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The language of holography

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Abstract

Holography has evolved over its 70+ years of history across widespread and diverse communities and locations. This has produced a complex language that is sometimes inconsistent, confusing, and incorrect, resulting in a general public that often appears widely confused and/or ignorant regarding what holograms actually are and are not. Today's holographers employ many types of recording media to record all types of waves, such as light, sound, radar, and simulated waves, and for many different applications and purposes. This study examines the language of holography along with its origins, problems, and possible solutions, while recognizing that certain "errors" in the language are so embedded in society that simple and ideal fixes may be beyond reach. This leaves us with certain questions, as follows. First, can the correct language be restored and should we undertake the task, or are we stuck with every three-dimensional image being called a hologram? Is it our duty to better educate the public with a more useful and consistent language, or should we just go with the flow? In this work, beginning with the insights provided by the pioneers of the field, we attempt to set the stage for a more useful holography language and definitions, specialized so as to be understandable and usable by various audiences, including those interested in non-optical holography. Such knowledge can help the general public to take greater interest and enjoyment in holography; this would also be beneficial to those more involved in holography. Accordingly, this article offers advice for achieving this result.

Introduction

People with relatively little optical background, such the general public and non-optical professionals, are most likely to encounter holograms in museums, magazines, art galleries, holographic displays, and security devices (such as those on credit cards). These are optical holograms, and are produced to create three-dimensional (3D) images of objects. Those who are vaguely familiar with holograms associate them with 3D imaging, whereas others may have no clue what holograms and holography are. After seeing an image in a good hologram for the first time, most viewers are surprised, fascinated, or even stunned, and almost always ask "how was it made"? The discussion immediately gets more difficult, and discretion with the language is needed to keep the further discussion meaningful.

Deepening the discussion on holography requires an understandable language, which, as with any language, becomes more complicated with depth. Teaching the general public interference and diffraction is not practical, necessary, or even useful. The optics community can provide the general public an understandable and accurate language and methods to enhance the enjoyment of holography, while maintaining consistency with the much more comprehensive, technical language required by the technical holography community. However, this requires that the technical community maintain accuracy and consistency in its own language.

Much can be learned from the evolution of holography and its language, which, after a brief emergence in 1947, was followed by a 15-year hibernation in obscurity. Then, breakthroughs sixty years ago (the anniversary we

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celebrate in this issue) revived it into an explosive revolution. Owing to those innovations, today's holographers in many different fields employ a wide range of recording and reconstruction processes. They use many types of recording media to study and display all types of waves, including light, sound, radar, x-ray, and simulated waves, and for many different applications and purposes. Since 1947, this evolution across widespread and diverse communities and locations has produced a diverse language which is sometimes inconsistent, confusing, and incorrect, resulting in a general public that appears widely confused and ignorant regarding what holograms actually are and are not. Most novices do not understand the exciting aspects of holograms.

This study examines the language of holography and its origins, problems, and possible solutions, while recognizing that some of the "errors" in the language are so embedded in society that simple and ideal fixes may be beyond reach. This leaves us with certain questions. For example, can the correct language be restored, and should we undertake the task, or are we stuck with every 3D image being called a hologram? Here, beginning with insights provided by the pioneers of the field, we attempt to (a) set the stage for a more useful and enjoyable holography language and definitions specialized so as to be understandable and usable by all audiences, and to (b) establish a foundation for a second comprehensive, general holography language required by the technical community, which does not necessarily need to be understood by the general public.

Historical Background

The concept and initial naming of holography was provided by Dennis Gabor, in 1947[1]. He abandoned holography five years later owing to fundamental technical problems that limited its usefulness, and most of his followers soon left the field as well. In the early 1960's, Emmett Leith, Juris Upatnieks[2,3], and Yuri Denisyuk[4], without awareness of Gabor's earlier work or that of each other, created new forms of holography that removed the problems that had limited Gabor. They created dramatic holograms containing visible, 3D images that gained international public and professional recognition. The resulting explosive revolution cleared the way for many applications, including those in art, display, advertising, security, inspection, diagnostics, computing, data storage, new optical components, spectroscopy, microscopy, and most of the sciences. These advances resulted in a Nobel prize for Gabor in 1971, an honor that many holographers believed the new pioneers deserved to share. Each new application expanded the language of holography, i.e., to describe the different procedures, hardware, software, and products to make them possible.

