Understanding ambient and flash exposure

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A camera's sensor records an exposure by measuring ambient and (optionally) flash light. Each pixel on the sensor records an intensity I by adding contributions from the constant ambient light I_a and the quick bursts of light from flashes $i = 1, \ldots, n$:

$$I = I_a + \sum_{i=1}^{n} I_i$$

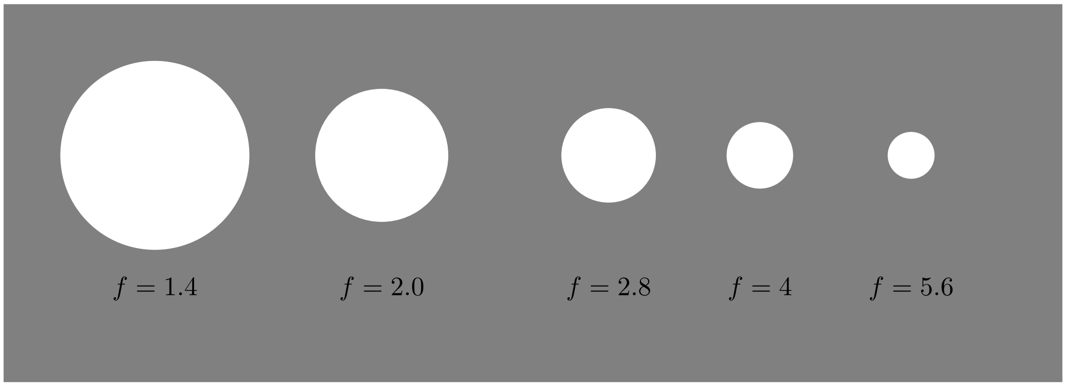
In this paper we first look at how camera and flash settings affect the exposure and, then, how a given setting can be changed to achieve a certain effect, for instance changing the contribution from the flash without having to adjust the flash setting.

1 Preliminaries

There are five variables that a photographer can use to change the exposure:

- The *aperture* f signifies the size of the lens opening with the traditional convention that a larger opening is denoted by a smaller number so that, for instance, an aperture of 2.8 lets in twice as much light as an aperture of 4.0 (see fig. 1). A so called *stop* is the change in aperture from f to $\sqrt{2}f$ (stopping down) or to $f/\sqrt{2}$ (opening up). Stopping down leads to half as much light hitting the sensor.

  Aperture affects the *depth of field*, i.e., how much of the scene is in focus: stopping down (making f larger) increases the range of distances that are in focus.



Figur 1: Decreasing aperture sizes, one stop difference between each setting.

- The *shutter speed* (or exposure time) s is simply the amount of time the sensor is recording light. Modern cameras allow s to be as small as $1/8000$ of a second[1].

- The *sensitivity* of the sensor is denoted *iso* and typically take on values $100, 200, \ldots$ in such a way that each pixel site on the sensor is twice as sensitive at, say, $iso = 200$ than at $iso = 100$.

- The *flash power* p is also measured in stops. In this paper we shall use the convention that $p = 1$ is full flash power, $p = 1/2$ is a stop less, i.e., half as much light, etc.

- The final variable d is the *flash-to-subject distance*. The intensity of the flash drops with the square of the distance so that when doubling the distance between the flash and the subject, only a quarter of the amount of light will reach the subject, a 2-stop difference.

  Photographers have two good reasons for placing the flash at a certain distance from the subject. First, light modifiers such as an umbrellas are used to make the light "softer" because a seemingly large light source

[1]Without going into technical details, we should also mention a special value for s which is the smallest amount of time that the entire sensor is exposed to light. This is called *X-sync speed*. If the X-sync speed is, say, 1/300th of a second and $s < 1/300$, the sensor is partially covered by shutters during the whole exposure. These shutters can be seen as dark bands in the final image if a flash impulse occurs during the exposure.

doesn't produce such harsh shadows. How soft the light is corresponds directly to the solid angle of the light, i.e., how large the light source appears to the subject. When moving the flash further away from the subject, the solid angle is less and so the light appears harder. (This is why the sunlight is considered hard: although the sun is an incredibly large light source, it is also millions of miles away and only occupies a small part of the sky.)

Another implication of the inverse square law is *light falloff*: the closer the flash is to the subject the faster the light will decrease (fall off) across the subject.

2 Ambient light

The ambient intensity is dictated by three of the camera variables,

$$I_a = I_a(f, s, \mathit{iso})$$

where f is the *aperture*, s is the *shutter speed* and iso is the sensor's *sensitivity*, as described above.

Photographers are used to certain equalities in exposure, for instance

$$I_a(f, s, \mathit{iso}) = \begin{cases} I_a(\sqrt{2}f, 2s, \mathit{iso}) & \text{stopping down, slower shutter speed} \\ I_a(f/\sqrt{2}, s/2, \mathit{iso}) & \text{opening up, with faster shutter speed} \\ I_a(\sqrt{2}f, s, 2 \cdot \mathit{iso}) & \text{stopping down, with more noise} \\ I_a(f, s/2, 2 \cdot \mathit{iso}) & \text{faster shutter speed, with more noise} \end{cases}$$

These equalities can be used for various effects: for instance, depth of field (how much of the image is in focus) is proportional to f. An image may suffer from motion blur if s is too large and noise (grain) will be greater at higher ISO's. As a rule of thumb, photographers like to keep only the interesting subjects in focus, have a fast enough shutter speed to avoid motion blur while keeping the ISO to a minimum to avoid excessive noise.

Example: A camera setting of $f = 2.8$, $s = 1/200$ and $\mathit{iso} = 200$ is equivalent to, for example, $f = 4.0$, $s = 1/100$ and $\mathit{iso} = 200$ *or* $f = 4.0$, $s = 1/200$ and $\mathit{iso} = 400$.

3 Flash light

Because the duration of a camera flash's light pulse is so fast, typically a millisecond, the camera's shutter speed does not normally affect the contribution from the flash to the overall intensity:

$$I_i = I_i(f, iso, p, d)$$

As described previously, p is the flash power setting and d is the flash-to-subject distance.