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Anatomy of a Digital Camera

June 12, 2001
By: Sally Wiener Grotta

Introduction

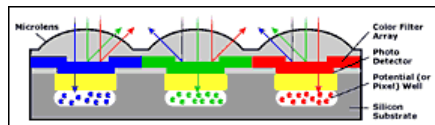
On the surface, most digital cameras and film cameras look like identical twins. Point the lens at your subject, press the shutter button, and you have captured an image that ultimately produces a photograph. But under the skin, digital camera technology is much more complicated and convoluted than film technology.

What's more, while film has improved and matured over the past 160+ years, digital capture is almost in its infancy, having been around in labs and studios a couple of decades, and becoming practical consumer products only within the past 7-8 years. Yes, digital cameras have experienced a remarkable, accelerated whirlwind of developments and growth in that time. But there remains considerable room for performance, interface, and image quality improvement, as well as plenty of nooks and crannies in these digital devices that are prime targets for new technological breakthroughs.

We're probably at the point in digital camera technology that to compare it to another 20th century technology--automobiles--we're just beginning to get into serious chrome, fins and dual headlights. In other words, digital capture capabilities have been proven, and the basics are well established, but we're still going through a somewhat gaudy growing period.

While future digital camera progress probably will tend to be evolutionary refinements rather than revolutionary inventions, the field is beginning to become very interesting. Most trend watchers and technology prognosticators predict that digital photography will become, in an astonishingly short time, as ubiquitous and commonplace as mass transportation, high-speed interstate highways, and other modern miracles.

Until recently, the primary purpose of a digital camera was to imitate and emulate the film experience. But just as movies could do and show so much more than a live theatrical play, digital camera capabilities have gone far beyond film. Their intended use isn't just to produce static hardcopy prints and transparencies, but to be active visual communications devices. Within minutes (or even seconds!) of recording a digital image, a photographer can print a picture locally, use it in a presentation, share it on the Web, and transmit it over the telephone (even wirelessly).



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Eventually, all these activities will be easily accomplished without ever using a computer, because more intelligence and functionality will be built into the camera itself. It's already happening with direct, wireless and IrDA connections to desktop printers, cellular phones and wireless networks. For instance, the HP PhotoSmart 912 digital camera has an infrared interface that, with the push of a single, dedicated button on its back, can transmit pre-defined print jobs (that are set up using the playback menu on the camera's LCD interface) to specific HP photo printers, as well as to other similarly equipped cameras.

Direct FTP, Web Browsing and More

The soon-to-be-released Ricoh RDC i700 uses a pen-based, PDA-like control panel that offers automatic uploads of images to the Web--with FTP direct upload via the camera's built-in modem. It allows users to transmit still and video images, as well as text and audio. It does this by incorporating them within a prepared HTML template.

In addition, the i700 accommodates Type II peripherals, such as an additional modem, LAN, or ATA card. The i700 even has its own built-in Web browser. Similarly, the Polaroid PDC-640M has a built-in 56.6k modem for connection to a phone line and a direct uplink to Polaroid's photo sharing site.

This year, a number of manufacturers have introduced inexpensive digital cameras (such as the Kodak mc3 and Samsung's Digimax 35 MP) that double as MP3 downloaders and players. In addition, many current models can capture brief, low-resolution movie clips--video and audio--that can be played back in the camera itself, shown on any TV, or uploaded and broadcast on the Web. At present, no cameras have been announced to support Bluetooth or other advanced wireless protocols; however, we can be certain that such technologies will be integrated with digital cameras in the future.



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Single-purpose digital cameras that simply take still pictures aren't going to be exactly passé, but they will become increasing less attention grabbing and appealing to consumers who want more multi-functional bang for their buck.

A Basic View Of Cameras

As digital cameras become more advanced and sophisticated, they will also become increasingly complex--lots of technology crammed into smaller and smaller boxes. Tiny wristwatch--and credit card-sized digital cameras, such as the Casio WQV1-1CR and SmaL's Ultra Pocket, are available today, but tie-tack and cufflink-sized digital cameras are already on the drawing boards and well within the realm of possibility.

How small, and in which strange or even bizarre configurations digital cameras will be available, is only a matter of time, ingenuity, and what the market will bear.

Here we will be exploring how digital camera components work, and what the future may produce in terms of new technologies and designs. But first, let's briefly look under the skin at the data flow, or image processing stream, of electronic photography, to better understand current state-of-the-art digital cameras.

Film Photography Basics

In a conventional film camera, light from a scene or subject is reflected and passed through a transparent glass or plastic lens, which focuses and directs it onto a thin, flexible sheet of plastic ("film") coated with a photo-sensitive silver halide emulsion. Light (photons) impacting on film causes an instantaneous chemical reaction, which, when later immersed into a series of chemical baths, develops and stabilizes the resulting image. It is the differences among the photons of a scene (color and intensity) that cause the film chemistry to capture and duplicate the scene almost identically.