Gabor's 1948 paper was titled "Microscopy by Reconstructed Wave-fronts", which probably led his early followers and others to appropriately call the process "wavefront reconstruction"; however, Gabor himself rarely referred to the process as wavefront reconstruction. He named the recording "hologram", as derived from the Greek *holos* (whole) and *gramma* (message), meaning a recording containing the total information required for reconstructing a wave, as this could become a 3D image of an object. The word "holography" was a natural extension of the terminology for the process.

In Gabor's words: "If a diffraction diagram of an object is taken with coherent illumination, and a coherent background is added to the diffracted wave, the photograph will contain the full information on the modifications which the illuminating wave has suffered in traversing the object: the image of the object can be reconstructed from this diagram without calculation. One has only to remove the object, and to illuminate the photograph by the coherent background alone. The wave emerging from the photograph will contain as a component a reconstruction of the original wave, which appears to issue from the object[5]". How to add the background with a separate, off-axis beam, so as to make the process much more useful, remained undiscovered for another 15 years.

Emmett Leith's and Juris Upatnieks' work dramatically improved the process in the early 1960's, and immediately rendering holography as practical. This work grew out of research on "side-looking-radar" and was documented by Leith, beginning in 1956[2,6]. The "Michigan Side-Looking-Radar" document contained the theory of the Leith and Upatnieks holograms. Unfortunately, this document was classified and could not be published for many years. Therefore, their first off-axis hologram appeared to derive from a method of understanding and processing radar waves, as reconstructed with visible light, years before lasers were invented and before Leith knew about Gabor's work[7]. Leith later stated about his work, in a 1986 interview, "It turned out that the theory paralleled Gabor's work which I didn't know then. I first came across a paper on holography, or wavefront reconstruction as it was called then, in the October 1956 Journal of the Optical Society of America. I read the paper and said, 'Oh my gosh, it's already been done'"!

During the same period, Soviet physicist Yu. N. Denisyuk, unaware of the other work in holography, solved Gabor's limitations by combining holography with a photographic recording method developed by Gabriel Lippman, who received the Nobel Prize for the method in

1908. Denisyuk's hologram added the background with a separate beam directed toward the other side of the hologram and makes use of the thickness of the a recording medium to enable wavefront reconstruction with white light reflecting from the hologram. He soon adopted the language originally posed by Gabor and called his process holography, now commonly known as Denisyuk holography. Denisyuk said, "a hologram of an object is the optical equivalent of the object itself". When illuminated by light, the hologram of an object does the same thing to the light that the object itself would do; thus, an onlooker viewing the light emerging from the hologram would see the same thing the onlooker would see when looking at the object, and the onlooker would not be able to distinguish the object from a hologram of it. "A really simple example", he said, "is that a hologram of a convex mirror will act just like a convex mirror when illuminated by a point source[5]". This represents yet another simple way to describe a hologram, assuming that one can relate to the concept of an "optical equivalent".

The inventions and language of these pioneers provide us with three separate categories for optical holograms: the in-line hologram of Gabor, the off-axis hologram of Leith and Upatnieks, and the white light reflection hologram of Denisyuk. These are now commonly known as Gabor holography, Leith Upatnieks holography, and Denisyuk holography.

Adolph Lohman, a highly respected early researcher, described holography in the following way: "The propagation of the light wave (sic. from the object) is interrupted somewhere by the photographic plate on which the hologram is recorded. The light wave is frozen in the hologram. When properly illuminating the hologram later in the second step (sic. the wavefront reconstruction), the light wave 'frozen' on the hologram is revived. It continues its travel to form an image as if the light wave had not been interrupted. Unlike classical methods of image formation, the hologram does not necessarily bear any resemblance to the image which will be formed when it is properly illuminated[8]". The hologram appears as a window through which a viewer can observe a 3D image of an object in the space behind. The image can also extend into the space in front.

Using this concept, a hologram can similarly be described as a window on which information is recorded that enables it to transform light coming from a point source of light into a different light wave, i.e., one that would have come from a 3D object sitting behind the hologram. A viewer looking through the hologram sees a 3D image of the object sitting behind the hologram. Transmission holograms transform light passing through the hologram, and reflection holograms transform reflected light.

