WHAT is a photograph? Well, a photograph is basically the recording of the differing intensities of the light wave reflected by the object and imaged by a lens. But information about the dimensions of the object is contained not only in intensity (square of amplitude) but also in the phase of the light wave.

In fact, the phase attributes of the wave are necessary for our eyes to see depth. An ordinary photograph records only the intensity attributes of the wave; it loses the phase completely. That is the reason why an ordinary
photograph gives a two dimensional (2-D) image. We have all grown accustomed to seeing the three-dimensional (3-D) world compressed into the flatness of a 2-D image in which the depth of the field is completely missing.

Strictly speaking, a normal photograph contains only one viewpoint of an object whereas in order to see depth our eyes need a minimum of two viewpoints. Each eye then records a slightly different viewpoint of an object. Our brain combines or blends the two and, thus, we are able to see depth. Such kind of vision using two viewpoints of an object is called stereoscopic vision.

However, the shortcoming of stereoscopic images is that when we move our head from side to side or up and down, we still only see the same two viewpoints whereas we should be seeing continuously changing viewpoints of the object. As a result, the image does not quite appear to be three-dimensional. In fact, to make a record of a three-dimensional (3-D) object, we need to record the continuous set of viewpoints of the object. This is done by using the principle of holography—a lensless technology of 3-D imaging.

**History of Holography**

The technique of holography was developed by the British physicist

Recent development of atomic mirrors (especially ridged mirrors) has provided the tools necessary for the creation of atomic holograms.

Unlike a photograph, a hologram is quite unintelligible and gives no idea about the image embedded in it. But, it contains information not only about the amplitude but also about the phase of the object wave.
“Skull and Rocks” by the artist holographer John Kaufman

Although Gabor showed the applicability of the holographic technique to light waves by using a mercury discharge lamp, the real development in (optical) holography began only after T.H. Maiman invented (ruby) laser in 1960. In 1962, Emmett N. Leith and Juris Upatnieks, working in the Radar Laboratory of the University of Michigan, USA used the off-axis technique, borrowed from their work in the development of side–reading radar to develop the first “transmission hologram” of 3-D objects (toy train and bird). The off-axis technique was a modification of the original in-line technique employed by Gabor using the mercury discharge lamp that produced both the virtual and real images on the same axis.

The difficulty with Gabor’s technique was that an observer focusing on one image always saw it accompanied by the out-of-focus twin image. This difficulty is overcome in the off-axis technique where the virtual and real images are angularly separate from each other and from the direct beam too. The off-axis technique developed by Leith and Upatnieks is still regarded as the staple of the holographic methodology.

The year 1962 also saw another development by Yuri Nikolayevich Denisyuk of Russia who introduced a scheme for generating holograms that was conceptually similar to the earlier colour photographic process of 1908 Nobel laureate Gabriel Lippmann. Denisyuk succeeded in producing a white–light reflection hologram, which, for the first time, could be viewed in light from an ordinary incandescent light bulb.

Another significant development in holography took place in 1969 when Stephen A. Benton of Palaroid Research Laboratories, Massachusetts, USA succeeded in creating white light holograms that could be viewed in ordinary white light. These holograms show all the seven colours constituting white light and are called “rainbow” or Benton holograms.

Benton’s invention was indeed a breakthrough in the field of holography because it made mass production of holograms possible using an embossing technique. This involves ‘printing’ the hologram by stamping the interference pattern onto plastic, which can be duplicated millions of times at a very nominal cost.

Benton’s technology attracted artists worldwide who adapted this to their work and in this way brought holography into public awareness. Benton’s holograms are used on credit cards, magazines and other commercial products to prevent forgery. Also, these embossed holograms are now being extensively used by the publishing, advertising and banking industries.

In 1972, Lloyd Cross developed a technique that combined white light transmission holography with conventional cinematography. In this way he was able to develop integral holograms, called “integrags”. Looking through a transparent cylindrical drum, the three-dimensional images can be seen in motion. Such holograms describing motion find applications especially in science fiction movies.

The year 2008 saw another technological breakthrough in the field of holography. Under the leadership of Tay Peyghambiar, optical scientists at the University of Arizona College Of Optical Sciences, working in collaboration with Nitto Denko Technical Corporation, Oceanside, California, USA, succeeded in making 3-D holographic displays that could be erased and re-written in a matter of minutes. Their device consisted of a special plastic film sandwiched between two pieces of glass each coated with a transparent electrode. In this device, the images are ‘written’ with the aid of laser beams and an externally applied electric field into the light sensitive plastic called ‘photorefractive’ polymer. The holographic displays in the new technique are capable of showing a new image every few minutes.

