Photography: photofilm to digital sensor

R. N. Misra

Photography has seen a vast change during the last one hundred years. The old chemical process of image registration has given way to digital sensors. The transformation has been slow, but in firm steps. The digital SLR camera embodies union of digital sensor and the camera. The entry of mobile phones with built-in cameras has revolutionized the whole concept of photography. Here we look into the historical aspects and recent developments in photography.

Photography has enjoyed the place of pride as a hobby, profession as well as part of supportive scientific instrumentation. Till the last century, photography was essentially based on chemical process. Silver halide suspension in gelatin, spread over a glass plate, plastic sheet or film served as the photosensitive surface. The camera lens forms an image of the object on the photofilm; silver ions are released in proportion to the light falling on the surface, thus forming a latent image on the photosensitive surface. In the next step, called development, the photochemical reaction initiated by the photons is carried forward by reducing chemicals like metol and hydroquinone in basic aqueous solution. The bright regions of the image would get dark and shadows would show up as light in shade, resulting in an impression on the photofilm as the negative image. In the next step, unreacted photosensitive material is dissolved in a fixer bath containing sodium thiosulphate, to stop the effect of light on the film. To get the positive image, the above process is repeated using negative image to expose another photosensitive surface.

Colour photography involves the use of three photosensitive layers separated by cyan, yellow and blue or magenta filters to generate colour negative. Final positive is printed by a similar process on a colour photosensitive paper. Introduced in 1935, colour photography was fairly complex and required careful processing. It was not very popular till 1970, due to high cost.

Since the features recorded on the photosensitive surface depend upon the grain size of the emulsion, large glass plates and photofilms were used for group photographs. Film rolls were introduced to facilitate multiple exposures in succession. The rolls of 70 mm perforated film and also of 5¼ inch width were used for aerospace photography. The 60 mm wide rolls of 750 mm length with black paper backing, available as 120 and 620 films were popular for general use. Wide use of perforated photofilms of 35 mm width in cinematography, paved the way for use of 35 mm film for still camera. This could provide a frame size of 24 × 36 mm, which became the de facto standard. With a diagonal of 45 mm and a lens of focal length of about 50 mm, it could provide a perspective as seen by the human eye.

Photography over three centuries

Evolution of photography can be considered to have commenced in the beginning of the 18th century. Photography can be visualized as two separate branches, the camera and the photosensitive surface. Tables 1 and 2 give the year of introduction of some of the landmark products. The year 2000 saw the dawn of the digital era, where these two branches merged together. The photosensitive surface consisting of silver halide has given way to solid-state digital sensor, which in turn has become an integral part of the camera.

Photographic objectives

Design of photographic objectives is centred on the prevalent photofilm size. Early lenses for 120 size film were of meniscus type with front aperture field stop. The better camera used multi-lens designs having arrangement for movement of lens to facilitate focusing. Variable focal length or zoom lenses were developed, which required movement of the lenses. Zoom lenses are now standard in all point and shoot cameras.

Rangefinders and SLR

A simple wire frame can serve as a viewfinder to select the required part of the scene on the photofilm, but addition of a split mirror in the optical rangefinder can facilitate the focusing process. The twin lens reflex (TLR) was the next refinement of camera, which used two lenses of equal focal length, one for taking photographs and the other to focus the scene on the viewfinder. The lenses were coupled to move together. In case of single lens reflex, or SLR camera, a single lens is used for viewing as well as taking photographs. A focal plane shutter made of flexible material is used just in front of the film. A mirror tilted at an angle 45° from the horizontal plane diverts incoming light rays to form an image on the viewfinder. Focusing is affected by moving the lens to and fro, and optical aids are provided for focusing. While taking photographs, the mirror flips up to close the viewfinder light path and allow the image to be formed on the film. Now the shutter opens to achieve the desired exposure and completes this phase. After completion of exposure, the mirror reverts to its original orientation.

