Application of the Quantum Optics Holophoto™ Process To Three-Dimensional MRI Scans and CT-Scans

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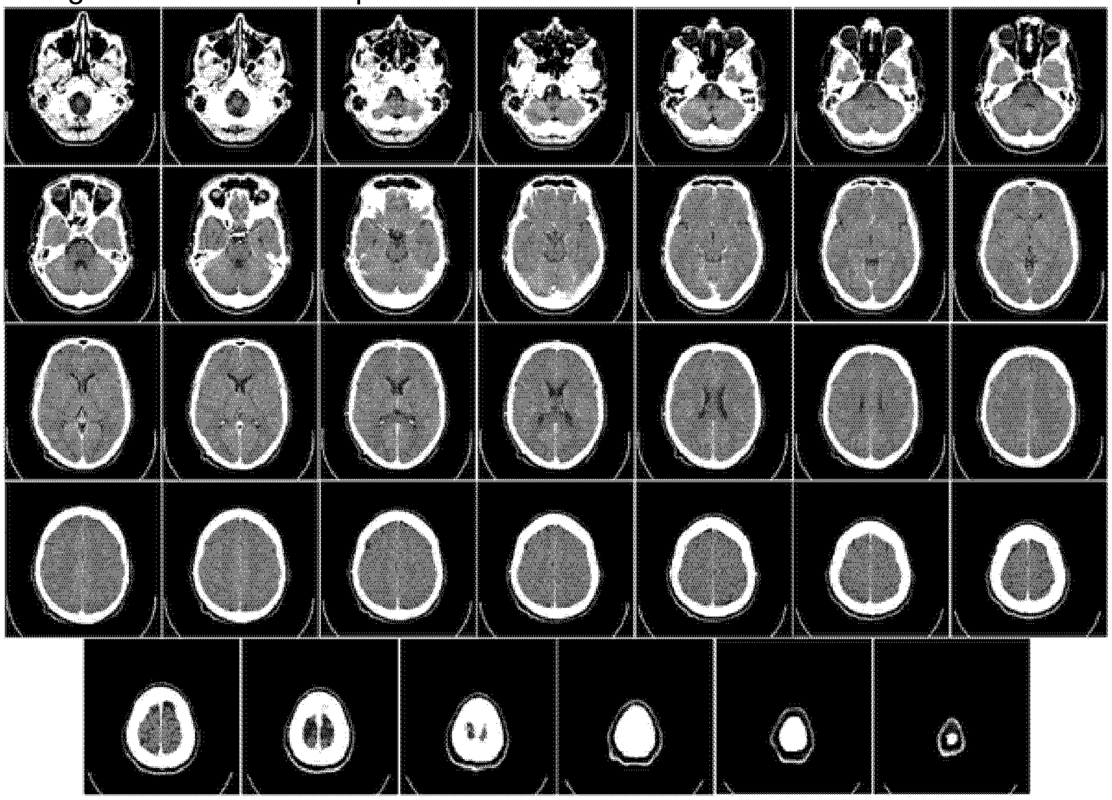
ABSTRACT

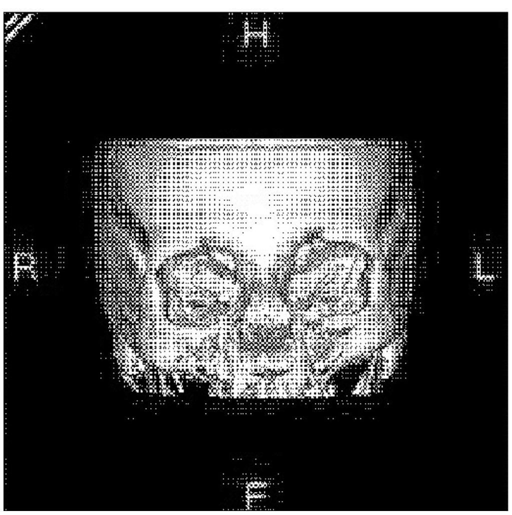
The Quantum Optics Holophoto™ Process is used to produce computerized true three-dimensional holographic images of CT-scans and MRI scans. These three-dimensional images are reconstructed from digital integral photographs and are produced dynamically. They can be produced on a flat or curved screen and rotated in space around a vertical axis, or they can be fixed in space where the viewer may "walk around" the image to see it from all viewpoints over an angular range of 360°. Although the image slices of the real object are created as an image fixed in time, the image display is in real time. The viewer may manipulate the image as desired to accomplish rotation, image segmentation, or magnification. Magnification of the image is uniform.

