HOLOLIGHT CONSULTANCY

Medical Applications

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Holographic Techniques

Recent improvements in hologram recording techniques and the availability of tools for the interpretation of holographic interferograms and the success of holographic techniques in imaging through tissues, ophthalmology, dentistry, urology, otology, pathology, and orthopedics shows a strong promise for holography to emerge as a powerful tool for medical applications. Holographic 3D images of eyes and interferometric testing of human teeth and chest motion during respiration were carried out quite early.

- Mostly the holographic interferometric techniques have been used for biomedical applications.
- X-ray holography can be applied for imaging of internal parts of the body and living biological specimens with very high resolution without the need for sample preparation.
- Endoscopic holography has opened up the possibility of noncontact high resolution 3D imaging and nondestructive measurements inside the natural cavities of internal organs.
- Three dimensional images of biological specimens can be synthesised from a series of two dimensional radiological images using the

techniques of holographic stereogram, holographic conical stereogram and multiplex hologram.

- Holographic contour generation is useful for measurements for biomedical specimen.

X-Ray Holography

TOP

X-ray holography has the potential of examining the samples in aqueous solution with very high resolution without the need for sample preparation that often results in structural alternations. A X-ray hologram with a resolution better than that of a detector can be obtained by Fourier transform holography with a zone plate. The X-ray beam from a selenium X-ray laser (wavelength =20 nm, pulse length 200ps, output power 500 kW) falls on a narrow band X-ray mirror (bandwidth 10% and reflectivity 25% at 20nm wavelength) which reduces the broadband X-ray background produced by the Se laser. The mirror is a substrate with a flatness and roughness of better than 2nm to preserve the coherence of the X-ray laser beam, and is coated with alternate 20 layers each of silicon and molybdenum to provide high X-ray reflectivity. The sample on illumination with the X-ray beam scatters in the forward direction and forms the object beam. The object beam interferes with the portions of the X-ray beam that miss the sample. The recorded hologram can be reconstructed optically.The x-ray resist polymethyl methacrylate has high resolution but it requires development and reconstruction.

If the source size is kept small to ensure spatial coherence and the diffraction pattern is enlarged by shadow projection, a moderate-resolution detector with a high quantum efficiency such as a backilluminated CCD camera can be used for recording the hologram, instead of polymethyl methacrylate. The reconstruction of such a hologram can be performed numerically. The system would permit the observation in real-time, which would be useful for biological samples. A resolution of 1.3 um has been obtained by taking d=1.0 um and N=23 lines/mm, and using a backilluminated CCD camera for hologram recording. The resolution obtained was limited by the resolution of the source size(1 um). These experiments show the promise of real-time observation of holograms of living biological specimens.

Endoscopic Holography

TOP

Endoscopic holography has potential of providing a powerful tool for non contact high resolution 3D imaging and nondestructive measurements inside natural cavities of human body or in any difficult to access environment. It combines the features of holography and endoscopy. The ability to record a 3D large focal depth and high resolution image of internal organs and tissues greatly enhances the detection capability. The holographic endoscopy is of two types. In the one form the hologram is recorded inside the endoscope, while the other form uses an external recording device.

Internal Hologram Recording Endoscope

The internal hologram recording endoscope produces full three-dimensionality of the reconstructed image with parallax and a large focal depth. The endoscope requires a miniaturized holographic setup inside the instrument and records a reflection hologram. It mainly consists of three parts; a film cartridge, a diaphragm and a single mode optical fibre (core diameter 4um) cable. The three parts are assembled in three adjusTAbLE stainless steel or brass tubes. The film is placed at 10 to the normal to the endoscope. The holograms are viewed under a powerful microscope allowing for the observation of individual cells. Due to large hologram aperture, the image with a low speckle noise and high lateral resolution is obtained. A lateral resolution of 7 um has been obtained in the reconstructed image that shows that the technique can be used for cellular structure analysis and may even substitute biopsy in tumour diagnosis. Specific dyes can be used to enhance the contrast of the tissue before recording the holograms as has been used extensively in gynecology and gastrointestinal tract.

External Hologram recording Endoscope

In the external hologram recording endoscope, a conventional endoscope is used. The system records the hologram outside the endoscope using an external reference beam. An endoscope with extremely small outer diameter can be used but this results in a loss of parallax and a small entrance pupil which produces speckles in the reconstructed image. However image plane holograms can be recorded to reconstruct the image without speckles. In order to obtain a high signal-to-noise ratio, the holographic endoscope must use gradient-index (GRIN) rod lenses. The speckle noise is reduced by illuminating and imaging the object by the same GRIN lens. An electro-optic crystal can be used as the photographic storage device in the holographic endoscope to provide in-situ recording, reconstruction, and erasure. These will make a new class of medical instruments for use not only in medical diagnostics but also in industrial testing.

Holographic endoscope can be attached to a salpingoscope for fallopian tube investigations or to otoscope for the inspection of outer and middle ear via an acoustic system to generate vibrations of the tympanic membrane . Holographic endoscope has been used with success for early recognition of cancerous indurations in the wall of urinary bladder.