Defining Hologram and Holography

Although the words of the early pioneers are useful in the search for useful definitions, they had no way of realizing how broad and complicated the field of holography would become. More useful and understandable definitions and languages are needed by the general public as well as the technical community, and although these do not have to be the same, they must be consistent, compatible, and sufficiently comprehensive to serve the technical community and general public for the experiences they will most likely encounter.

A completely general definition covering all holograms is unlikely to be understandable or even useful to many people who will see and enjoy optical holograms; however, broad definitions and language are needed to cover the newest forms and applications of holograms, especially non-optical holograms, such as acoustical, digital, and real time holograms, as well as the many types and uses of holography. We conclude that an optimal approach is to adopt at least two consistent definitions: one that is comprehensible to the general public, and a second to be understood and used more by the technical community. A general and comprehensive definition can accommodate all types of holograms. Although there is no intent to review the details of all types of holograms here, selected types are named and referenced below. Moreover, we provide additional details on digital holography because of its novelty, emerging importance, and applications in the field.

Many people have never knowingly seen a hologram, or at least a good one. Many people who have not seen (but think they have seen) a hologram, and even those who have had some experience, are not likely to know how widely holography is used. By far, the most commercially successful and ubiquitous holograms are the embossed, cast, or printed holograms appearing on credit cards[9], money, stamps, advertising, decorations, souvenirs, and magazine covers. Billions of such holograms have been produced. Practically everyone owns one or more such holograms, and many owners do not even know their product is a hologram. Embossed, cast, and photopolymer holograms are printed directly into photosensitive materials placed on a surface in various ways. Such holograms, which can be produced for pennies each in mass production, can act effectively as security devices and anti-counterfeiting tools, thereby saving millions of dollars. This is simply because the production process requires expensive equipment, and is far too complicated for most counterfeiters.

Sketches or figures like Figs. 1, 2 can be helpful for answering the inevitable question "How is a hologram made"? A common manifestation of an optical hologram is a photograph of the interference pattern resulting from overlaying two laser light beams originating from the same laser, known as the object and reference beams, as shown in Fig. 1. Lasers are used because proper interference requires coherent light; this can be provided by a laser. The object beam comprises light reflected from an illuminated object, and the reference beam arrives unperturbed from the laser.

When such a transparency of the photograph is later illuminated with a similar reference beam of light (Fig. 2), a visible 3D image of the object can be seen in the space originally occupied by that object. The viewer can move around and continue viewing through the hologram, and the image will continue to be visible from different angles. The hologram acts like a window with the object sitting behind it.

Based on the above discussion, the following is a definition for the general public/layman who will most likely encounter holograms largely for creating 3D images,

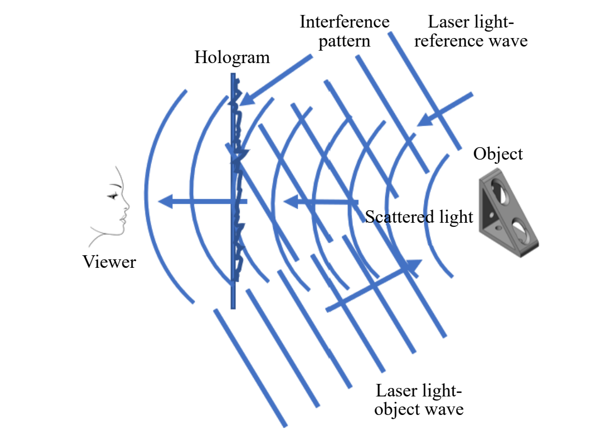

Fig. 1 Recording a hologram of an object.

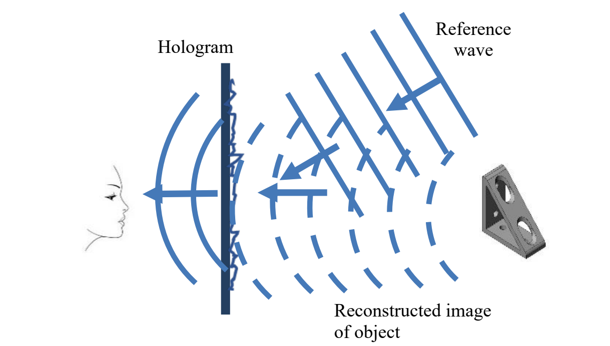

Fig. 2 Reconstructing a 3D image of the object.

e.g., in holographic art galleries, holographic displays, and museums, and on credit cards. For these audiences, an optical hologram can better be understood from a description such as that of Lohman[8].

