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Digital Photography

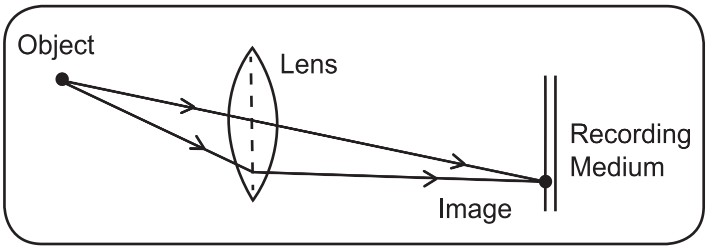
All cameras have three main parts to their construction:

a) An optical system
b) A control system
c) An image recording medium.

a) The optical system

The purpose of the optical system is to create an image and focus it onto the film or digital sensors. A simple system could be just one convex lens:

Figure 1



This system is basically identical for both a film camera and a digital camera. More complex systems may include mirrors or prisms as part of the focusing and control systems. A simple lens on its own would only focus objects at a fixed distance. By moving the lens back and forth, it is possible to focus objects which are at different distances.

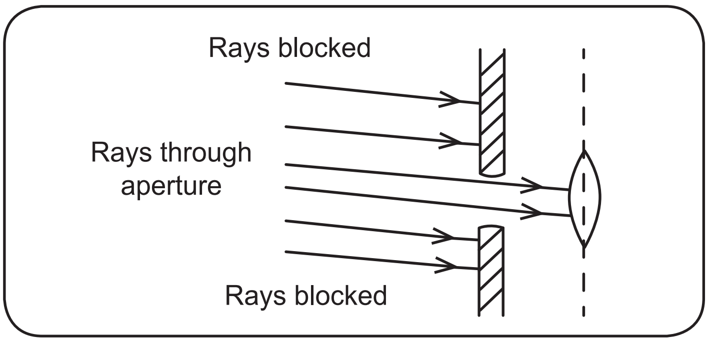
b) The control system

Again, both film and digital cameras must have a method of controlling the amount of light reaching the film or image sensor. Too much light and the image will be overexposed (and perhaps blurred for a moving object). Too little light and the image will be underexposed. Linked to this is something called *dynamic range* (which will be discussed later).

There are two ways of controlling the amount of light reaching the sensors or film. There is an *aperture*. This restricts the size of the opening at the lens. And there is a *shutter*. This controls the length of time that the light is allowed to reach the sensors or film.

The aperture:

Figure 2



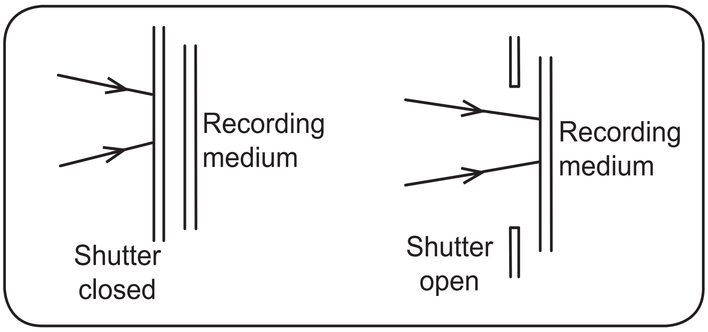
It is best to have the aperture as small as possible. This increases the *depth of focus* of the camera. Objects at slightly different distances can be focused without moving the lens. A smaller aperture also reduces the amount of aberration (distortion) of the image. This is partly due to different wavelengths of light (different colours) travelling at slightly different velocities through glass, thus refracting slightly differently.

However, a smaller aperture reduces the amount of light entering the camera – this may be unacceptable, especially in low light situations.

The aperture is mechanical in all cameras. The same is not true for the shutter.

The shutter:

Figure 3



The shutter allows the incoming light rays to reach the recording medium for only a set amount of time. Obviously, the shutter and aperture work together to achieve the ideal amount of light reaching the medium.

If the aperture opening is increased, the time that the shutter is open must be reduced to allow the same quantity of light through. This increases depth of focus and reduces distortion (as mentioned), but it may cause other problems. Increasing the opening time of the shutter will increase the amount of blurring when photographing a moving object. It may also introduce blurring of a stationary object if the camera is held unsteadily.

