

Spatial Imaging's guide to dimensional imaging techniques

This is an extensive, text based guide to ways of simulating the three dimensional world with specific reference to holograms and holography. Most common questions are covered, based on what people have asked over the years. If you are really interested in using holography, then read this document. If there is something I've missed or you don't understand, please email us at sales@holograms.co.uk.

Introduction

Throughout history, there have been attempts to represent ideas about ourselves and the world around us. The sophistication of these representational techniques has increased in modern times leaving a bewildering number techniques.

Realism in two dimensions has been both conquered and distributed through painting, printing and photography. The fourth dimension, time, is catered for by film and television.

The final barrier to a realistic facsimile of the world is the third dimension - depth. The problem is very simple: make one eye see one picture and make the other eye see a different picture.

The following pages attempt to give an overview of the different techniques available to represent the third dimension. While some of the techniques such as polarising glasses can be applied to film, the focus is on printed and display materials.

While there is a huge amount of information on three-dimensional imaging with respect to computer graphics, this document does not cover this area, except in relation to hard copy.

There are no books specifically covering all the different ways of achieving the illusion of depth. Aimed primarily at the design and production professional, the following pages clarify many of the misconceptions surrounding the subject. Advice on which technique will best suit a particular application from promotion to products is given.

Every attempt has been made to make the information herein both up to date and factually correct, errors and omissions are the authors. In some cases very detailed explanations of specific processes have been omitted either to simplify an understanding of a technique or where proprietary methods are involved.

Holograms

What Holograms are not Hologram makers are often asked to make an image float in the middle of a room or cinema. They are also asked to make holograms of people walking around a room or holograms of herds of animals running toward the viewer (life size). This is simply not possible. Current cinematic 3D projection techniques do not use any holography.

Those who have seen Star Wars and other science fiction films where the term hologram is used, often confuse science fiction with reality. Unfortunately, no one has found a way of projecting a fully three-dimensional image into space, remotely from the projection device.

There is a simple but as yet impossible obstacle to overcome before this can be done; that is, how do you make light bounce off air? After all when you see something, you actually only see the light bouncing off it. If light did bounce off air we would be in total darkness as the light from the sun would bounce off air in the atmosphere and back into space. This is why laser light shows use smoke - it gives

the light something to bounce off. Volumetric displays may use a moving vortex to give the illusion of depth, but this is not holographic.

Another problem is the amount of information in a hologram. Even in the simplest hologram, there is many times more information than in, for example, a photograph. As we reach the end of the millennium, computers simply do not have the power to process the data contained within even a simple hologram. Another misconception is that 3D TV systems use holography. They do not. Sometimes you hear of holographic projection screens. These are conventional projection screens made using a partly holographic process. They are not as the term suggests, ways of projecting holograms.

What are holograms?

Holography is the recording of the phase and amplitude of the light waves that bounce off an object.

Holograms are made using laser light and optical components in a special type of camera. The camera is nothing like a normal camera but a table made to hold the laser, mirrors and lenses which make the hologram. The process is complicated and takes many years to master. That said, there are some basic points about making holograms, that give some idea of the process. The following is a very simplified description of the process and is not meant to be a 'how to'.

Making a simple hologram

Please skip this section or read it later if it gets a bit technical.

In normal light, such as that from a light bulb or the sun, the individual 'particles' or waves of light (called photons) move randomly through the air. Coherent light is light in which the photons are moving together in an ordered way. Imagine that in sunlight the photons move like a crowd of people in a shopping centre, whereas in coherent light the photons move like a marching army. To make a hologram a source of coherent light is needed. The best source is a laser. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.

A hologram is the recording of two sets of waves. The first wave, called the reference beam, comes directly from the laser. The second wave hits an object, bounces off and interferes with the first wave. The hologram records this very complicated pattern on a high quality photographic plate.

The first thing to do is split the laser beam into two parts. Both beams must come from the same laser to make sure all the photons are in step with each other. To split the laser beam in two, a device called a beam splitter is used. A beam splitter can be as simple as a piece of ordinary window glass or a precision coated optical device. Like most things in life, the more you pay, the better the result. The purpose of the beam splitter is to allow some light to go straight through and for some light to reflect off its surface. In this way, the single beam becomes two beams.