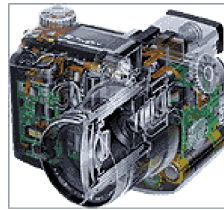
The only light-regulating devices employed by a traditional film camera are the shutter (metal or cloth curtains or blades that rapidly open and close to control the length of time that the film is exposed to the light) and the aperture (a mechanical iris or hole that regulates the amount of light allowed to pass through the lens). Both these variables are established and set by the photographer before the picture is taken, though they may not be activated until the instant the shutter button is pressed. The aperture (or f-stop) used to be set manually, by turning a collar on the lens barrel, which, in turn, physically adjusts the iris-like opening inside the lens itself through which light will travel. Of course, in this day and age, most film cameras have some sort of built-in intelligence (both analog and digital) that automatically measures and precisely regulates exposure, as well as shutter speed.

Reduced to its bare essentials, state-of-the-art film-based photography is, for all intents and purposes, a simple chemical and mechanical process that is much the same as it was when invented in the 1830s by pioneers like Daguerre and Fox-Talbot.

Digital Photography Basics

In digital cameras, there are more, and more complex steps involved in image capture. But like film photography, the principles and basic elements probably will remain the same for many years to come, no matter how advanced the technology eventually becomes.

Digital cameras also use a lens, but instead of focusing an image onto film, it directs photons of light onto photosensitive cells of a semiconductor chip, called an image sensor. The image sensor's reactions to the photons are analyzed by the camera's built-in intelligence, to determine the proper settings for correct exposure, focus, color (white balance), flash, etc. Then, the picture is captured by the image sensor, which feeds it to an ADC (Analog to Digital Converter) chip, which analyzes the electrical charges and converts them to digital data.



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Using still more intelligence (a digital camera can contain several processors and other chips, including application-specific processors--ASICs--and a master CPU), the data is analyzed according to internal, brand and model-specific programming ("algorithms") and reassembled into a file that can be recognized and read as a visual image. This image file is saved to some sort of built-in or external electronic memory system. After this point, the image file can be downloaded to a computer, output to a printer, or displayed on a television set. Or it may be internally accessed, or sub-sampled, to be viewed on the camera's own LCD viewfinder, where the user has the option to apply still more algorithms to it, using the onboard operating system interface (accessed, usually, on the LCD), or to trash (delete) it and start over again.

Throughout this multi-step process, the camera's intelligence continuously polls the operating system, to be able to instantly execute and integrate the photographer's settings (which he/she inputs using the numerous dials, buttons, switches, LCD and control panel). It's a complex system, with lots of data and instructions moving over numerous paths--all jammed into a small, lightweight battery-powered box that you can hold in the palm of your hand.

The above describes just the bare bones outline of the digital image capture process. It is the details that distinguish different digital cameras. So, let's look more closely at each step of this process in a typical digital camera. (Exceptions to the basic design will be covered in future installments, as we look more deeply at each component of the digital camera system.)

How Many Pixels, How Many Sensors?

Image Sensors

Up until now, almost all marketing attention has been on how many pixels (how big and detailed a picture) a digital camera can capture. That issue is related to the physical size and density of the image sensors--the CCD (Charge-Coupled Device) or CMOS (Complementary Metal Oxide Semiconductor) chips that are the heart of digital cameras. Image sensors are silicon chips that have numerous photosensitive areas (or photosites) constructed with photodiodes and arranged in arrays within the CCD or CMOS chip structures. The photosites are referred to as pixels. The pixels react to the light striking them, creating electrical charges proportional to the incident light.

The number of pixels that are concentrated on the image sensor is measured

either as an x/y axis formula, such as 640x480 (which represents the number of pixels in the width and height of a sensor), or as a total number, such as 1,000,000 pixels (which is commonly expressed as 1 megapixel or 1MP). By the way, a pixel (which stands for "picture element") is the smallest complete piece of picture data that can be measured, captured or displayed, which is why the same word is used in descriptions of monitors and scanners.

Manufacturers sometimes give two different numbers when listing technical specifications for a CMOS or CCD. The first number always lists the total number of pixels on the entire sensor, such as 3,340,000 pixels or 2.11MP. The second figure is the number of active pixels, or, those pixels actually used to capture the subject. The difference between them is usually less than 5%.