Exposure and related issues

The amount of light reaching the photosensitive surface would decide the signal magnitude, represented by darkness in the photofilm or electrons collected in the photosites in case of solid-state sensor. The fast films were more sensitive to light compared to slow films, but had more graininess. On the other hand, slow films had less graininess and, therefore, could record more details in image compared to high-speed films. A measure of film speed was the ASA number, a linear representation. A photofilm of 200 ASA would be two times faster than the one having 100 ASA rating. German standard DIN is logarithmic, and 100 ASA corresponds to 21 DIN and 400 ASA to 27 DIN. An unified standard was introduced in the 1980s and was designated as ISO,

Table 1. Landmarks in photography: camera

Year	Camera	Inventor/manufacturer
1814	First photographic image using *camera obscura*	Joseph Niepce
1888	Kodak roll-film camera	Eastman Kodak
1900	Brownie, first mass-marketed camera	Kodak
1925	35 mm Still camera	Leica
1948	Polaroid camera	Edwin Land
1973	SX-70 camera for instant photography	Polaroid
1978	First point-and-shoot autofocus camera	Konica
1984	First digital electronic still camera	Canon
1999	VP-210, first mobile phone with built-in camera	Kyocera Corporation

Table 2. Landmarks in photography: photosensitive materials and processes

Year	Process	Inventor/manufacturer
1727	Darkening of silver nitrate upon exposure to light	Johann Heinrich Schulze
1837	Daguerreotype, silver-coated copper plate, 30 min light exposure	Louis Daguerre
1839	Fixer sodium thiosulphate, 'hypo', glass-negative	John Herschel
1841	First negative–positive process 'calotype'	William Henry Talbot
1851	Collodion process, light exposure of few seconds	Frederick Scott Archer
1884	Flexible, paper-based photographic film	George Eastman
1898	Celluloid photographic film	Reverend Hannibal Goodwin
1901	120 film format	Eastman Kodak
1909	35 mm acetate base 'safety' motion-picture film	Eastman Kodak
1935	Kodachrome reversal film	Eastman Kodak
1941	Kodacolor negative film	Eastman Kodak
1942	Electric photography (xerography)	Chester Carlson
1954	High-speed Tri-X film	Eastman Kodak
1963	Instant colour film	Polaroid
1973	First large image-forming 100 × 100 pixel CCD	Fairchild Semiconductor

where numbers are identical to ASA, except that DIN is also indicated, e.g. ISO 100/21. The term 'exposure value' (EV) is a combination of camera shutter speed and lens aperture (*f* number). A value of +1 for EV would indicate exposure one stop more than the current aperture, or with double the shutter time with the same aperture.

Digital camera

Arrival of the digital camera, about 15 years ago, has dramatically changed the scenario. Solid-state sensors were developed during early 1970s and charge coupled device (CCD) sensors came into existence in 1973. These were followed by complementary metal oxide semiconductor (CMOS) sensors which are less precise but economical, and therefore much in use for general photography. The digital sensor depends on the charge storage principle and size of the potential well would determine how many electrons it can hold. The process is essentially linear and range of sensitivity of the sensor depends on full well capacity and minimum number of electrons which could be detected. Assigned ISO ratings would correspond to the gain setting of the charge amplifier and in the high gain condition, less number of electrons need to be collected in a particular exposure time to give full-scale signal, and thus ISO value is increased. Noise is amplified as well and signal generated at high ISO value will show graininess akin to the high-speed films.

Concept of depth of focus and depth of field in a camera

The photographic film was used to record the image and a positive print was made from the negative for actual presentation. In any camera, point objects would not form a point image, but a circle of finite size called blur circle, and it has to be small enough so as not to affect the quality of image. A print of 200 × 250 mm size is considered adequate for seeing from a distance of 250 mm. In such a situation, the human eye can normally resolve details of the order of 0.25 mm on the print. The original negative for 35 mm film is of 24 × 36 mm size, and thus an enlargement of about eight times is called for. Thus the details in the image recorded on the film should be about 0.030 mm or 30 μm. Therefore, a blur circle of 30 μm, or 1/1000 of the focal length of the lens, whichever is larger is considered acceptable.

Hyperfocal distance

The hyperfocal distance *H* is defined as the distance at which the blur is still tolerable within the definition of blur circle. Thus, for a lens focused on an object at infinity, *H* is defined as the distance beyond which all the objects up to infinity seem to be in reasonable focus. The blur extends in both positive as well as negative directions from the focus. Thus the objects beyond infinity would also be in focus! Thus, if the camera is focused at hyperfocal distance *H*, then all the objects from half of this distance to infinity would be in adequate focus. That is what is provided in a fixed focus camera.

Compact point and shoot camera

Development in photography has centred around point-and-shoot compact camera. The CMOS sensors are of small size and lenses are specially designed for small image format. Zoom lenses are almost invariably used along with autofocus facility. The image being captured is seen on the LCD screen provided in the camera. These cameras are declining in popularity on account of availability of built-in cameras on mobile phones, which are improving day by day.