The next problem is that the laser beam is very small, only 3 or 4 mm in diameter. If we want to make a hologram of something, even as small as a matchbox, the beams must be spread out to cover the object.

This is done with a lens. The more powerful the lens, the more the light is spread out. Professional hologram makers use the lenses from a microscope, often called a microscope objective.

We now have a laser, a beam splitter and two beams that are spread out. Using some mirrors, the first beam (reference beam) is shone onto the holographic plate. The second beam is directed at an object. The recording plate is placed where these two beams meet. The whole set-up is called a holographic camera:

If the reference beam and the beam bouncing off the object both hit the holographic plate from the same side, a transmission hologram is made. If the reference beam hits the plate from one side, while the beam from the object hits the plate from the other side, the result is a reflection hologram.

There are many kinds of holograms, but all holograms fall into two basic categories:

1. Transmission holograms
2. Reflection holograms

Zebra holograms

These are reflection holograms that are computer generated, can be tiled to make *any* size hologram, have full colour, including white, full parallax (you can see side to side, and up and down) and can be relatively cheaply mass reproduced. They can contain small amounts of animation or multiple discrete channels. The input format is 3D Studio scene files. Spatial Imaging can generate these. They are made by only one company in the world, Zebra Images and come in 24 inch X 24 inch panels. The technology used to make these holograms came from research started at MIT in Boston at the Spatial Imaging Group under Steven Benton, the inventor of the transmission hologram – see below.

Because these holograms are computer generated, the production process can be controlled in ways not possible with conventional holography. That said Zebra holograms still use lasers and produce their effect by recording an interference pattern of a photo-sensitive material, like conventional display holograms, albeit in a very sophisticated, computerised manner. Spatial Imaging are an official distributor of Zebra holograms and would be pleased to discuss any questions you have about them.

Transmission holograms

Most holograms you will see in every day life are transmission holograms. The hologram is transparent to allow light to pass through from behind and reconstruct the holographic image. The holograms found on credit and bankcards are of this type. They are called transmission holograms because ideally they are lit from behind, like a photographic transparency (slide), the light being transmitted through them.

Often it is not possible to light the hologram in this way so a mirror or aluminised foil backs them. This is why bankcard holograms have a silvery appearance. The light then bounces off the mirror backing and effectively lights the hologram from behind, as on a credit card.

Transmission holograms are also known as rainbow holograms as the light being used to illuminate them is split into a spectrum, the hologram representing the 'correct' colour(s) from one angle, while at other angles seen in different colours of the spectrum (from deep blue to red).

Transmission holograms can be large (>1m²) or small (<10mm²), be one off's, or mass-reproduced using a technique known as embossing. This will be explained in the manufacturing section.

Reflection holograms

The other basic type of hologram is the reflection hologram. This is usually a single colour - often yellow/gold looks the best and brightest - but can be two or even three colours. Black and white holograms, although difficult to make, are possible. Using

the photographic analogy again, reflection holograms are like photographs in the sense that they are lit from the front and reflect the light back to the viewer.

The reflection hologram looks visually different to a transmission hologram. Its monochrome nature and high resolving power makes it look more like a three dimensional photograph. Generally 50cm X 60cm is the largest size made.

Imaging Techniques in Holography

There are two basic decisions to make when specifying a hologram. The first is the way the images will be generated and the second is the production process. These two factors are in turn linked to the number and size of holograms required, the brief and the overall effect desired. The following pages discuss the imaging techniques followed by the production processes involved.

Display holograms

The term display hologram is usually used to describe large, single holograms for use in shop windows, bars, exhibitions, universities, trade shows and other places where an eye-catching single piece is required.

They can either be transmission or reflection holograms. The two most common sizes are 30cm X 40 cm and 50 cm X 60 cm. These reflect the sizes in which the holographic material is supplied from the manufacturer.

Larger film is available which is 1 metre wide by 10 metres long. For this reason, the largest holograms that can be made from a single piece of film is about 1 metre square. Apart from Zebra Holograms (see earlier), conventional holograms above this size are prohibitively expensive and are uncommon. This is why one does not see "bill-board" size holograms - yet.