There are several reasons for this discrepancy. Some are so-called dark pixels, or, defective, inactive pixels inevitably created during the manufacturing process (Creating a 100% perfect image sensor is virtually impossible, using current sensor fabrication technology.) In addition, portions of the sensor can be used for other purposes, such as to calibrate the signals read from the sensor. By masking a small number of pixels at the edges so they are not exposed to light, the background dark current (or noise) generated by the pixels can be determined, and this noise can be subtracted from the actual image data. Also, portions of the sensor may be masked to create images with a specific aspect ratio. (That's the proportion of horizontal to vertical dimensions.)

Incidentally, increases in image sensor size are logarithmic, not linear. Going from a 3MP to 4MP sensor doesn't increase image size 25%, but by a smaller increment. That's why the newer digital cameras with higher density image sensors offer only evolutionary, incremental image size boosts, which may or may not be of importance to the user.



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Presently, all consumer digital cameras employ a single CCD or CMOS sensor. Some high-end professional digital cameras, as well as many better camcorders, use multiple sensors, with the incoming light equally divided among them via an optical beamsplitter (prism). Multiple sensors can eliminate color aliasing, or the tendency for edges of red, blue, and green to separate in an image. However, multiple sensor cameras require greater precision to build, and because of the beamsplitter, they tend to be bulkier and less rugged. They also require advanced optics and more precise manufacturing processes, so the overall cost (not to mention the greater engineering challenge) is typically more than a single sensor camera.

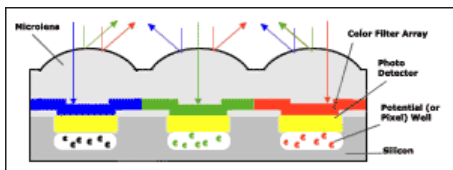
Interestingly, multiple sensor devices do not always follow simple linear mathematics. In the standard scenario (which most multiple sensor camcorders follow), there are three separate red, green and blue CCD or CMOS full resolution sensors, which contribute 1/3rd of the color information for each pixel. That means, for instance, in a 3MP three-sensor camcorder, each of the sensors will be a 3MP sensor. However, in still digital cameras, how the information from multiple sensors is used varies with each manufacturer, and in fact, with each model.

Some three-sensor cameras will use sensors that each have 1/3rd the resolution of the full picture, and use interpolation. But other multiple sensor cameras may use combinations of the primary colors on each sensor, and develop complicated algorithms for combining them. For instance, the now discontinued Minolta RD-175 had three CCDs, two of which were green, and the third, which was red and blue. (This doubling of the green is similar to the Bayer pattern color filter array for single sensor devices that is described below.) Each of the RD-175's sensors contained less than 1/2 MP, but through mathematics, they were combined to create a rather good quality 1.7 MP image.

In many digital cameras, only a portion of the pixel is photosensitive, so it is important to direct as much light as possible to the area that can capture it (a phenomenon called "fill factor"). For this purpose, most consumer image sensors have a "microlens" directly over each pixel to direct the photons down into the photosensitive "well" of the pixel. The photons are actually converted to electrons by a silicon photodiode positioned on top of the well, and the well behaves like a capacitor, capable of storing an electrical charge.

Digital Capture Of Your Image

Because image sensors are inherently grayscale devices and have no color to them, sensors used in digital cameras typically employ a color filter array (CFA), wedged between the microlens and the pixel well. The CFA is constructed to assign a single color to each pixel. Digital camera manufacturers choose among a variety of CFA architectures, usually based on different combinations of primary colors (red, green, blue) or complementary colors (cyan, magenta, yellow). Whatever type of CFA is used, the idea behind all of them is to transfer only the color of interest, so each pixel sees only one color wavelength. All CFAs also attempt to reduce color artifacts and interference between neighboring pixels, while helping with accurate color reproductions. (Below, we explain how later in the data stream, the camera's image processors reassemble the image from all these individual bits of colors.)



[click on image for full view](#)

One of the most popular and ubiquitous CFAs is called the Bayer Pattern, which places red, green and

blue filters over the pixels, in a checkerboard pattern that has twice the number of green squares as red or blue. The theory behind the Bayer Pattern is that the human eye is more sensitive to wavelengths of light in the green region than wavelengths representing red and blue. Therefore, doubling up the number of green pixels is supposed to provide greater perceived luminance and more natural color representation for the human eye (this is similar to the weighting assigned to the green color component of a composite video luminance signal where Luminance (Y)=0.59G +0.30R +0.11B).

It also produces what appear to be sharper images. The science of perceived color versus scientifically measured color is a complex issue that has generated numerous solutions. And different manufacturers subscribe to various color models and algorithms for defining what they consider to be the best color for digital cameras.