Multiplexed Holography For Medical Tomography

TOP

Multiplexed holography can be used for complete display of three-dimensional tomographic medical data. It uses photographically scaled images of the objects for making the hologram. The technique thus provides a way to make hologram whose images are of a different size from the original object. A series of photographic transparencies are made, all of which ate used to make a multiple-exposure composit hologram. the reconstruction of the hologram produces the original object with a magnification equal to the scale factor of the transparencies. Holographic stereograms, known as Cross holograms uses multiangular views of the object. The method consists of three steps: data acquisition, image processing, and making of the stereogram.

Since the holographic stereogram retains only the horizontal parallax of the object, it is limited to those applications in which surfaces are important such as prostheses and craniofacial surgery. Moreover, most biological data such as CT or MR scans are generally collected as serial scans rather than multiangular views, multiplexed holography that reconstructs the image with all the sections at correct depths (locations) and both horizontal and vertical parallaxes is more useful.

Multiplexed holograms which retains full parallax and physical depths cues are known as volumetric multiplexed holograms, or multiplane-multiplexed holograms.

A volumetric multiplexed hologram is made from a stack of images such as a CT or MR scan. The first image in the stack is projected onto a screen placed in front of a holographic film. A hologram of this image is recorded by adding a reference beam. Next the screen is moved a few millimeters away from the holographic film and the second image in the stack is projected onto the screen, and a second exposure is made on the first one. All the images are similarly recorded, each at slightly greater distance than its predecessor. The film is then developed. When the hologram is reconstructed, it shows all the slices distributed in the three-dimensional space at different distances. Dispersion compensation techniques can be employed for making the multiplexed hologram so that the image can be viewed by a white light source.

The process of volumetric holographic multiplexing is similar to that of "inverse tomography" in which the projection screen mimics the tomographic slicing mechanisms, and the screen's gradual displacements mimics the patient's's linear translation through the scanner. Since the volumetric multiplexed hologram uses serial sections at different Z coordinates in space, it can be termed as 'zeta multiplexed hologram'. in contrast to a holographic stereogram which is known as 'theta multiplexed hologram' because it involves images at different angles.

It may be pointed out that the volumetric multiplexed hologram faithfully reconstructs complete information including physical depth cues and all of the grey-scale tonality in every slice without geometric or photometric distortion. the success of the technique, however, depends on the accuracy in ALIGNment of the serial sections in different exposures.

The complete system for producing and display of clinically useful multiplexed hologram can be automated.

Holographic Light-in-Flight Recording Method

TOP

The holographic technique of light-in-flight recording can be effectively adapted for implementing first-arriving light principle for imaging through human tissue. The holographic method permits the use of both continuos and pulsed lasers with short coherence length. A short coherence length in holography is equivalent to a short pulse. Holography permits a gate that is as short as the pulse itself . A short-pulse laser beam is split into object beam and reference beam. The object beam passes through the tissue, and the reference beam is delayed so that it arrives at the recording plate in coincidence with the first-arriving light. Thus only the first-arriving light is recorded as a hologram. In practice, the reference beam is incident at a large angle to the recording plate, so that it arrives at different parts of the plate at different times. A part of the hologram would record the first-arriving light and the later-arriving light would be recorded at the other parts.

Holography in Ophthalmology

TOP

Recording of a three dimensional image of the eye was one of the earliest applications of holography in the field of ophthalmology. Any retinal detachment or intraocular foreign body can be detected. Holography can also be applied for the measurement of corneal topography and crystalline lens changes and for the study of surface characteristics of both the nerve head and the cornea. Current methods of determining the shape of the central surface miss the central part and its periphery. The major advantage of holographic technique is the ultra high precision (sub-um range) with which such measurements are possible. The elastic expansion of the cornea can also be measured by holographic interferometry. This information is vital for corneal surgery. The expansion of the cornea of fresh enucleated bovine eyes has been examined as a result of a small increase in intraocular pressure using double exposure holographic interferometry. Their first investigations have revealed that each bovine cornea has its own typical expansion. The studies made so far show that holography has potential to investigate corneal endothermal morphology, changes on the cornea, crystalline lens changes, and surface characteristics of both the nerve head and the retina.

Diffractive bifocal Intraocular Lens

A very useful application of diffractive optics is in the correction of refractive errors for old persons who have been operated for cataract by the use of a bifocal intraocular lens. Such persons have difficulty in changing the focus of their eyes for near distant and far distant objects. bifocal lenses are implanted in place of the natural eye lenses. The bifocal lens is a combination of a conventional refractive lens and a diffractive lens, the former focussed to infinity and the later for near distance vision. The efficiency of the diffractive lens is set at 50%, thus both the near and the far foci are accommodated over the whole visual field. The diffractive lens is fabricated on the rear of the conventional lens. When the eyes are focussed for a distant object, a blurred image is superimposed due to the presence of diffractive lens and vice versa, which obviously reduces the image quality. In most cases, the blurred image is discarded by the human visual perception and retinal processing system.