Generally, this type of hologram uses real objects or real people as the subject. Natural subjects work very well. Their intrinsic complexity is shown in very fine detail using this type of holography.

Product shots are done in a similar way. The constraints are very similar to those of a normal photographic studio. The scale is 1:1. If a hologram of a mouse were required, the holographic plate would need to be about six inches square. If a portrait is to be made, a 30cm X 40cm plate would cover the head and shoulders of the sitter.

Using a Pulse laser, a single shot produces a three-dimensional image. Moving subjects such as bullets and birds in flight can be captured, as the pulse of light is extremely short.

More than one image can be made on a holographic plate. For example, two objects could occupy the same volume, or the image could change as the viewer moved from left to right. The latter is known as a multi channel hologram.

When entering into production of a display hologram, there are certain common activities in the process. Consultation with the client will concentrate on what the hologram has to achieve. This is down to the hologram design. This usually involves a visit to the site and discussions as to the purpose of the hologram. Normally a set of two-dimensional visuals will be produced to start the production process. These will take into consideration location and size of the hologram. Ambient light conditions are important, as is the angle of view.

Special consideration must be given as to whether the hologram receives any direct sunlight. It is strongly recommended that the hologram be placed in a position that avoids direct sunlight. The hologram will usually be illuminated by a ceiling mounted tungsten halogen spot light. Powers are available between 25 and 75 watts. A 50 W bulbs usually sufficient.

If high ambient light conditions are a problem, a transmission hologram may be preferable to a reflection hologram.

Mounting display holograms

There are many ways to display holograms. There are no standards for mounting display holograms, and often the client will have their own ideas.

One popular mounting technique involves fixing the image to an oversized piece of bevelled glass. The glass hologram is fixed with special tape to the glass-mounting sheet. Both the hologram and the mounting glass can be screen printed or sandblasted with graphics, company logo or text. Holograms cannot reproduce exact colours, so the screen printing process allows logos and other corporate graphics to be perfectly colour matched, even to the Pantone level. The surface of a display hologram is normal float glass. Anything that can be done to normal glass surface, can be done to a hologram surface.

Consideration must also be given as to how the mounted hologram will be fixed to a wall or ceiling. One of the most elegant methods is to use suspended cables. The various fittings are available off the shelf, or can be specially made by any number of engineering companies. This is particularly relevant to back lit transmission holograms, where they must be positioned in such a way as to allow light to pass through the hologram from behind.

Lighting display holograms

The mounting and lighting of a display hologram are closely linked and should be considered together.

Various light sources can be used. The two factors to consider are that the light is as much a 'point source' as possible, that is it is not diffuse, and for some specialist applications that it is as monochromatic (single colour or wavelength) as possible.

By far the most common way of lighting a display hologram is to use a low voltage (12V) Tungsten Halogen spotlight with a high reflective (NOT diffuse) reflector. These are very common and available in most lighting retail outlets. They are available in 25, 30, 50 and 75 Watt powers. The higher the power, the brighter the hologram will appear.

These lights use low voltage so a transformer is required to reduce the input voltage. Many types are available that have an integral transformer. If a number of lights are required, a larger transformer can be used to drive several lamps. Alternatively, a track lighting system with its own integral solid state transformer may be more suitable. Some of the very latest Halogen lamps can now operate directly from mains voltage.

Ideally, a hologram should be illuminated with the conjugate of the beam that was used to make the hologram. A hologram is usually made with a diverging beam, so ideally the illumination source would be a converging beam. This is the opposite of conventional lighting where the light diverges from the source.

For technical reasons during hologram manufacture it is rarely possible, without great expense, to make the hologram with a converging reference beam so that perfect illumination can be achieved with a common spotlight. However, for most applications this is not a problem. In reality, only portraits show this effect to any large degree, because the eye is so tuned to recognising faces. A 'half way house' solution would be to partially collimate the white light source using a small lens in front of the light. Although expensive, these are commercially available and are commonly used in shops. Alternatively they can be made to suit specific applications.