All digital cameras have the electronic equivalent of a shutter (it's not a traditional film-based mechanical shutter) built into the image sensor. Its purpose is to regulate the precise length of time that light strikes the image sensor. The electronic shutter is an on/off switch that closes off (or allows access to) the image sensor to the incoming photon stream. Some digital cameras also incorporate a more expensive mechanical shutter, not for redundancy, but to prevent additional light from hitting the image sensor after the initial exposure is completed. This helps eliminate after-exposure artifacts like ghosting, streaking or fogging (known in the industry as "smear").

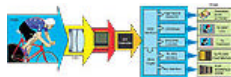
When you press a digital camera shutter button halfway, its focus and exposure are frozen, in anticipation of an imminent image capture. Those are exactly the same steps that occur when you press the shutter button halfway on a typical point-and-shoot film camera. What happens next, however, is radically different from a film camera. When the shutter button is pressed fully on a digital camera, a number of events, or sequences, occur almost simultaneously.

1. The first event is the mechanical shutter closes (if the digital camera has one) and the sensor is instantly flushed of any electrical charge. That is because the image sensor is always active, allowing electrical charges to continuously fill up the sampling points. (On some better digital cameras, the image sensor might be in a sleep state immediately prior to image capture, to help reduce heat and improve the signal-to-noise ratio.). If no instructions are received, the image sensor will also continuously flush those same electrical charges about every 1/60th of a second. Therefore, before the image sensor can be ready to capture your picture, all residual electrical charges must be flushed.

Interestingly, some digital cameras (such as the Olympus Camedia E-100RS) will hold the most recently flushed data in a temporary memory buffer, and can display it to you after you shoot, in case you prefer it to the scene you composed and captured. This ESP-like pre-shoot capture mode is great for capturing kids or animals that tend to blink or move every time they hear the click of a camera.

2. Whether the camera throws away the pre-shoot electrical charge or puts it into a temporary memory buffer for possible selection by the photographer, one of the camera's several processors makes use of the data to adjust and set the parameters for the photo you are about to take. For instance, the camera's processor that controls white balance may use those values to try to determine what pixels in the current image should be white. And it may try to adjust the overall colors to remove any hue shift from that "white point." Similarly, the controls for focus, flash and other pre-shoot determinations are set or activated, based upon the electronic charges flushed out of the image sensor immediately before the picture is taken. These parameters are also held in a buffer, so that they may be used later in the image-processing phase. If the LCD viewfinder is being used to compose the picture, it will also receive this image data.
3. Once all electrical charge has been flushed from the sensor and the shooting parameters set, the image sensor is ready to accept the image that you told the camera you wanted to capture, when you pressed the "shutter" button. So, the camera opens the mechanical shutter and activates the electronic shutter; both remain open or active according to the exposure time determined earlier, with the mechanical shutter closing at the end of the exposure.
4. The shutter then opens again while the camera is recycling, and will close only when the photographer presses the shutter button and starts the flushing process for preparing to take another picture. If the processor (or the photographer) had decided to trigger an electronic flash for the scene (usually the digital camera's built-in strobelight), it will illuminate the scene until a separate light sensor decides that the flash has produced enough lumens for that specific exposure and turns it off.

Note: Olympus envisions the digital capture process to take the following graphic form:



click on image for full view

Because of the time it takes for the image sensor flush, as well as to read and set the shooting controls, there is always a brief, unavoidable, but often annoying delay, or lag, between when you fully press the shutter button and when the picture is actually taken. In a typical consumer digital camera, this delay can take anywhere from 60 milliseconds (that's so fast that it is virtually instantaneous) to as long as 1½ seconds.

Integrating larger memory buffers and faster processors can reduce shutter lag, which is why most expensive digital cameras tend to shoot faster than most budget devices. Among more expensive, professional cameras, the new Nikon DH1 has a 128MB buffer, and some cameras, like Kodak's DCS

520, 620, and the Fuji S1, have 64MB buffers. There are only a handful of prosumer and higher end consumer cameras with buffers as large as 16 MB or 32MB.

In addition, some image sensors (most specifically CMOS) are multi-functional chips that have intelligence built into them, which helps reduce the time involved in transmitting and using information captured by the sensor. Like any other digital systems, digital cameras will operate faster when their internal bandwidth is improved.

On Becoming Digital

Backing up a bit in the process, when the image sensor converts incident photons to electrons, it is dealing with analog data at this stage. The next step is to move the stored electrical charges out of the sensor's pixels and convert them to a stream of voltages via a built-in output amplifier, and then send the stream of voltages to an external or on-chip analog to digital converter (ADC).

One of the major differences between CMOS and CCD image sensors is that CMOS can have the ADC on the sensor, while the CCD must use an external ADC chip. CMOS image sensors in particular are inherently noisy and benefit from integrated ADCs. The ADC converts the various voltage levels to binary digital data. The digital data is further processed and ultimately organized according to color bit depth for the red, green, and blue channels, reflecting the color and intensity (or shade) associated with a specific pixel.