It is possible to place an ultra-thin (5 to 10 um) diffractive lens directly on the eye's cornea, where natural tissue growth over it would secure it, creating a semitransparent contact lens that would provide full visual ability.

Holography in Dentistry **TOP**

- both continuous wave and pulse laser holography have been used for applications of holography in dentistry.
- The holograms offer a convenient way of storing toothprints, i.e. dental records of the casts of upper and lower centitions for legal and forensic

purpose.

- Holograms can be used for storing orthodontic study models that can be retrieved by a laser beam or a white light source for accurate 3D measurements. This saves a lot of storage space. The holographic images are clinically reliable and random errors are not clinically significant. by studying the old and new records, orthodontists can watch the progress of their patients .
- Holograms can be employed as training aids in the disciplines of dental anatomy and operative dentistry.
- Holographic interferometry has been used for the contactless measurement of in-vivo tooth mobility and its movement in three dimensions, and measurement of dimensional changes of the tissue bearing surfaces of maxillary full dentures due to deformation of dentures material by oral fluids.
- Holographic contouring technique can reveal the topography of teeth.

Holography in Otology

TOP

The human ear is embedded in temporal bone that forms part of the skull base. The ear may be broadly divided into three parts: the outer ear, the middle ear and the inner ear. The outer ear consists of pinna (not shown in the figure), the external auditory canal and the tympanic membrane. The tympanic membrane is the inlet of the middle ear, which transmits the sound coming from the outer ear to the inner ear through auditory ossicles viz. malleus, incus and stapes. The middle ear is located within the tympanic cavity and contains a chain of auditory ossicles. The inner ear is the cochlea that has a coil like shape. The cochlea is separated into two parallel canals by basilar membrane. The receptor cells for hearing sense are spatially distributed on the basilar membrane.

- Double exposure and time-average holographic interferometric techniques are powerful for studying different parts of the human peripheral hearing organ.
- The vibration behaviour of models of the inner ear parts such as unrolled cochlea and coiled basilar membrane have been studied by time-average holography.
- Time-average holographic interferometry has also been used for the study of vibration analysis of incudo-mallar joint with forces applied to the middle ear muscles has demonstrated that the incus and malleus move like a lever around a

frequency dependent axis.

Study of Tympanic Membrane

The tympanic membrane is important in coupling the acoustic sound pressure in the outer ear canal to the motion of the middle ear ossicles. Holographic contouring techniques may be applied for precise measurement of the shape of the tympanic membrane. When sound waves fall on the tympanic membrane in the outer ear, it vibrates. These vibrations are transmitted by the leverage action of the auditory ossicles to the stapes footplate attached to the annular ligament and finally to the fluid system of the inner ear. The vibrations propagate through the lymphatic fluid in the cochlea and cause basilar membrane to vibrate which in turn cause stimulation of the receptor cells on the cochlea. In order to use holography as a clinical tool for living persons, special care is required with regard to the optical system due to the difficult optical access through the narrow and curved outer ear canal. The device is made flexible by using a endoscope fibre bundle for the object illumination and using a thermoplastic film for recording the hologram. The device produces the results in 10 seconds, therefore is useful for routine clinical applications for quick study of the vibration pattern of tympanic membrane.

The holographic time-average interferometry is particularly suiTAbLE in studying the modes of vibration of the eardrum of living human as the modes of vibration are observed simultaneously over the whole area.

Many infants and old persons develop severe otitis media with effusion causing the malfunction of the eustachian tube leading to medial recess of the tympanic membrane under the compression of atmospheric pressure. This results in hearing loss, ear obstruction sensation, autophony, etc.

The time-average holography of a fresh human temporal bone sample has revealed a small tilt movement with a piston like oscillation of stapes . The vibration patterns of macerated human skull using time-average holographic interferometry has thrown light on the mechanism of sound transmission of sound transmission by bone conduction. The sample was excited by bone conduction vibrator.

Hearing impairments occur when micro-fractures of petrous pyramids in the human skull base are created by accidents. Double-exposure holographic interferometry has been applied for the study of deformation of the human skull under different load conditions to investigate petrous pyramids.

Holography in Orthopedics

TOP

Holography offers an excellent tool for the contactless study of orthopedic structures, specifically external fixtures to reveal and measure strains on fixation pins and rods. Such studies are important in osteosynthesis with external fixture used for long bone fractures, to prevent dislocations of both fractured ends that are mainly caused by decrease in strength of the fixation pins. Dry bonein cantilever bending mode has also been studied by heterodyne holographic interferometry to determine the piezoelectric coefficients of bone.

Summary

Holographic interferometric techniques have been widely applied with success for the study of different parts of human body including cornea, tooth mobility, tympanic membrane, basilar membrane, cochlea, temporal bone, incudo-mallar joint, chest, stull, and bones. Endoscopic holography is a powerful tool for non contact high resolution imaging and nondestructive measurements inside the natural cavities of human internal organs. X-ray holography has shown the promise of real-time observation of living biological specimens.

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