The vast majority of display holograms are known as white light display holograms, as the illumination source is standard incandescent light (such as a spotlight). For greater clarity and depth, a more monochromatic light source may be required.

The simplest way to achieve this is by filtering a conventional bulb, either by buying a dichroically filtered Halogen bulb, or by physically placing a filter over the light. The problem here is that the transmissive wavelengths of the filter must precisely match that of the reflection hologram. This can be difficult because the replay wavelength of a reflection hologram will change with ambient temperature and humidity.

Sodium and Mercury Vapour Lamps emit light in quite narrow bands of the spectrum and can be used to light holograms. Usually, additional filtering is required to allow a very narrow band of the spectrum for the sharpest image.

An ideal light source is the laser itself. While lasers have in the past been prohibitively expensive and delicate for display purposes, modern diode lasers are approaching a price level similar to that of high quality incandescent lamps. They are also far more rugged than the old gas lasers. Diode lasers for displaying holograms are more powerful cousins of the lasers found in CD players. They can be purchased with integrated optics for spreading the beam, are small and can be run from batteries if necessary. In the near future laser lit holograms may become more common because of these factors.

Holographic portraits

Although not strictly a type of hologram, because of their unique qualities, the holographic portrait is a distinct art. One of the basic rules of conventional holography is that the subject matter must not move during the exposure. The term no movement means no more than one tenth of the wavelength of light used to make the hologram. This is a very small distance. If we take the common continuous wave Helium Neon laser as an example, this has an wavelength 633 nanometres. A nanometer is one thousand millionth of a meter! Forget about trying to stay still.

With portraiture, a different technique is required. The sitter is exposed to a very short high-energy burst of laser light, so rapid in fact, that the sitter cannot move a tenth of the wavelength of light during the exposure. This type of laser is called a Pulse laser and was one of the first types of laser to be developed.

Typical examples would be the Ruby Pulse Laser which uses a Ruby crystal as the lasing medium and the Neodymium Yttrium Aluminium Garnate (YAG) laser, a modern solid state laser. The Ruby Pulse Laser emits a wavelength of 694 nanometres (deep red) while the YAG laser produces green light.

If one wanted to make a portrait of a person they would come to a holographic studio and a master hologram made. The sitter is positioned within the hologram camera and a single flash of laser light illuminates them for a fraction of a second. The technique is not dangerous and many famous people, including Presidents and pop stars have all had their holographic portraits made. The master hologram can only be seen in laser light. A white light reflection transfer hologram is made allowing the final copy to be any single colour (red, yellow, blue etc.). Using a double exposure transfer technique, black and white hologram transfers are possible.

The next step for holographic portraits is a full colour images. This requires the use of red, green and blue pulse lasers all exposing in unison onto a panchromatic emulsion. In the near future, this will be possible, but as yet there have been no true, full colour portraits made.

Holographic stereograms or "moving holograms".

A hologram may be produced from a series of two-dimensional pictures. These may come from video, computer graphics, artwork, and photography, or can even be hand drawn animation.

Using a specialised holographic printer, such as Spatial Imaging's Digital Input - Holographic Output (di>ho) printer, the images can be sequentially recorded onto a

holographic plate. The result is a hologram that presents a succession of two-dimensional images.

If the initial images are made in the correct way, the resulting holographic image can be three-dimensional. Alternatively the images may be animated and appear to move as the view changes from side to side or from top to bottom.

A combination of 3D and movement is also possible. This effectively creates a "holographic movie." There is a technical limitation to the number of frames from which the hologram is made. The maximum is about 60 frames. This creates a small piece of animation. An example would be a footballer scoring a goal. This is not a route for making full length feature films.

One of the advantages of this type of holography is that images can be appropriated from existing sources such as video and film archives. If the right sequence is chosen, very effective holograms can be made, for example of people who are no longer alive.

Moving holograms can be either reflection or transmission holograms, one-offs or mass reproduced.

The largest, full colour, animated hologram available was until recently 50cm X 60cm - now using Zebra holograms we can produce tiled holograms of unlimited size. Colour movie footage must be produced. This can either be commissioned or appropriated from existing footage.