A shorter opening time (often called increased shutter speed) is needed to reduce blurring. But this may require the aperture opening to be increased, introducing the problems mentioned above.

Photography in bright conditions is ideal, if it is possible. A greater intensity of light entering the camera means the aperture size can be reduced and the shutter speed increased.

> ***Example:*** *How would doubling the diameter of the aperture affect the shutter speed, if the same amount of light is to reach the recording medium?*
> ***Answer:*** *Doubling diameter causes the area to increase by a factor of four. This means the shutter speed is increased to four times its previous value (or the shutter is open for only one-quarter of its previous time).*

More on the shutter:

So far, we have concentrated on aspects that are the same for a film camera and a digital camera: however the shutter may well be different, depending on the camera.

A film camera must have a mechanical shutter. If it is not set up for flash, there is no need to have any electronics in it at all.

A digital camera may have a mechanical shutter: however, the shutter can also be electronic. In this case, there is not really any shutter at all. When the button is pressed, three things happen:

a) The light sensors are "wiped" - all data is removed from all the sensors.
b) The light rays are then allowed to fall on the sensors for a set amount of time.
c) The sensors are "frozen" - they no longer react to the incoming light and the data on them is recorded.

Some higher quality digital cameras will use a mechanical shutter for longer exposure times: however, they will switch to an electronic shutter for short exposure times (high shutter speeds).

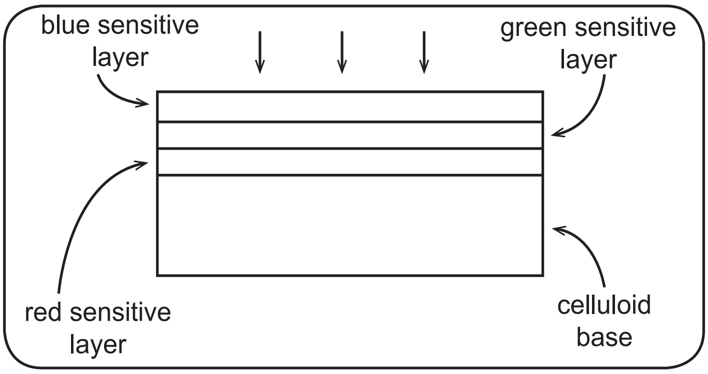
> ***Example:*** *Why would you possibly want to use both mechanical and electronic shutters in a camera?*
> ***Answer:*** *Using the mechanical shutter means that steps (a) and (c) above are unnecessary. Some photographers think that this is preferable: however, as technology has improved, more and more quality cameras these days have only electronic shutters. They do make a sound like a mechanical shutter opening and closing – this is either to let you know the camera has functioned, or just for nostalgia.*
> *Certainly, the electronic shutter is the only one that can be used for very high-speed photography. It is also preferable in shooting video, especially at high speed to produce ultra-slow-motion clips.*

c) The image recording medium

i) Film photography

Film cameras use a chemical process to record the intensity of the light forming the image. To record colours, different chemicals are used. Each chemical is chosen to respond to a different colour.

Figure 4



As the layers lie on top of each other, this is a subtractive process:

- The red-sensitive layer forms a cyan coloured dye
- The green-sensitive layer forms a magenta coloured dye
- The blue-sensitive layer forms a yellow coloured dye.

When the film is processed to produce a negative, the final colour is formed by a subtractive process, with the top layers acting like filters. The negative is then used to produce a print (the final photograph). Thus, the negative colours look a little weird, but the final photograph is correct.

There are obvious weaknesses to using film.

> ***Example:*** *Suggest weaknesses of using film for photography.*
> ***Answer:*** *A few possible weaknesses are:*
> - *Film is expensive*
> - *Film cannot be reused and takes time to process.*
> - *For videos, you end up with a reel that must be played through a projector.*

Another problem with film is that there is a graininess to the photographs due to silver halide particles forming in the film. These are not noticeable with standard size photographs, but if the photograph is enlarged, a graininess in the sharpness of the photo emerges. This graininess sometimes resembles tiny flecks in the picture. This limits the *resolution* of the film. We will see that there is a similar problem with digital photography, again affecting the resolution of the photography.