The term CT-scan refers to X-Ray computed tomography. It is a medical computer imaging method for creating a three-dimensional X-Ray representation of an object. It is an X-Ray image of sections or "slices" around a single axis of rotation. The object is placed in the interior of a toroidal rotating X-Ray generator. The object to be scanned is translated relative to the torus perpendicular to its plane and along its axial direction. A CT-scan has also been known as a CAT (computed axial tomography) and body section tomography. A CT-scan is a very important diagnostic tool to supplement standard X-Ray and ultrasound imaging. X-Ray slice data is generated using an X-Ray source that rotates around the object. Pixels in the image are displayed in terms of relative radiodensity. Currently, three-dimensional images of the object are produced by computerized stacking of the slices. The simplest method of performing this function is called Multiplanar Reconstruction (MPR). Optionally, a special projection method, such as maximum-intensity projection (MIP) or minimum-intensity projection (mIP), can be used to build the reconstructed slices.

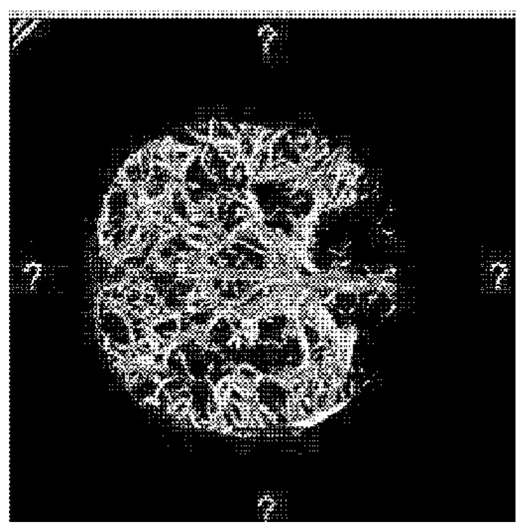
Three-dimensional surface rendering is done by setting a radiodensity threshhold value. For example, this level can be set to be that of bone. The three-dimensional reconstruction is done using edge detection algorithms. However, such rendering only produces an image of the surface. The interior structure would not be visible. Only the surface closest to the viewer is observable. On the other hand, volume rendering allows the interior structure to be made visible. Different colors may be used to show different radiodensity levels or the outer surface may be rendered semi-transparent to allow viewing of the interior structure. Finally, where neither surface rendering or volume rendering produces the desired view of the interior structure, image segmentation may be used to remove unwanted structures from the image. These techniques are well known in the art.



A typical CT-scan of a human brain is shown above. Note that there are thirty-four slices shown. The high-intensity white periphery of each slice represents bone.



A two-dimensional representation of the 3-dimensional reconstruction



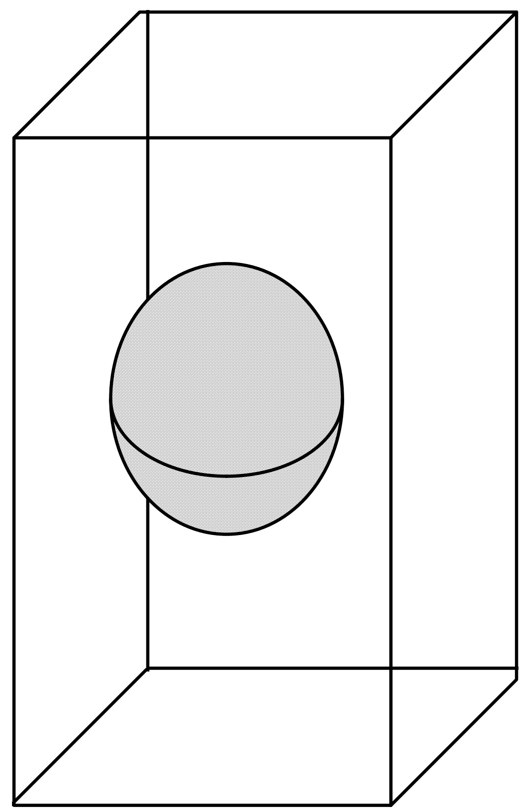
using volume rendering is shown above.

The above photograph shows a reconstruction of the interior structure using image segmentation. Here, the bone has been removed to show the vessel structure in the interior of the brain.

The term MRI stands for magnetic resonance imaging. MRI images provide far better contrast between the different soft tissues of the body than CT or X-Rays. This makes it especially useful in diagnosis of the brain, muscles, heart, and cancer. The basic mathematics of the 2-dimensional Fourier Transform for MRI images is very similar to that for the CT-scan. The three-dimensional reconstruction from MRI slices is similar to that for the CT-scan. Surface rendering, volume rendering, and image segmentation are used in virtually the same way.