With the advent of inexpensive digital video, supplying a hologram manufacturer with images suitable for hologram production directly from video or video/computer graphic combinations is no longer an expensive or time consuming process.

The Tagged Image File Format (TIFF) is generally considered the most versatile format and most hologram makers use this as a standard. Images can be created using any operating system such as Macintosh, Windows, SGI etc. There is no difference as far as the hologram manufacturer is concerned.

2D/3D Holograms and Colourgrams (2D/2D) Holograms can be created from flat artwork. There are two basic types, the 2D/3D hologram and the 2D hologram, sometimes known as a colourgram. These are generally mass - reproduced embossed holograms used as brand authentication or security.

2D/3D holograms are made by producing flat films of the different LAYERS in the hologram. Each layer would be separated by one or two mm. The illusion of depth is created by making holograms of the flat artwork at different depths, hence the name 2D/3D - two dimensional layers, separated in three-dimensional space.

Display holograms, either reflection or transmission, can also be 2D/3D holograms and have been made to form dimensional logos and corporate graphics for shop displays. A 2D hologram is completely flat and uses holographic diffraction to generate colour. This type of hologram can be generated from an individual full colour image. An example would be an embossed hologram postcard.

2D/3D holograms have been very popular in the past, but are now generally regarded as old fashioned. More commonly they are used in conjunction with dot matrix holograms for a more sophisticated effect.

Dot matrix or diffractive pixel images

This type of hologram is generated from a single computer image, and is almost exclusively of the embossed type, although photopolymer dot matrix holograms are possible. The holographic image is made up of a series of dots or pixels using a special holographic printer. Each pixel or dot can diffract coloured light at a different angle. The image seems to be kinetic as it is moved and different regions of the image are illuminated. They may be called optically variable image devices (OVID) or diffractive optically variable image devices (DOVIDS). This term is also used on an

older variant of the dot matrix hologram whereby small areas of diffraction are produced using masking techniques.

This is probably the fastest growing commercial use of holography today. The images made with this technique can be seen in any lighting conditions and the artwork is relatively simple to generate. Although this technique has been traditionally used for security printing, it lends itself to promotional material and packaging due to the less than perfect lighting in retail outlets.

The technology for producing these types of holograms is rapidly becoming more sophisticated.

Multi-layered and 3-dimensional effects are now possible. The resolution of the holograms has also increased with a current maximum of about 2000 dpi. The resolution at which the image is printed determines the cost. Common resolutions are 100, 400, 800, 1000 and 1200 dpi. A hologram at 1000 dpi will contain one million dots per square inch - obviously many more dots than one made at 100 dpi (10,000 dots per square inch). The higher the resolution, the longer the hologram takes to print and so the higher the cost per square inch.

Multigrams

A multigram is the generic term given to a hologram that combines two or more origination techniques in the final image. A typical example would be the combination of a stereogram sequence with a diffractive pixel image.

An extension of this basic idea would be to include a "hidden image" element within the combination. A hidden image is usually a master hologram, encoded into the transfer hologram, so it can only be seen in laser light. When illuminated with laser light, an image can be seen to project out from the hologram and be visible on a surface.

Multigrams are generally used for very high security applications where anti-counterfeiting is paramount.

They are quite costly to originate because their production involves several mastering stages. These holograms are almost exclusively produced by the embossing method.

Conventional 3D embossed

This technique involves making a hologram of an object, usually a model. Once one of the most common type of hologram, this technique has been largely replaced by stereograms, 2D/3D and diffractive pixel holograms.

Manufacturing techniques

There is no single answer as to how holograms are made. The way holograms are reproduced usually depends on the number of copies required and the size. These two elements usually determine the methods and materials used in production, which directly effects the unit cost.

Once again the two main type of holograms are used to explain the different manufacturing process. With one or two exceptions, all techniques start with a master hologram. This is either used directly to produce copies, or as part of additional intermediate stages to the final hologram.

Types of transmission hologram

Embossed holograms

Embossed holograms are the shiny holograms seen on credit cards and packaging. The original hologram is made into a metal copy. Duplicates of this are made and these are used to make millions of copies by embossing the pattern into soft aluminised plastic. Embossed holography is by far the most common form of holography as the material can be produced quickly and cheaply in large quantities.