Nomenclature Primer

Unfortunately, digital camera bit-depth nomenclature is inherently confusing. To understand it, we have to look at the basics of digital color. All colors in a digital camera are created by combining the light or signals of the three primary colors--red, green, and blue. These three primary colors are also called channels.

Bit depth of color may be stated for each of the three channels (as in 10-bit, 12-bit, etc), or for the entire spectrum by multiplying the channel value by three (30-bit, 36-bit, etc.). However, the conventions of bit-depth nomenclature sometimes go beyond logic, and you just have to know certain things. For instance, 24-bit color (which is sometimes also called True Color, because it is the closest the digital world can get to the number of colors the human eye can perceive) is defined as 8 bits per channel.

But 24-bit color is never called 8-bit color. When you hear someone talking about 8-bit color, it does not relate to 8 bits per channel, but to 8-bits for the entire spectrum, or a total of 256 different colors, which is a very limited spectrum indeed. In contrast, 24-bit color offers 16.7 million different colors. One way to remember the naming convention is to think of 24-bit color as a dividing line. Any bit depth over 24-bit can be named either according to the per channel or the full spectrum numbers. From 24-bit depth and less, you'll seldom hear of anyone using anything other than the full spectrum bit depth.

Until last autumn, almost all consumer digital cameras were 24-bit color devices (using 8-bit ADCs). There are now some models, like the Olympus E-10 and HP PhotoSmart 912, that can generate 30 or 36-bit color data (10 or 12-bit ADCs). However, some digital cameras capable of capturing a higher bit depth have an 8-bit ADC, which means that they can save only 24-bit color. (A few cameras, like the Canon PowerShot G1, can save a RAW 36-bit image, but it is a proprietary file format that cannot be read directly by any imaging program. While Photoshop can read up to 16-bits per channel, most of its functions are not available for such files. Canon's upload software first must convert the data into a TIFF file that Photoshop can use. What's more, most output devices usually are unable to use all that data.)

So why capture all that bit depth if it is impossible or difficult to save or use it? The greater the bit depth, the more details or tonal ranges you'll capture, especially in the shadows and highlights. Once the camera (or its upload software) has all this data, it can analyze all the bits, and when it converts the image down to 24-bit, it will attempt to retain the most critical image data.

So why capture all that bit depth if it is impossible or difficult to save or use it?

If the algorithms are programmed well, the result will be more tonal ranges and detail in the highlights and shadows than what you'll get from a simple 24-bit capture and save. Higher color bit depths, derived from higher quality and higher bit-capture and ADC, is one of the things that separates professional digital cameras from consumer and prosumer digital cameras, in addition to the professional devices' better optics, advanced features, etc. It is also one of the reasons that an under \$1,000 digital camera that has a higher resolution image sensor than a \$10,000 camera probably still won't generate as high quality an image as the more expensive models.

Image Processing, The Differentiator

The ADC passes the digital data stream to a DSP (Digital Signal Processor) chip or chips--the exact configuration varies from camera to camera. In the DSP, the many points of data are assembled into an actual image, based on a set of built-in instructions. Such instructions include mapping the image sensor data and identifying the color and grayscale value of each pixel. In a single sensor camera using a color filter array, demosaicing algorithms are used to derive color data per pixel.

Think of the color filter array's checkerboard of color pixels as a mosaic, or a tiled representation of a captured picture, made up of only three or four primary or complementary colors. Out of that handful of colors, all other hues can be created. Demosaicing algorithms analyze neighboring pixel color values to determine the resulting color value for a particular pixel, thus delivering a full resolution image that appears as if each pixel's color value was derived from 3 physical sensors (if RGB colors are used). Thus, the assembled image exhibits natural gradations and realistic color relationships.

In addition, the DSP defines the image resolution. While most digital cameras can be set to create various resolution images, most of them will capture all the data that their respective image sensors can deliver. For instance, when shooting in the VGA mode with a 3 megapixel digital camera, instead of capturing only

a 640x480 image, the camera will shoot and capture a full 2048x1548. Then, the DSP will sample down or interpolate up to the resolution that the photographer selected in the operating system (on the LCD or control panel) or by pushing a button when the shot was first set up.

However, some image sensors (usually CMOS) can selectively turn off pixels rather than down-sampling or interpolating-up, thereby setting lower or higher resolutions at the time of the initial capture. CMOS sensors have this ability, because they are direct access devices similar to RAM, and they can quickly select the desired data by fast row/column access. That's in opposition to CCDs, which are serial output devices, in which all data must be delivered, and the processor must then do its sampling/interpolating process. Obviously, a CMOS chip that captures only the amount of data that is wanted can speed up processing times.