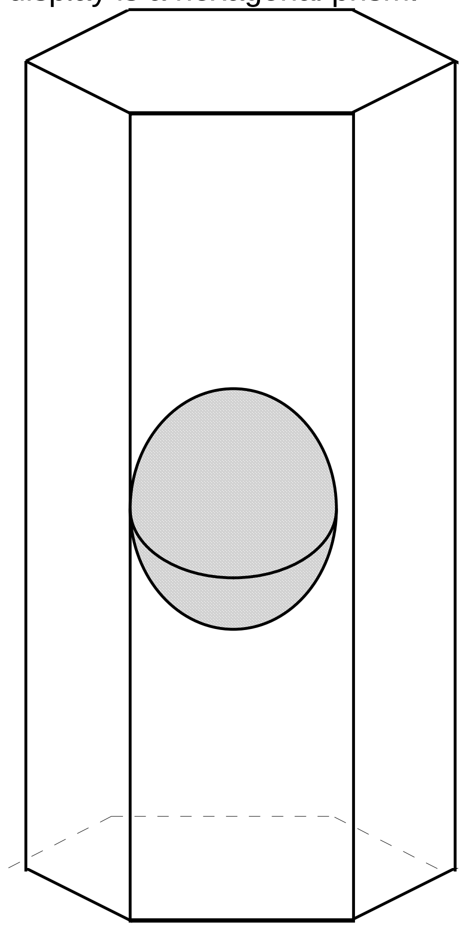
A typical three-dimensional reconstruction of a skull is shown in the photograph on the previous page. The viewer is facing towards the front of the skull. However, the paralax information is available over a 360^{o} viewing angle. Therefore, the skull may be rotated around its central vertical axis. Because of the way the scan was generated, there is only horizontal parallax. No vertical parallax is present. The photograph of the skull is a two-dimensional representation of the three-dimensional reconstruction. Because of the availability of horizontal parallax image information, stereoscopic photographs are often produced to allow viewers to see the image in 3-D. However, these photographs are not very useful as they are fixed in time and position.

It would be very useful to medical personnel if a dynamic display were to be produced in full three-dimensions where the viewer could dynamically view the object from any angle. It would be useful further if these images could be dynamically manipulated such that the interior structure of the object would be optionally visible. Also, it would be very useful if these images could be dynamically magnified or demagnified.



The above drawing illustrates the ability of a viewer to see a three-dimensional representation of the object from all viewing angles where the display is a rectangular prism. The illustration shows the three-dimensional image of a skull being reconstructed along the vertical axis of the rectangular prism.

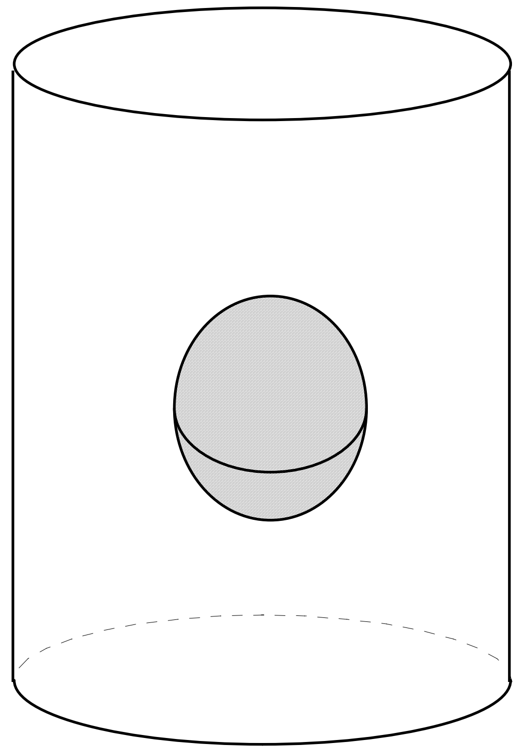
The left drawing below illustrates the ability of a viewer to see a three-dimensional representation of the object from all viewing angles where the display is a hexagonal prism.