Embossed holograms are the type found on credit cards. The subject may be animated (stereograms) a small model (the Visa Dove), flat art work 2D/3D or 2D/2D or a diffractive pattern (Diffractive Pixel Image).

The technique of embossed holography lends itself to mass-reproduction. A run of several million holograms is not uncommon.

Embossed holograms are mastered on a Photo-resist plate, a light sensitive material on which ridged patterns of holographic fringes are recorded. The plate is very easily damaged and must be handled in clean conditions with great care. The photo-resist plate is a piece of glass, specially coated to:

- a) Record the hologram.
- b) Prevent internal scattering of light on the plate via a special coating.

Once the hologram is recorded, this glass plate is coated with a very thin layer of pure silver in a vacuum coating chamber to make it conductive to electricity. A nickel "shim" is "grown" from the master hologram in a special electroforming tank. This first "grandmother" shim is a thick (1mm) piece of nickel.

Once grown, (approx. 24 hours after being placed in the tank), it is peeled from the photo-resist, destroying the original photo-resist hologram. Copies of this grandmother shim are grown to produce mothers and copies are grown off the mothers to make daughter shims. These are now production shims that are fixed to a heated roller on an embossing machine.

A thin aluminised plastic film passes through a set of rollers and the holographic image is transferred or embossed into the plastic. The resulting material can be used as hot stamping foil for foil blocking, or is adhesive backed and wax paper backed for pressure sensitive labels (stickers).

There are two formats for embossed holography:

1. Narrow web (6" – 12")
2. Wide web (24" - 48")

The narrow web embossing machine can emboss a 6"X6" area and the maximum size for a single image hologram is normally restricted to this size.

For wide web embossing there is an additional production stage whereby small shims, typically one inch square, are mechanically recombined into a large single pattern. It is not possible to create a large single image with this technique. It is used to make a "wallpaper" pattern that repeats seamlessly to form a continuous pattern.

Embossed holography is by far the most common form of holography, as the material can be produced quickly and cheaply in large quantities. Examples in addition to credit cards would include confectionery packaging, toothpaste packaging and other security holograms. Typically, a small security hologram would be produced on a narrow web machine, while packaging material would be produced on a wide web machine. A higher quality material is achievable using narrow web embossing.

Conversion

Conversion or converting is the term used to describe the post manufacture cutting and application of holograms, for example, blocking holograms onto greetings cards or applying hologram labels to CD jewel cases

Silver halide

This is a photographic type material, similar to conventional black and white photographic film but with a very high silver content. When processed the film is virtually transparent. Though it can be used in a mass reproduction process, it is normally reserved for display holograms. The film is sensitive to red laser light, usually from a Helium Neon, Krypton or Ruby Pulse laser. The material comes as either film or glass plates.

Plates are more expensive than film. The material is processed in a similar way to photographic film, via a special developer and bleach. Mass reproduction of silver halide holograms is now limited to 10" X 8."

Photopolymer has largely taken over this medium for replication work (see later).

Silver Halide is ideal for large display transmission holograms. The largest size of film available is 1m X 10m. Multicolored and full, true colour transmission holograms are possible. These make the separate "rainbows" overlap causing colour mixing or areas of distinct colours. It is generally simpler to make large transmission holograms than large reflection holograms.

Ideally, a silver halide transmission display hologram should be lit from behind. With the right type of imagery, some beautiful effects can be achieved.

Types of reflection holograms

After embossed holograms, the next most common type of holographic material is photopolymer. This is a relatively new material, but has quickly taken over from the more expensive and more difficult to handle silver halide material.

Photopolymer

Photopolymer is a light sensitive plastic that can be used to make holograms. The material lends itself to mass reproduction and forms a commercial bridge between embossed holography for millions of copies and silver-halide holograms for small runs. The images are made using a high powered Argon laser and are copied from a "sub- master" hologram using a scanning laser beam.

The finished product is normally a single colour (red, yellow or green) and produces clean bright, easily viewable holograms. Multicolored and full colour copies have been made but are still rare and expensive. Three colour, i.e. full colour, photopolymer hologram requires red, green and blue lasers, and are difficult and expensive to produce at this time.