Optical Hologram (n). A recording of a light wave that behaves like a window in which the light rays and waves coming from an object are frozen (recorded). With appropriate illumination of this window, the recorded waves can be turned on at a later time and can then continue to travel onward beyond the window, such that a viewer sees a 3D image of the original object in its original position. If the original object was a 3D object, the viewer sees it in the hologram as a nearly perfect 3D image of the object; in an excellent hologram, this image cannot be distinguished from the object itself.

3D Imaging Products That Are Not Holograms

Throughout most of the history of humankind, humans have been restricted to recording two dimensional (2D) images in drawings and paintings. One exception was in sculpture, a difficult and time-consuming process. Revolutionary steps occurred when artists discovered and began employing shadows and perspective methods to provide an illusion of 3D images. Not long after photography enabled the 2D recording of live scenery, stereoscopy was invented[10]. It was discovered that by presenting two different views of a scene recorded at different angles to our separate eyes, an illusion of depth was achieved. Stereo viewing created its own language as people began calling this "3D"; this was an incorrect description of what was actually seen, revealing errors in the language of 3D viewing long before holography. Viewing two 2D photographs provides much less of the 3D information seen by two eyes in a real scene or when viewing an image produced by a hologram, and provides only an illusion of a 3D image.

Full 3D imaging provides more than just depth information. With full 3D imaging a viewer perceives depth, focus, and parallax. Parallax (vertical and horizontal) is what is seen when the viewer moves their head up and down or sideways. The nearest objects move relative to the objects further away, allowing the viewer to see around an object in the foreground by moving the eyes up and down or side to side. In true 3D imaging, a viewer can focus the eyes differently at different depths; this also enhances the perspective in an image. This allows a viewer, at any time, to see both close and distant objects with better resolution.

Experienced and knowledgeable hologram viewers spend much more time looking at images in holograms than images in stereograms, because there is much more to see. When experienced viewers observe holograms on display they are often in constant motion to assist with the viewing, a process that is sometimes referred to as the "holography dance". We can teach the general public about the "holography dance" to improve hologram appreciation. By closing one eye, a viewer immediately transforms a stereo image into a 2D image, whereas a single eye provides 3D information when viewing a true 3D image. With one eye closed, moving one's eye up and down can determine if the image seen is a true 3D image, or one photograph from a stereo pair recorded in the hologram.

Because pure hologram images retain all of their 3D properties, distance perceptions, vertical and horizontal parallax, and focus, they are almost always more interesting in appearance than stereoscopic images (and can even be exciting). Nevertheless, owing to our fascination with 3D imagery, many techniques have emerged and continue to emerge for providing 3D illusions. Of these, many, like stereoscopy, are very effective entertainment devices that are not based on holography; nevertheless, they are often mistaken for holography and even passed off deliberately as holograms for publicity. The following are examples of techniques and devices that are not based on holography.

a. Stereo photography and projection imagery
b. Pepper's ghost images
c. Fly's-eye images
d. Lenticular photographs
e. Light field imaging
f. Virtual reality headsets
g. Integral photographs

The first holograms from both Gabor and Leith were holograms of photographs. Since then, holography techniques have often been combined with photography and stereoscopy methods, so as to take advantage of the simplicity, lower cost, and portability of the photography. The illusion of 3D can be retained with holograms of photographs and stereo pairs and with the help of stereography, with tradeoffs in accuracy and the loss of some 3D information. Photography is a simple and inexpensive process, whereas holography is less portable and more expensive.

Taking photos of a person sitting on a stool as a camera is translated in front of the person provides photos with different angles that can be used as stereo pairs to give a 3D illusion. A similar procedure places the individual on a turntable that rotates as a fixed camera takes photos at different angles. Various techniques can transform sets of photos into what appears to be a 3D image of an individual. One non-holographic method, known as integral photography, uses a lens array to produce an effective 3D illusion and is common in souvenir stores. Holograms of such photographic recordings are now recorded with results that sometimes improve upon the non-holographic methods and have become widely used. The trained eye can easily distinguish holograms from stereo photographs presented without holography, because holography can preserve vertical parallax, whereas photography does not.