In the same region of the image-processing stream where the data is converted to an image with a specified resolution, each manufacturer applies its "secret sauce"--the algorithms that are brand specific. In other words, DSPs add image enhancements based on the manufacturer's image characterization. Thus the image processing performed by every camera is unique, and incorporates its own color balance and saturation settings to produce what the manufacturer feels are ideal pictures.

Some tend to make pictures warmer (pinkish), while others go for cooler (bluer) color. Some set the default saturation level to high, producing bouncy, bright colors. Others choose a neutral, more realistic saturation, for greater subtlety and color accuracy. (Which color or saturation predilections a manufacturer chooses to incorporate in a specific digital camera model is based upon that company's interpretation of what kinds of colors and skintones their typical buyer would prefer. Such choices are not made arbitrarily--often, they are major corporate design decisions.)



Color Contrast Example: Blueish Tone



Color Contrast Example: Warmer (Pink)

In addition, using either one or several DSPs, working with other on-board intelligence, the camera combines its knowledge of the settings used to shoot the picture with its analysis of the type of image it appears to be. (Does the picture have lots of blue that could be sky, or a block of beige that might be skin?) Preferences and feature options that the photographer preset in the camera's operating system interface will also be referenced and used. If a camera has a tendency to produce unwanted noise, or if its electronic shutter tends to create fogging, an algorithm will be defined by the camera manufacturer to make the appropriate corrections.

Similarly, sharpness or softness is applied, a preprogrammed white balance used, etc. It is here, in the image processing stage, that you'll find the greatest differences among various digital cameras produced by different companies.

Saving The Image File--The Media

Once an image emerges from the DSP or DSPs, a processor converts and organizes the simple data stream into an image file--usually in JPEG, TIFF or RAW format. Metadata related to how and when the image was captured (f-stop, shutter speed, white balance, exposure compensation, flash setting, time/date stamp, etc.) is usually attached to the digital file. Unless it is in RAW or TIFF format, the file is compressed according to the photographer's selected choice (usually high, medium, or low compression) and the camera's intelligence. The camera's compression algorithms try to balance file size and processing speed with maximum image quality. Then, the image is saved either within the camera's internal built-in memory (usually on inexpensive digital cameras), or to a removable memory card or device (found on most digital cameras).

The advantage of using removable memory is that you can swap out the memory card or device when it is full, and replace it with a fresh one. This allows you to keep shooting, without taking the time to upload all the pictures to your computer and then erase the memory. In addition, removable memory gives the user the flexibility of upgrading to higher storage capacities.



SmartMedia card

The most common types of removable memory are CompactFlash (CF) and SmartMedia (SM) cards. Generally, the type memory card you use is determined by the brand and model of your digital camera. For instance, most Toshiba, Fuji, and Olympus cameras use SmartMedia, while most Kodak, Nikon, Canon and Hewlett-Packard models save to CompactFlash. However, the lines between the two are blurring, since some Olympus and Canon models come with slots that accommodate both types of cards.

There are numerous differences between CF and SM cards. SmartMedia cards are smaller, thinner, and less expensive to produce. But they are made of thin plastic and their gold contacts are exposed, which makes them more prone to damage or destruction (such as by static electricity). CompactFlash cards are thicker and more robust, and incorporate built-in intelligence. That, plus the ability to add on-board memory buffering, expedites read/write times. In addition, CF cards can be produced in higher densities--at present, the highest SM card available is 128MB, while SanDisk just released a 512MB CF card. A relatively new, slightly thicker CF card, called Type II, can pack in yet more solid state memory, and even house a tiny hard drive; IBM's Type II MicroDrive is available in densities up to 1GB. But the downside of CF cards is that they are considerably thicker than SM cards, requiring more space in the digital camera design.



CompactFlash card



Sony Memory Stick

Other kinds of memory cards include Sony's Memory Stick, MultiMedia (MM), and Secure Digital (SD). In addition to solid-state memory cards, there are a variety of miniature drives used for specific camera models. These include, but are not limited to such devices as the 730MB magneto-optical drive on the new Sanyo IDC-1000Z, the 156MB CD-R of the Sony Mavica CD1000 and a similar 3" 156MB CD-RW disc on the Sony Mavica CD200 and CD300, high density 120MM floppies on the Panasonic PVD-SD5000, and the 40MB Clik! disk on the Agfa ePhoto CL30 Clik! camera. Presently, these storage solutions tend to be proprietary technologies, since they work mostly on specific brands and models. Whether they will

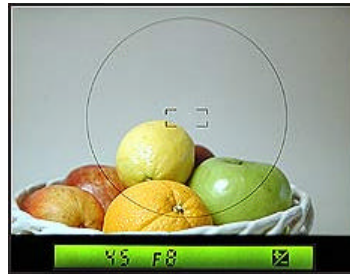
become more ubiquitous remains to be seen.