Digital SLR camera and mirror-less camera

The digital SLR (DSLR) is a adaptation of the SLR mechanism with solid-state sensor. Sensitivity of a large sensor is better than that of a smaller one. The film camera used 24 × 36 mm format for SLR, but the DSLR may use smaller formats. The optical performance factors are somewhat different and need to be taken care of while taking photographs with DSLR. The image is continuously taken by the solid-state sensor and displayed on the LCD screen. Since the mirror was already part of the old film-based SLR, it remained in the DSLR having solid-state sensors, without any role to play. The new logical direction is the mirror-less camera with reduced size and mechanical complexity of mirror mechanism.

Sensor size and image resolution in digital camera

As mentioned earlier, photofilm-based cameras employed large image formats, and accordingly, lenses of such cameras had large focal lengths. Adaptation of solid-state sensor in photofilm camera bodies resulted in a different perspective of image, due to small sensor size. The fine details recorded on the sensor depend upon pixel size and diameter of the objective lens. The usual pixel size is about 1.5 μm. Objective lens of focal length f and diameter D would form point image at wavelength λ, having radius of $1.22\ \lambda(f/D)$. The lenses used in mobile cameras have an aperture of about $f/2$, and the smallest feature which this lens can resolve in green light of 0.55 μm wavelength will be 2.68 μm.

Mobile phone camera

As the solid-state sensor is small in size, it is possible to implement full camera function in a small module. A sensor size of 5 mm implies that the total camera module could be accommodated in a cube of 6 mm side, with electrical contacts provided at the bottom. Initial adjustment for focus is provided by threads in the lens mount. This module can be easily accommodated in a mobile phone, which has ample processing power to spare for camera operation and image handling. Reduction in the size of optics for the small sensor brings altogether different design requirements for the optics. For a mobile phone camera, 6 mm lens used along with a sensor size of 8.80×6.60 mm would result in about 3280 and 2460 points resolved in the H and V directions. Therefore, 8 megapixels is all the resolution which could be useful. In actual practice, 2–3 times the pixel count improves the picture so the sensor may at best be useful at around 24 megapixels.

Focusing issues in mobile phone camera

For the mobile phone camera, hyperfocal distance could be about 1 m. Thus if the lens is focused at 1 m, objects could be in focus from 0.5 m to infinity. Therefore, focusing for the average mobile phone camera is not critical and fixed lenses are used for cameras below 5 megapixels. Advantage of focusing becomes apparent above this value. Required movement of lens is of the order of 0.1 mm, which is readily achieved by means of voice coil motor. Focusing is done by movement of the lens in feedback loop with sensing of spatial frequencies present in the output signal. A negative aspect in this type of motor is that a fixed current needs to flow continuously through the voice coil to hold it in the required position. Current drawn by focusing coil and flash adds to the difficult power situation in case of a smartphone.

Satellite photography

In 1946, cameras were used on V-2 rockets to take photographs of the earth. Satellite missions have always included a camera as standard equipment to keep record of the activity and environment. Examples are historical manned space flights of the 1960s, and landing of man on the Moon in 1969. Early space flights depended upon bulky film camera, which needed chemical processing after recovery at ground. In contrast, all modern spaceborne cameras are based on digital sensors with facility to record radiations in several visible as well as infrared wavelengths. A linear sensor array, similar to those used in document scanners, can be successfully utilized in cameras mounted on spinning satellites, where the second dimension is added by spin. As the satellite moves in the forward direction, the sensor array captures images of new regions. Array sensors, like the ones used in consumer cameras and mobile phones, are also used in the case of stabilized satellites. Images of other celestial objects can also be acquired for astronomical studies. The satellite imagery, taken from earth observation satellites, orbiting the earth in polar sun-synchronous orbit, has immense value for resource studies. The high-resolution cameras can resolve details to the tune of a metre at ground and even better. These can provide data to government agencies for decision making and remedial measures in adverse climate events.

Conclusion

The developments in the field of photography are driven by user preferences as well as advances in optical material, solid-state device technology and precision mechanics. Advances in mobile phones also play a role in this field.

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R. N. Misra lives at No. 7, Mahavir Nagar, Vastrapur, Ahmedabad 380 015, India.
e-mail: rn07_misra@yahoo.com

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