fraction of it, and concentrates it into smaller area. The formula relating imager illuminance L_{chip} (lux) to object illuminance L_{scene} (lux), for perfect diffuse (white) reflectance, small magnification (objects a lot more distant that focal length) and no lens absorption, is computed in Eq 1 from Fig. 1, resulting in the following useful expression

$$L_{\text{chip}} = \frac{L_{\text{scene}}}{8f^2}$$

The implication of this result is that chip illumination is much smaller than scene illumination: Remember you must also include scene reflectance (averaging to 18 %=Kodak gray). For an f/1.4 lens which is already a fast lens, a gray scene will only illuminate the chip with about 1/5/8/2=1/80 of the scene illumination! The computation of the above relation is shown in Fig. 1 and Eq 1.

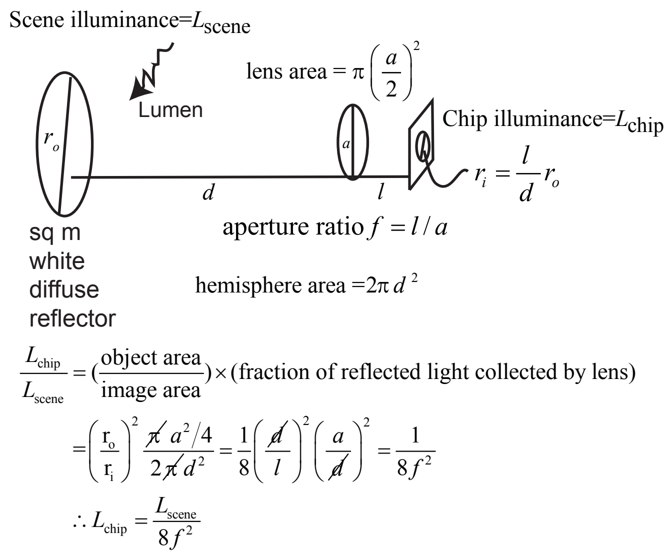

Fig 1. Computation of this formula: L_{chip}= lux on chip =(lm on chip)/(chip area illuminated)=(lux on scene)*(scene area)*(fraction caught by lens)*(chip area).

$$\begin{aligned}
\frac{L_{\text{chip}}}{L_{\text{scene}}} &= (\frac{\text{object area}}{\text{image area}}) \times (\text{fraction of reflected light collected by lens}) \\
&= \left(\frac{r_o}{r_i}\right)^2 \frac{\pi a^2/4}{2\pi d^2} = \frac{1}{8}\left(\frac{d}{l}\right)^2 \left(\frac{a}{d}\right)^2 = \frac{1}{8f^2} \qquad (1) \\
\therefore L_{\text{chip}} &= \frac{L_{\text{scene}}}{8f^2}
\end{aligned}$$