Viewfinders

At the same time that the image is processed and saved to memory, it also may be displayed on the LCD viewfinder or electronic eye-level viewfinder. Most LCD viewfinders are 1.8" or 2" TFT color panels consisting of between 65,000 and 220,000 pixels, with a refresh rate between 1/8th and 1/30th of a second. They are designed to be viewed at an optimum distance of 8" to 18".

It is almost always preferable to use your camera's eyelevel viewfinder for composing your images, and use the LCD primarily for setting parameters and then viewing the captured image. Even when using high-resolution LCD viewfinders, digital cameras sample the image so you don't see a direct 1-to-1 resolution on the viewfinder. Therefore, they cannot be easily used for detailed focusing or framing. Worse yet, LCDs are voracious power consumers and can quickly drain a set of batteries if used heavily. Another major disadvantage is that because of their proximity to the CCD or CMOS image sensor, in a typical camera design, LCDs can produce noise that translates into unwanted visual artifacts. (That's one of the major benefits of the articulated LCD viewfinders that swivel away from the camera body, such as on the Canon G1. It moves the LCD, and its potential to generate noise on the sensor, even further from the sensor.)

Most digital cameras incorporate one of three types of traditional eyelevel viewfinders: a clear glass frame, a beamsplitter, or a swinging mirror. In a beamsplitter viewfinder (also called a pellicle mirror), 90% of the light passes through a stationary angled mirror to the sensor, and 10% is redirected at a 90-degree angle up through a pentaprism to the photographer's eye. The advantage of this system is that the mirror does not move, eliminating vibration, and with no moving parts, it is inherently more reliable. But its primary disadvantage--a fatal flaw when shooting indoors and low light environments--is that so little light passes to the photographer's eye that the subject may be too dark for proper composition and focus.



Fuji S1 Viewfinder

Most single lens reflex film cameras and professional digital cameras incorporate a swinging mirror that reflects 100% of the light to the photographer's eye during image composition. When the shutter button is pressed, the mirror instantly swings out of the way, temporarily blacking out the viewfinder but sending 100% of the light to the film or image sensor. Then the mirror instantly swings back, so the photographer can continue to view the subject. At faster shutter speeds, the period that the mirror is blacked out to the photographer is, literally, less time than it takes to blink. It's mechanically complex and more prone to breakdown, but much preferred over a beamsplitter system for better viewing.

A much less expensive and less complicated eyelevel viewing solution is the ubiquitous optical glass viewfinder, which is used in most consumer digital cameras. It's made of clear glass, and rather than showing exactly what the lens sees (through-the-lens, or TTL viewing), it sights along the top or side of the lens. Its advantages are that it uses no power, has no moving parts, and is brighter than any TTL system. However, it tends to be very inaccurate (it generally shows much less than is actually captured, so you can end up with unwanted material along the edges of your picture), and introduces parallax.

Parallax occurs because the viewfinder is positioned 1" or 2" away from your lens, and therefore you are viewing the scene at a slightly different angle than the lens. This doesn't matter when you are shooting far-away scenes, but as you get closer, the difference in angle between what you see and what is actually captured increases. When shooting macros (12" or closer to your subject), glass viewfinders are virtually useless because the parallax error is so great.

The electronic eyelevel viewfinder is a newer technology that replaces the optical viewfinder with a tiny, low-powered, high-resolution color monitor that you view by holding the camera up to your eye. In addition to direct, detailed viewing that can clearly show whether a subject is in focus or not, most electronic viewfinders also display important data about the photographer's settings--f-stop, shutter speed, flash status, etc. The major disadvantage is that this technology, while popular in camcorders, is relatively new and primitive in still digital cameras and, therefore, may not always be as bright, clear or responsive as a traditional optical viewfinder.

As with an LCD viewfinder, an electronic eye-level viewfinder also can display a lower resolution version of the saved image, which has been sub-sampled by a processor. Or, it may be an electronic thumbnail from the TIFF or JPEG file header. As the technology improves, we expect electronic eyelevel viewfinders will also replace LCD viewfinders in many models.

A Busy Electronic Factory

Besides the chain of activities we described above, quite a bit of background processing is constantly going on in a digital camera. A master CPU controls everything, while other processors and application-

specific integrated circuits (ASICs) may be checking and processing various system functions and states. For instance, the operating system must be continuously surveyed, to check the photographer's settings, so they can be applied at the appropriate time and occasion. The battery status needs to be constantly queried, to make certain there's enough power to continue and complete an entire image capture, process, and save cycle without interruption. Continual component check-ups confirm everything is working correctly, and so forth. Even in the simplest point-and-shoot digital cameras, nothing is simple.