Examples would include licensed images such as Star Wars[®], Star Trek[®] and "Super-Hero" images typically 3" X 3" square. These are usually packaged and card backed for sale in retail outlets. Other giftware would include holographic sunglasses, badges etc.

Silver Halide

(See also above regarding transmission holograms)

For mass reproduction of reflection holograms, a laser viewable sub-master is made and copies taken from this. Using special chemicals, a gold coloured hologram can be produced. Multicolored holograms are possible, but this is generally reserved for single images. Because of cost and production constraints, photo-polymer has now become the preferred material for mass reproduced reflection holograms.

Dichromate

Dichromate holograms have been used in the past to make pendants and key rings. The process involves coating a flat substrate, usually glass with a layer of gelatin impregnated with potassium dichromate. After exposure in the holographic camera the material is processed in a series of alcohol/water mixtures. The process is labour intensive and as such production is now almost entirely in the Far East, though one or two specialist manufacturers still exist in the USA. The final product must be encapsulated to prevent moisture attacking and destroying the gelatin.

Common examples would include watch faces, jewellery and 1-2 inch holographic pendants of a pyramid or Egyptian Cat. Some beautiful full colour examples exist. These are expensive, crafted holograms and have almost entirely been superseded by photo polymer.

Pricing - the economics of scale

Pricing a holographic job can be a frustrating process, especially to those unfamiliar with hologram production, which is nearly everyone. There is often more than one company involved, all quoting specific prices for specific processes. The stages in production can be difficult to understand and often lead to confusion.

Conventional printers can often complete holographic jobs with existing equipment but either ignorance or an unwillingness to run non-standard material steers them away from using holography to it's best advantage.

As we have seen, the most common type of hologram, the embossed hologram, is made using a mass reproduction technique. Using this process, it is usually uneconomical to print small runs. Two hundred business cards based on a custom hologram are simply uneconomical. Very high profile documents may warrant the expense but are not the norm. Runs of 20,000 would be at the low end of feasibility and runs of one million or more can be manufactured at prices close to conventional printing.

Costing for custom embossed holography

The first questions to ask is why use holography and what type of hologram?

There are many possible answers:

Security : Stereogram, Diffractive Pixel 2D/3D or 2D/2D?

Promotion: Emphasis, Distinctiveness, Quality, Viewability (Diffractive Pixel hologram), Movement or animation (stereogram), Customer appeal etc. There are many examples of holography increasing sales due to successful targeting of markets in packaging and promotions.

There are considerations for the use of the final product, (water and heat, reader tolerant etc.) production volumes, the look and feel of product and of course costs. To optimise both time and money, production processes must be planned and a clear idea defined of what is required by both client and producer. It is generally too expensive to proof holograms as the expensive part of the process is making the first image.

While pre-visualising a hologram is a reserve of the professional, samples of similar jobs usually provide a close enough match to proceed.

Project management is key in a successful embossing job. There must be close co-operation between the hologram maker, hologram printer, conventional printer and converter. Ideally, someone who knows all the processes involved will oversee all aspects of the job.

The simplest job to cost is for pressure sensitive labels (stickers) supplied kiss-cut on a roll of waxed back paper. This greatly reduces unknown factors. The client knows what a sticker is and usually has dealt with similar, non-holographic labels.

Size and quantity are the two most important parameters.

Certain extra elements may be required. The standard high quality foil is 50 micron polyester but is also available in 20 or 30 micron thickness. Some packagers prefer this material.

For security labels, specialist tamper evident foils are available. One type reveals the word "VOID" when an attempt to remove the hologram is made. Others reveal a chequered pattern to show tampering. As a guide, the minimum order for this specialist material is 5 rolls and costs are approximately twice that of normal 50 micron material. Tamper evident foils are used on high value, high counterfeit risk products such as vintage wines and spirits, software packaging etc.

Over printing of the hologram is also possible. The material must be first coated with a print receptive lacquer, then screen-printed in register to the hologram. Each process adds cost and is only suitable where either large volumes or high unit cost is permitted. If 3000 holograms, 2" square, full colour overprinted, applied to card with full colour printing on the back is requested, the unit cost will be several pounds. The same specification for one million holograms will bring the price into pence.