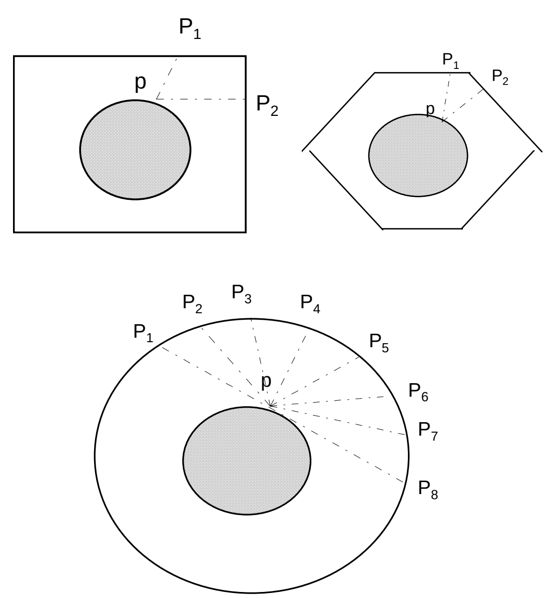
The above left illustration shows the three-dimensional image being reconstructed along the vertical axis of the hexagonal prism.

The above right drawing illustrates the ability of a viewer to see a three-dimensional representation of the object from all viewing angles where the display is a cylinder. The three-dimensional image is reconstructed along the vertical axis of the cylinder.

The following sequence of drawings show top plan views of the rectangular prism apparatus, the hexagonal prism apparatus, and the cylindrical apparatus showing visibility of Point P from different directions.

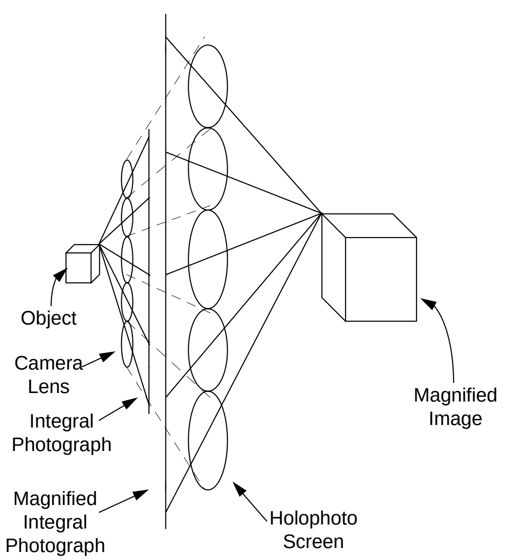


Point P is an image point on the surface of the skull. It is also a peripheral point on a section of the MRI or CT-scan.



An integral photograph is a matrix of small photographs of the same scene, each taken from a different viewing angle. When properly illuminated, an integral photograph reconstructs a true three-dimensional image of the photographed scene. A hologram is exactly like an integral photograph, but with a much greater number of viewing angles. Conversely, an integral photograph behaves like a hologram. However, they are easier to make than holograms.

There is a basic optical principle, which dictates that a three-dimensional image cannot be magnified uniformly. A magnified three-dimensional image will be distorted in the depth direction. The Quantum Optics Holophoto™ Process produces uniformly magnified three-dimensional images from integral photographs. The principle is illustrated in the drawing below.



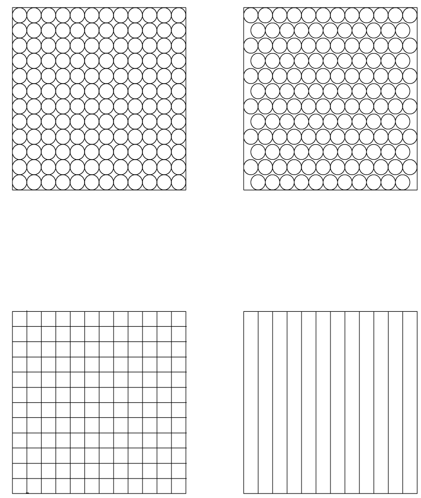
A three-dimensional object (shown above as a cube on the left side of the drawing) is photographed by a camera having a matrix lens array instead of a single lens. The lenslets in the array are very small. Each lenslet photographs the object from a slightly different viewing angle than would be seen by the adjacent lenslets. The photograph produced by this camera is a matrix of small elemental photographs, where the photograph matrix has the same size and shape as the matrix lens array. When the photograph is developed, if it is placed in front of the lens that made it, a true three-dimensional image would be produced in front of the lens array.

However, if the photograph were to be magnified, and a new lens array is an enlargement in all dimensions in proportion to the original lens array, viewing the magnified photograph through the new lens array would produced a uniformly magnified three-dimensional image. This is the basic principle of magnification and projection of the Quantum Optics Process.

The drawings below illustrate various types of matrix lens arrays used for objects and reconstructing three photographing -dimensional images. The upper left drawing shows spherical lenslets arranged in a rectangular array. The upper right drawing shows spherical lenslets in a hexagonally close packed arrangement. The lower left drawing shows crossed cylindrical lenslets. The lower right drawing shows parallel cylindrical lenslets in an arrangement typical of a lenticular lens sheet.