Holography cannot yet and may never improve all 3D imaging techniques, which are quite effective in providing the desired 3D information/illusion for various applications. Virtual reality (VR) headsets are an example where video stereo photography is being pushed to its very limits in recording and computation, so as to achieve effective illusions of large, dynamic scenes for games and training purposes. Holography may eventually compete with existing VR headsets, but the necessary hardware and software does not yet exist. The same is true for video recordings of rock stars in action, none of which are holograms. Holograms have been made of stationary rock stars, but not as a live video depicting singing and dancing on a stage.

Digital Holography

Digital holography (which became viable only after the more recent advent of high-resolution digital technology) is possibly the fastest growing technical holography topic, with over 100 new publications per year. This may be owing to the possibility of performing advanced holography research without the necessity for expensive lasers, optics, or even laboratories; all that is required is a relatively inexpensive computer. Digital holography also has an important role in (and potential for) hologram production, making it commercially important. Techniques developed by this industry have enabled faster and lower-cost hologram production than anyone had imagined. In science and medicine, digital holography is revolutionizing microscopy.

In digital holography[11,12], information in the hologram is recorded and stored in a digital format as discrete bits in a computer. A hologram of a wavefront can be produced by interfering the wavefront with a reference wave on the sensor of a digital camera or sensor and then storing the information in the camera or in a computer. The fundamental requirement for recording a digital hologram is that the pixel size in the camera must be small enough to enable the recording of the fringes in the hologram.

Some holographers object to referring to a recording stored in a computer as a hologram, rather thinking of a hologram as something that can be seen and used to display a 3D image. Nevertheless, after storing the hologram in a computer, it can be employed, computationally, to reconstruct and propagate the stored wavefront to any place in a virtual space. For example, it can be used to compute and display the intensity, i.e. focus, at some distant plane, and then to display it on the computer monitor. This enables electronic scanning through a 3D image. Thus, a hologram stored in a computer can be used to provide the same advantages as other non-digital holograms.

Fig. 3 illustrates the recording and reconstruction operations for digital holography. In general, the digital hologram can be transferred to a spatial light modulator and displayed like any other hologram, and, therefore, should be called a hologram.

In digital holography, the object is illuminated by coherent light, some of which is scattered and mixed with a reference wave on a digital sensor.

The resulting interference pattern is recorded by a computer. At this stage in digital holography, there are two choices for reconstructing and viewing the wavefront, which are also illustrated in the figure. Most commonly, the recorded hologram is analyzed computationally by applying well-known diffraction and propagation equations, which can propagate the wave to any desired plane in virtual space; then, the intensity at that plane can be displayed on the monitor. In this way, the reconstructed image can be scanned electronically and displayed plane-by-plane.

Alternatively, the stored hologram can be transferred to a spatial light modulator illuminated by a reference wave as shown in the figure, and viewed in the same way analogue holograms are viewed.

With digital holography, holograms can be produced, and holography experiments can be run, numerically, not only without lasers, but also with synthetic wavefronts (without having real wavefronts at all). In this way, holography experiments can be simulated, providing a straightforward way to test an optical setup before it exists as hardware.

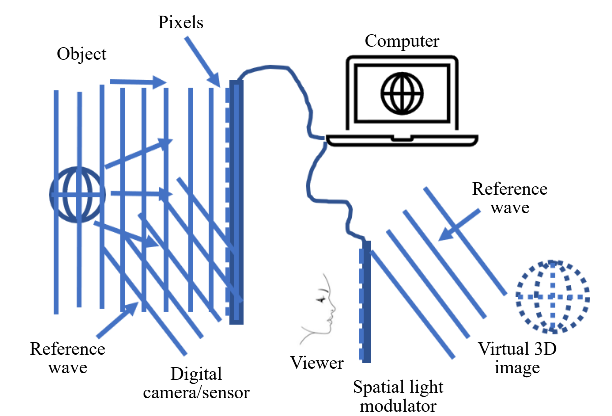

Fig. 3 Recording a digital hologram and reconstructing wavefronts from it.

The data stored in a digital hologram in a computer can be used to produce a variety of different types of holograms. The computer can control an etching machine to reproduce computer-generated holograms. These have a wide range of practical and commercial applications, such as for use in spectroscopy gratings, holographic optical elements, and embossing and casting masters for use in mass production. Holograms can be printed into direct writing materials like photopolymers. These operations result in yet another vocabulary of holography procedures and materials.