The number of processors, DSPs, ASICs and other chips varies widely among digital camera brands and models. However, one increasingly popular trend is to consolidate as many functions as possible onto fewer chips, to save cost and space in the design.

All this on-board processing requires lots of electrical power. In previous years, when we tested digital cameras, we needed to stock up with scores of AA alkalines. This is because digital camera power drain was so significant that it was necessary to change batteries after taking relatively few pictures. The current generation of digital cameras has improved, both in electrical efficiency and in their ability to better utilize battery power. Many digital cameras have abandoned alkalines for more efficient and advanced battery technologies, such as rechargeable nickel metal hydride or lithium-ion batteries. And a handful of manufacturers, like Sony, have developed "smart" batteries for their digital cameras that inform the user, to the minute, precisely how much power is left (To learn more about Battery technology, please read ["Batteries: History Present and Future of Battery Technology"](#)).

As cameras become more sophisticated, with more components and greater speed requirements, power consumption and efficiency will continue to be an important area for future developments.

Digital Camera Quality... Much More than Just Pixels

It is important to understand that digital cameras are true systems, in which the picture is a result of a sum of the parts and how well they function together. No one component alone determines image quality or speed or efficiency, though a single bottleneck in the process can throw the whole system off and negatively impact on overall image quality.

In early digital cameras, the most significant limiting factor was the comparatively poor quality and tiny size of the image sensors (about the size of a pea, back then). Camera manufacturers realized that fine, high-quality lenses would be wasted if used in such cameras given that their image sensors were not able to capture high quality images. So, the first consumer digital cameras used small, plastic lenses with relatively poor optical quality.

On the other hand, current high-quality, 3+ megapixel-class image sensors have finally reached a rough parity with film--it's now the rest of the system that has to play quality catch up. This is particularly true of digital camera lenses, which are continuing to be redesigned and improved so they carry more light, transmit color better, offer better corner-to-corner resolution, and focus and direct the light head-on so that every pixel on the image sensor is activated. Similarly, it's becoming incumbent upon all other digital camera components to produce greater quality, speed, efficiency and so forth, in the rush to keep up with rapid image sensor developments.



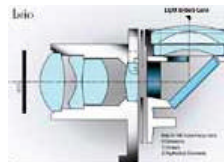
click on image for full view

The Crystal Ball

Over the next year, and well into the future, there will undoubtedly be significant advances in digital camera technology. Image sensors will improve and expand to higher densities (the first 5 megapixel consumer cameras are scheduled to hit the market this summer). They will require smaller and more tightly packed pixels, as well as a physically larger form factor. The smaller the pixels become, the more the demand will be for precise delivery of photons through the lens and micro-lens systems. The more tightly pixels are packed together, the greater need to control or correct noise, as well as develop other image enhancement algorithms.

At the same time that sensor densities increase, everything else probably will become smaller and more compact, so that the cameras themselves can be miniaturized. At present, smaller cameras are technological compromises that must do without some functionality in order to fit into such a compact size. But as chips are consolidated for multiple functions and the various technologies become more efficient, future miniaturized cameras will have full functionality.

Another approach to miniaturization will involve radical re-engineering of the camera itself. For example, the new Olympus Brio D-100 is unusually slim for a digital camera. The only way they could fit in the optics and all the components into such a skinny package was to position the CCD at 90 degrees to the lens, using a mirror system in between the lens elements to angle the light. It's a simple, though optically revolutionary idea that involved some significant new designs.



click on image for full view

Conversely, larger, pro-like cameras will continue to invade the consumer price range. At the lower end of the market, less expensive, low-resolution cameras will come into their own. Despite their relatively low resolutions, basic image quality could equal or even surpass some current high-resolution devices. (Remember, the number of pixels is only one aspect of digital capture, and image quality is a synthesis of the entire process.)

Each succeeding generation of digital cameras will exhibit more intelligence than ever, as they edge towards true multifunction devices. Convergence will become the catchword, as digital cameras, digital video camcorders, voice recorders, videoconferencing cameras, PDAs, and cellular telephones begin to blur into single devices. So, we'll see even greater ingenuity applied in image processing and camera engineering to counter noise and other problems inherent in jamming so much electronics into such a small space. And, of course, the prices will come down, while quality and performance will rise. It will be

an exciting time for digital photographers...which means for all of us.

In our next installment, "[Anatomy of a Digital Camera: Image Sensors](#)", we will delve more deeply into how image sensors work, and explore the differences among CCDs, CMOS chips, and developing types of image sensors.

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