**Principle of Holography**

Holography is actually a two-step process that involves recording of the hologram and reconstruction of the image from the hologram. For recording the hologram, a highly coherent laser beam is divided by a beam splitter into two beams. One of these beams, known as the reference beam, hits the photographic plate...
Holograms are often used as a plot device in science fiction movies. In Total Recall, the main character uses a device similar to a wristwatch to produce a hologram of himself to deceive his foes. Star Trek: Voyager, introduced the bizarre concept of Emergency Medical Hologram (EMH) doctor. In a recent highly popular science fiction movie Avatar, holographic displays were used extensively on terminals and HUDs.

directly. The other beam illuminates the object whose hologram is to be recorded. This gets reflected by the object. The reflected beam, called the object beam, falls on the photographic plate. The object beam and the reference beam are made to mix with each other to form the interference pattern on the photographic plate. The resulting interference pattern forms the hologram.

However, unlike a photograph, a hologram is quite unintelligible and gives no idea about the image embedded in it. But, it contains information not only about the amplitude but also about the phase of the object wave. It has, therefore, all the information about the object.

For viewing the image, the hologram is illuminated with another beam, called the read-out or reconstruction beam. In most cases, this beam is identical with the reference beam used during the formation of hologram. This process is termed as reconstruction.

The interference pattern (in the developed photographic plate) or hologram acts as a diffraction grating (a structure with a repeating pattern e.g. a metal plate with slits cut at regular intervals). The waves diffracted through the hologram carry the amplitudes and phases of the waves originally diffracted from the object during the formation of the hologram.

In this way the reconstructed image is obtained.

To get a high quality hologram, light beam of high coherence is needed. Generally, the helium-neon gas laser, which gives highly coherent and continuous output beam, is used for this purpose. Sometimes, high power pulses from a laser like ruby laser are also used. The holograms are recorded on special photographic plates, which are of very high resolution and record very fine interference fringes. The plate is developed and fixed (processed) in the usual way.

There is a kind of magic about the hologram, which is often called a window with a memory. With naked eye, it does not give any picture of the object. The viewer is able to see only the interference pattern on the surface. However, when the hologram is positioned in its holder and viewed in a monochromatic light beam, such as that produced by laser, the random patterns are transformed into a sharp and detailed three-dimensional image of the object. The image looks like a solid object hanging in space.

Applications of Holography
Holography finds application in many diverse fields.

Data Storage: An important application of holography is in the field of information or data storage. The ability to store large amounts of information in some kind of media is of great importance as many electronic products incorporate storage devices. The advantage of holographic data storage is that the entire volume of recording media is used instead of just the surface. In 2005, holographic versatile disk (HVD), a 120 mm disk that used a holographic layer to store data, was produced by some companies. This had the potential of storing 3.9 TB (terabyte) data. Further developments in the field are going on and it is expected that holographic data storage would become the next generation of popular storage media.

Security: Another major application of holography is in the coding of information for security purposes and in preventing counterfeiting. Such holograms, called security holograms, are replicated from a master hologram that requires very expensive, specialized and technologically advanced equipment, such as electron-beam lithography system. This kind of technique allows creation of surface holograms with a resolution of up to 0.1 micrometre.

The security holograms are widely used in many currency notes. Security holograms in multiple-colour are created with several layers. They are used in the form of stickers on credit and bankcards, books, DVDs, mobile phone batteries, sports equipments, branded merchandise etc.

Cryptography: Holographic methods may also be used in cryptography for secret communication of information. This is done by recording the holograms of secret documents, maps and objects. The images can be reconstructed at the receiver end.

Holographic Microscopy: Holographic microscopy is yet another potential application of holography. A conventional microscope has a small depth of field (the range of depth over which an object is in focus at any microscopic setting). Biological specimen, generally suspended in a fluid, move about making them sometimes in and sometimes out of focus of the microscope. However, this motion can be “freezed” in a hologram taken through a microscope. The reconstructed 3-D image can then be studied at leisure.