Comprehensive and General Definition

In searching for a correct, useful, and optimal definition of holography, the author sought out the opinions and preferences from many friends and associates worldwide. In almost every case, individuals responded with their own different definition. Although some seemed inadequate or not sufficiently general, most provided insights, and were incorporated into the wording and ideas leading to the results arrived at here. Many of the suggestions were too restrictive and left out important features or hologram types, or placed requirements that were not necessary. Accordingly, it is a challenge to obtain universal agreement on the best definition of holography. The author recently participated in a panel discussion with experts, who also found it difficult to arrive at a single definition of holography.

General definitions of holograms and holography should accommodate at least the following properties, features, wavelengths, and applications of holograms: security, mass production[13], computer graphics[14], spaceflight[15], microscopy[16,17], acoustics[18], x-rays[19], microwaves[20], and art.

They should include terms and phenomena understandable by a person with an optics background, and who is also qualified to create a completely general definition of holography. Those who do not understand any of the following points lack knowledge of the important features of holography that must be covered by a general definition.

1. Holograms are recordings that capture and preserve all of the information (i.e., the amplitude and phase) in waves required to reproduce the waves (including light, sound, radar, microwaves, and x-ray waves), in such a way that an accurate replica of the original wave can be reconstructed and propagated.
2. When a visible image of an object is reconstructed from a hologram and viewed through the hologram, it can be seen in 3D; moreover, if the object has depth, it can be focused and “seen” from its sides, and exhibits

parallax.

3. Not all holograms are used for storing and displaying 3D images.
4. A hologram is not an image, and an image is not a hologram.
5. Real-time holograms of time-varying waves can be recorded continuously and used simultaneously to reconstruct a changing wave or its conjugate.
6. Not all holograms are recorded on photographic or photosensitive materials.
7. Holograms can comprise any material, and many different mechanisms can enable the storing of the necessary information for a sufficient time, i.e., to enable reconstructing the original wavefront from which the information was obtained.
8. In digital holography, holograms can be created, stored, processed, and analyzed in a computer without using lasers or optics.
9. In digital holography, wavefronts can be reconstructed, focused, filtered, projected, and interfered numerically in a computer, as if in space.
10. The information stored in a hologram can exist on the surface and/or throughout a volume of recording media, or in a computer.
11. Holograms can exist in air/gas (otherwise known in physics as four-wave mixing).
12. Holograms known as HOEs (holographic optical elements) can replace and/or act as many types of optical elements, such as lenses, mirrors, and beamsplitters.
13. Holograms can be produced without using lasers, coherent light, or any type of real wave. (e.g., embossed, etched, computer-generated holograms, and digital holograms)
14. A phase conjugate mirror is a hologram.
15. Holograms are not required to produce 3D images, as 3D images and 3D effects can be produced by other optical methods.
16. Holograms are used for various applications, as follows.

• 3D imaging
• Security-Mastercard, Visa, currency, passports, stamps, tickets, documents
• Advertising and displays
• Portraiture
• Art
• Interferometry
• Measurement
• Information storage, archival, retrieval, and processing
• Optical elements
• Visualization of radar, sonar, ultrasound, lidar, magnetic resonance imaging, computer-aided tomography scans in 3D
• Stamping masters for producing embossed holograms
• Aberration correction

Holography clearly requires its general definition and language to include much more than the layman's definition given above. More general definitions that are consistent with the "window" definition, but which also cover the entire field of holography, are as follows.

Optical Hologram (n) A recording of a light wave that employs the principles of diffraction and interference phenomena to store information sufficient to enable reconstruction of an almost perfect replica of the original wave.

Hologram (n) A recording of any type of complex wave, such as a light, sound, x-ray, radio, or synthetic wave, that employs the principles of diffraction and interference phenomena to store information sufficient to enable reconstruction of a nearly perfect replica of the original wave.

Holography (n) The process of recording and using holograms; usually a two-step process, in which the first step records or creates the hologram, and the second step employs it to reconstruct and manipulate wavefronts and images.

Notably, the above definition of "hologram" includes the expression "complex wave"; this can be interpreted in two different ways, both of which are correct. A layman may think of a complex wave as another way of saying "complicated wave", which is correct; a scientist is more likely to think of it in mathematical terms, i.e., as a wave described by a complex expression, with a real part providing the amplitude, and the imaginary part representing the phase. This latter definition is also correct, and enables operations like conjugation, a mathematical procedure for changing the sign of an imaginary term to reverse the direction of the wave while maintaining its phase.