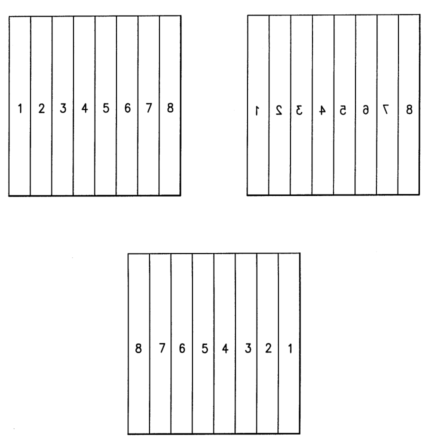
Each lenslet in the array creates an elemental picture of the entire scene from a different viewing angle than any other lenslet. The integral photograph itself is an array of these elemental pictures. When the integral photograph is replaced behind the original or similar array, a viewer in front of the array can view the entire scene in three-dimensions. When the viewer is far enough away from the lenslets so that the individual lenslets cannot be seen, the light waves that reach the viewer's eyes are the same rays that would reach him if the scene were really there. The viewer cannot perform any visual test to determine whether or not the scene is real.

The last statement is not quite complete. The three-dimensional image produced by reconstruction from an integral photograph is pseudoscopic (*i.e.,* the spatial positions of foreground and background are reversed). However, the statement about the visual test for reality just made holds true with a three-dimensional image that has been everted from pseudoscopy to orthoscopy.



Vertical parallax is not necessary, and vertical parallax information is not preserved for reconstruction from a CT-scan or MRI. Only horizontal parallax in an integral photograph is necessary for a viewer to observe an object in three-dimensions. Therefore, by eliminating vertical parallax, the viewing screen need merely consist of small vertical cylindrical lenslets. This is sometimes referred to as a leticular sheet, and is quite common in autostereoscopic displays. The integral photograph is therefore a linear array of vertical elemental images extending for the entire height of the integral photograph.

Clearly, when a viewer observes a three-dimensional object or scene, it is orthoscopic. However, the magnified three-dimensional image from an integral photograph is pseudoscopic. A pseudoscopic image is turned inside-out. What should appear in front appears in back, and *vice* versa. Eversion is the process of converting a pseudoscopic image to an orthoscopic image. A method of everting a three-dimensional image involves manipulating the individual elemental pictures in the integral photograph. In the drawing on the next page, we are dealing with horizontal parallax only. A lenticular lens sheet is used as the matrix lens array. To evert the image the order of images in upper left configuration below must be reversed to produce the integral photograph shown in the lower configuration.



However, while the left-right orientation of the final integral photograph has been reversed with respect to the original, the individual elemental images maintain the same left-right orientation as the original. While it may be intuitive that reconstructing the new integral photograph would create a three-dimensional mirror image of the original object, that is not the case. The elemental images determine the left-right orientation of the reconstructed object. The elemental left-right image orientation of the new integral photograph must be identical to that of the original. Therefore, the left-right orientation of the three-dimensional image reconstructed from the new integral photograph will be true as well as orthoscopic. On the other hand, a three-dimensional image reconstructed from the upper right integral photograph (shown above) will be a mirror image of the original scene, and it will also be pseudoscopic.

The two-dimensional integral photograph of a three-dimensional CT-scan or MRI is created by a computer. The software employs an algorithm based upon simple projective geometry. The magnification factor is computed as desired. Based upon the magnification factor, the height of the three-dimensional image as wel as the distance of the object from the screen is determined. The screen configuration (the placement of the lenslets) is determined by the computer. The correct image contents of the two-dimensional array of elemental images is displayed on the screen.

The Quantum Optics Process as applied to MRI and CT-scans utilizes a digital display. Unfortunately, the resolution required to reconstruct a three-dimensional image is an order of magnitude greater than what is available from conventional video displays. The patented Holophoto™ screen solves this problem.

An orthoscopic three-dimensional image from the CT-scan or MRI can be reconstructed on a single flat or curved viewing screen. Because it is a real-time video image produced by a computer, it can be magnified, demagnified and rotated. Image segmentation may be used dynamically to observe either the interior or exterior structures. However, the real advantage of the display is that a screen can be constructed that would be shaped as a prism or cylinder. With such a device, a viewer can walk around the display and view the three-dimensional image from any angle.

The image is reconstructed from slices of the object projected onto the corresponding slices of the device. Although the slices in the original CT-scan or MRI are planar, they are rendered using an interpolation algorithm so that they should not appear to be separated from each other. By constructing thick slices, a seamless three-dimensional image (in height) can be reconstructed.

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