Holographic Interferometry: One of the most promising applications of holography lies in the field of interferometry. It was a chance discovery by a number of groups working around the world. In the year 1965, R.L. Powell and K.A. Stetson,
Feature Article

Haines and Hildebrand, and G.W. Stroke and A. Lebyerie, all from the University of Michigan, and Ann Arbor and J.M. Burch from England simultaneously but independently discovered holographic interferometry. They found that the holographic images of vibratory (or moving) objects got washed out. However, if double exposure were used, first with the object at rest and then in vibration, interference fringes would appear. These fringes are characteristic of the stresses and strains suffered by the body; hence they can be used for testing stresses, strains and deformations of objects under the effect of mechanical stress or thermal gradient.

Holographic interferometry can also be used for studying vibrations in objects. This has been used to study the vibration modes of both string and percussion musical instruments. The technique can also be applied for non-destructive testing of materials, to detect cracks, disorders, voids and residual stresses in a test sample without destruction of the sample. Holographic interferometry can be used for testing automobile engines, aircraft tyres, artificial bones and joints.

Medical Applications

Some of the prominent fields of medical science in which holographic technique is used include endoscopy, dentistry, urology, ophthalmology, otology, orthopaedics and pathology.

In the field of ophthalmology any retinal detachment or intraocular foreign body can easily be detected. In corneal surgery, holographic technique can be used for measurement of elastic expansion of the cornea, which is a very vital information for the surgery. Holographic lenses can make one lens provide several different functions, such as correcting regular vision and also acting as magnifiers for reading, all in the same lens and throughout the entire lens at the same time.

Endoscopic holography, which combines the features of holography and endoscopy, provides a powerful tool for non-contact high-resolution 3-D imaging and non-destructive measurements for natural cavities found inside the human body or any difficult-to-access environment.

In otology, different parts of the human peripheral hearing organs are studied using double exposure and time-average holographic interferometric techniques.

In urology, holographic techniques can be used for detecting kidney stones and for the diagnosis of other urinary problems e.g. tumors in the urinary bladder.

For applications of holography in dentistry both continuous wave and pulse laser holography have been used. Besides other applications in dentistry, holograms can be employed as training aids in the disciplines of dental anatomy and operative dentistry.

Other Applications

The holographic technique can also be used for making high quality gratings that are used with precision optical instruments.

Holography has also been used as a powerful display tool. Holograms find important applications in museums, aquariums, drawing rooms, display windows and laboratories. A new class of artists, called holography artists or holographers, has emerged. They use holography to express their creativity and create holograms of unparalleled beauty and essence that are displayed in galleries around the world.

Holographic optical elements (HOEs) are used in heads-up displays (HUDs) in airplane cockpits. They allow pilots to keep their eyes on the sky or runway while still being able to read their instrumentation, which appears to float in front of their cockpit window. This feature is available as an option on several automobiles too.

Holography is also used for determining the three-dimensional size of a package in post offices, large shipping firms and automated conveyor systems. A holographic scanner is used for this purpose.

In otology, different parts of the human peripheral hearing organs are studied using double exposure and time-average holographic interferometric techniques.

Holograms are often used as a plot device in science fiction movies. In Total Recall, the main character uses a device similar to a wristwatch to produce a hologram of himself to deceive his foes. Star Trek: Voyager, a foreign television series introduced the bizarre concept of Emergency Medical Hologram (EMH) doctor. In a recent highly popular science fiction movie Avatar, holographic displays were used extensively on terminals and HUDs.

Holography has various non-optical applications as well. Electron holography, originally invented by Dennis Gabor, to improve the resolution of electron microscopes, is the application of holography technique to electron waves rather than light waves.

Acoustic holography is a method used to estimate the sound field near a source. This is done by measuring acoustic parameters away from the source via an array of pressure and/or particle velocity transducers. The measuring techniques involved in acoustic holography are becoming increasingly popular especially in the field of transportation, vehicle and aircraft design. The general idea of acoustic holography has led to different versions such as near-field acoustic holography (NAH) and statistically optimal near-field acoustic holography (SONAH).

Developments in the field of physics (and applications) of atomic beams gave rise to another non-optical variety of holography called atomic holography. Recent development of atomic mirrors (especially ridged mirrors) has provided the tools necessary for the creation of atomic holograms. However, such holograms have not yet been commercialized.

Next in line are holographic television and motion pictures. It could be truly said that the promise for holographic technology is indeed limitless.

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