The above general definitions are consistent with the layman's definition, and they also rule out other forms of 3D image recording. They include the processes and languages used for the following types of holography.

1. White Light Reflection holograms (Denisyuk holograms)
2. In-line holograms (Gabor holograms)
3. Off-axis holograms (Leith-Upatnieks holograms)
4. Synthetic wavefronts (described below)
5. Embossed holograms
6. Cast holograms
7. Holograms of photographs
8. Holographic optical elements

9. Holographic gratings
10. Image plane holograms
11. Phase conjugate mirrors
12. Real time holograms
13. Digital holograms
14. Computer generated holograms

Existing Incorrect Definitions and Language in Holography

Compounding the language problems today are the many products that are referred to as "holographic", but that certainly do not fall within the ranges of our last two definitions. In legal language, a "holograph" is a handwritten document describing the wishes of the writer, which adds confusion to the definition of a hologram. People sometimes mistakenly use hologram and holograph interchangeably.

An on-line search for the definition of "holography" can partially explain the confusion regarding holography. A Google search for "Hologram Definition" produces incorrect definitions, describing holograms as images. A hologram is emphatically not an image. Others are equally incomplete, or outright wrong. Such definitions appear in legitimate dictionaries. The following are actual definition examples found from a random search.

1. Hologram- a three-dimensional image formed by the interference of light beams from a laser or other coherent light source.

2. Hologram- If you've ever looked through a View-Master, you've seen a hologram — an image or photograph that appears to be three-dimensional.

3. Hologram definition: A hologram is a three-dimensional photographic image created by laser beams.

The incorrect expressions widely accepted in holography, some even by experts, may explain much of the confusion in the public understanding. Incorrect definitions now appear in many classical dictionaries and on-line. Some of this language is so widely used and part of the common language that it may be difficult or impossible to remove. This situation possibly began when many people began referring to the images produced by holograms as "holograms", opening the door for all 3D images, including non-holographic images, to be called "holograms". Some widely used phrases are listed below.

1. "He is a hologram". A person or an image of a person cannot be a hologram; what is seen is a holographic image of a person. 3D images and effects can be produced without using holograms, and existed long before holography.

2. "That image is a hologram". Holograms can be used to produce images, but they, themselves, are not images; rather, holograms are recordings.

3. "Reconstruct the object". Objects are not reconstructed. Images of objects are reconstructed.

4. "I will reconstruct the hologram". With one exception, holograms are not reconstructed; holograms are produced or formed (constructed), and then are used to reconstruct wavefronts and images. The exception is the case where a hologram has been formed and then duplicated (reconstructed) somewhere else, as another hologram with the same information. With this exception, "reconstructing a hologram" literally makes no sense. This error is one that will be especially difficult to correct, because many holography researchers and colleagues use this literally meaningless expression.

Discussion and Conclusions

In the foregoing, we described and analyzed existing problems in the language of holography. Understandably, many people now think all 3D images are holograms. Many companies call their products holograms when they are not, many holographers are unaware of applications of holography besides 3D imagery, and communications in holography can be confusing and incorrect. This is further compounded by incorrect definitions for holograms existing in respectable dictionaries. Is this situation repairable, or is the language so widely accepted that we must live with it? Does the scientific community have an obligation (or even the ability) to better educate the general public regarding holography to help them appreciate and enjoy the richness of holography?

As with the arts and all forms of entertainment, holography can become more enjoyable as one learns more about its structure, what to look for, how to look, what there is to be appreciated, how it can offer more, and what it offers that is different than other forms of 3D imaging. Learning some of the holography language and how to look at holograms can provide depth to improve discussions and entertainment, and to make them more enjoyable. One of the greatest gifts holographers could give to the public is an understandable, useful, consistent, and accurate language that will help others enjoy holography. That would also be valuable to the field of holography.

With hopes of developing definitions that should prove useful for different holography communities, we offer consistent definitions. The first definition for optical holography should be understandable and useful to all, and covers most holograms likely to be encountered by the general public. The second definition is a completely general definition for the scientific community that is consistent with, and more general than, the first; it is especially useful for optical scientists. The general definition accommodates applications in the many diverse industries where holography plays an important role.

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Conflict of interest

The author declares that he has no conflict of interest.

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