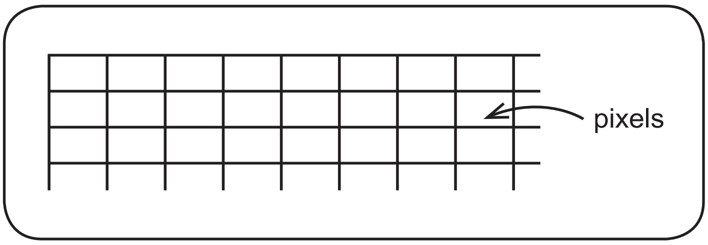
Film is being used less and less in photography. Let us look now at how digital images are formed and stored.

ii) Digital photography

An image in a digital camera is formed by millions of light sensors combined to form the whole image sensor. These light sensors can be of two sorts – CCD (charge coupled device) or CMOS (complementary metal oxide semiconductor). Without going into any detail, CMOS sensors are becoming more and more widely used, and are likely to be found on the highest quality digital cameras these days.

Each light sensor gives an output voltage depending on the amount of light falling on it during the exposure time. This voltage is stored as a binary number. Thus, the whole of the image really consists of a very long binary number. This number is used to create the image on an LED screen. The image is formed as an array of tiny squares or spots known as *pixels*.

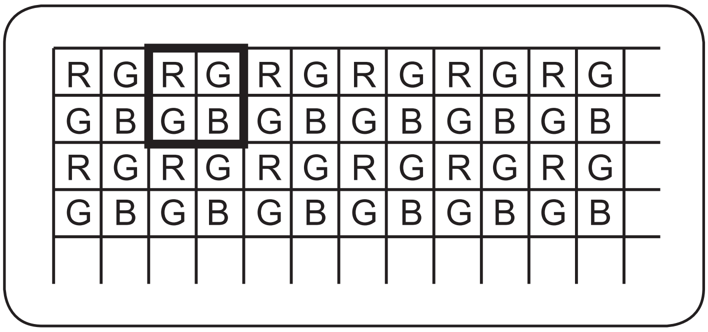
Figure 5



Normally these pixels are so small that we cannot distinguish them individually. The photo looks like a continuous image. We will discuss this further in a moment.

Almost all photographs these days are colour. However, each light sensor only responds to the total intensity of the light falling onto it. On their own, the light sensors could only produce a monochrome image. To solve this problem a colour filter array called a *Bayer filter* is used, permanently positioned over the light sensors. The Bayer filter is composed of blocks of four red, green and blue filters as shown.

Figure 6



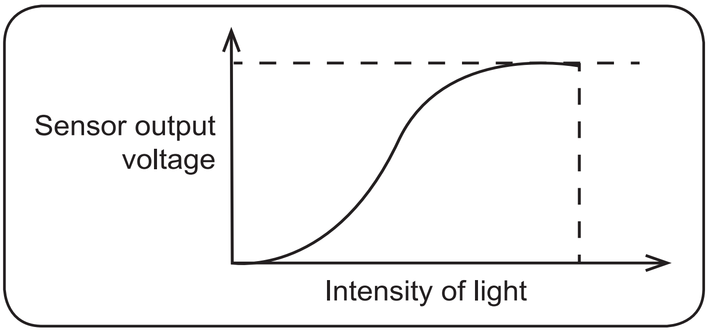
Notice that in each block there are 2 green filters, but only 1 red and 1 blue filter, causing the final image to be biased towards the green part of the spectrum: however, our eyes are more sensitive to green light than to red or blue light, so the final image is seen as more "true-to-life" by our eyes.

Dynamic range

This is an important property of the light sensors and depends largely on their quality (affecting the cost of the camera, of course).

Poor quality sensors will give almost no output for low light levels and then will give maximum output (saturation) at reasonably high light levels. Parts of the image tend to be underexposed or overexposed. This graph shows how a poor-quality camera will respond.

Figure 7



We can see that there is very little difference in output for a range of lower light levels, and again very little difference in output for a range of higher light levels. A good-quality camera should give a much more linear graph. The sensors should be able to respond differently for a range of low light levels, and for a range of high light levels.

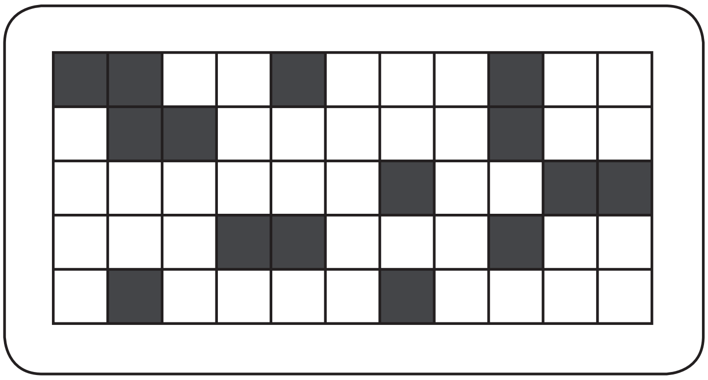
How many pixels?

Nowadays cameras advertise 20 megapixels, or even more, for their final image. But how many pixels do we actually need? One megapixel is fine for printing photographs. Less than this is completely adequate for a picture on a website. Why do we need more?

We've used the term *resolution* before. It refers to the amount of detail that is visible without any deterioration in the sharpness of the image. It is when an image is enlarged that the number of pixels becomes critical. If a photo is enlarged, or used to produce a poster, then as many pixels as possible are needed to form the final image.

If an image from a camera with a limited number of pixels is enlarged, then the image begins to break up into individual pixels. The limit of resolution has been reached (compare this to graininess in film cameras).

Figure 8



Often an image in the camera is enlarged using the "zoom" function. Film cameras use *optical zoom*, where the lenses are moved back and forth leading to a magnified image. The resolution of the image will not be affected.

But digital cameras also have *digital zoom*. This uses the electronics to enlarge the central part of the image by spreading out the pixels. This obviously affects the resolution. Optical zoom is always preferable. Digital zoom should be used only when the maximum optical zoom available has already been set.

Storage

As mentioned, a digital photograph is really just a string of binary numbers. Thousands of images can be stored on a memory card. Even more can be stored by compressing the images using different techniques, e.g. JPEG, TIFF, etc. These use clever methods of combining pixels to reduce the file size: however, this does lead to a certain amount of loss of resolution.

One important choice that must be made is the *bit depth* that is used for the sensors. More bits mean a larger file size. Fewer bits reduce the variation in intensity recorded for each pixel (lowering the picture quality). Considering just a black-and-white image:

A 2-bit depth system would contain 4 choices as follows, (0,0)(0,1)(1,0)(1,1); so a 2-bit photo would contain 4 possible choices, black, dark grey, light grey, and white for each pixel.

A 3-bit depth system would contain 8 possible choices, ranging from (0,0,0)(0,0,1)(0,1,0) right up to (1,1,1), giving a wider range of shades of grey. But it would increase the file size, reducing the number of photos that could be stored on the memory card.

Questions

1) It is still possible to look at photographs from a film camera which are over a hundred years old. Will the same be true for digital images in a hundred years?
2) A 4-megapixel camera can produce a decent print of size 40 cm by 50 cm. What would the area covered by each pixel be on this print? And what would the distance across each pixel be in mm?
3) How would increasing the number of pixels from 4 megapixels to 20 megapixels affect the resolution of an image?
4) With a set number of pixels, would there be higher resolution working in black-and-white rather than colour?
5) If a 4-bit depth system was used, how many shades of grey could be recorded?

Answers

1) Perhaps. But techniques change so fast that things become obsolete very quickly. Many people have music on vinyl or on cassette tapes, but no turntable or cassette player. And you could store digital information, including music or pictures, on a minidisc. Who has a minidisc player these days? The file formats such as JPEG will almost certainly be replaced in the future. Will the technology in a century still be able to cope with today's formats or today's media?
2) The area of the print is 2000 square cm, or 0.20 square metres. If this is divided by 4 megapixels, the area of each pixel is 5.0×10^{-8} square metres. Or the distance across each pixel is about 0.2mm. Our eyes would struggle to resolve this into individual pixels.
3) With the 4-megapixel camera (as compared to a 20-megapixel camera), each pixel would have to cover 5 times the area. The distance across each pixel would then be about 2.2 times as great. Thus the 20-megapixel camera would have over double the resolution.
4) You should do. With colour 4 light sensors are required to produce the information at one spot on the image.
5) Fourteen. Plus black and white, of course.

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