Foil blocking (sometimes called hot-stamping) costs depend on complexity, quantity, size and material. There are many printers capable of foil blocking. The hologram suppliers will either put you in touch with suitable printers in your area or project manage the whole job.

Costing display holograms

The other end of the spectrum is display holography. This can be a viable option for a company centrepiece for a foyer or show. Prices would be comparable to a commissioned painting or inexpensive sculpture.

Once mastered, holographic copies can be reproduced at about one sixth of the original cost. Pricing display holograms is relatively straightforward:

1. Are there models, make-up, artwork, props or other elements of the image required?

If so, these can be costed as they would be for a photographic shoot. A display hologram is usually a hologram of something or someone. Does it have to be made or does it exist?

2. The master size is either 10" X 8", 30cm X 40cm or 50cm X 60cm or unlimited in 60cm by 60cm increments for Zebra holograms. Check the price.

3. Is the copy a reflection or transmission hologram?

4. How is the hologram to be mounted, and will the holographer oversee this work?

It is often the case that mounting and installation will cost as much as the hologram itself. See the relevant section.

Specific areas of holography

Nearly one billion dollars worth of holographic material are sold world-wide per year. Sales of holographic production are increasing every year and vary by market sector. The main areas, with the percentage of the market they fill are:

Security Printing 32%

Brand Authentication 29%

Giftware 7%

Packaging 13%

Promotion 10%

Stationary 8%

Publishing <1%

Clothing <1%

Display <1%

Security printing and brand authentication

These two areas make up over 60% of the holographic market and are the most important for the industry.

There is a huge amount of information regarding security holograms focusing on product type and application. All the types of holograms mentioned have at some time been used for either brand authentication or security. The embossed hologram now accounts for over 99% of all security holograms.

Most of these are what are termed Diffractive Optically Variable Imaging Devices or DOVIDS. These come under the heading of Diffractive Pixel and dot matrix images described above. In addition to this, Multigrams (usually combinations of stereograms and DOVIDS) are the reserve of the security industry.

Security holograms are usually small, bright, colourful and intricate images, designed to beat the counterfeiter.

Transparent holograms

Transparent Holograms are primarily used to enhance security against duplication and alteration, although an increasing number are being used in promotional applications such as book covers. The primary benefit is that conventional printing and photographic techniques can be used in conjunction with transparent holograms. A typical example would be ID or membership cards having a transparent hologram over personal details and a photographic portrait.

Transparent holographic films are an extension of traditional, metallised embossed holograms. Selective demetallisation is also possible. These films can be applied to existing card manufacturing techniques, as the underlying imagery is not obscured. They are impossible to photocopy and can add a protective barrier to photographs, digital data and conventional print. Currently there are only a small number of companies capable of producing transparent overlays and of these very few (if any) would undertake the whole production process 'in house'.

There are two types of commercially available transparent, holographic overlays:

1. Selectively Demetallised Films
2. High Refractive Index Coated Films.

1. Selectively Demetallised Films are the result of selectively removing aluminium from pre-metallised films. The process involves printing a chemically resistant lacquer onto the metallised holographic material then dissolving the unprotected aluminium with an alkali solution. The process is usually geared to leaving about 25% of the aluminium on the film, (75% transparent), although total, selective demetallisation is possible. The total demetallisation can be in register with, for example, photographs or bar codes. The relief structure in the demetallised area becomes optically matched by the adhesive layer and so effectively disappears, adding a further barrier to copying.

2. High Refractive Index Coated Films are produced by substituting the traditional aluminium coating with a high refractive index coating to produce a truly transparent hologram. Refraction of light through the transparent media reconstructs the hologram in accordance with Snell's Law. The high refractive index coating is usually a metal oxide (such as Titanium Oxide) or refractory inorganic compounds, the choice governed by the vacuum coating equipment available. These coatings are invariably more expensive than evaporated aluminium coatings.

Very thin high refractive coatings are broad band, producing iridescent, pearlescent effects, whereas thicker coatings produce a narrower band response, shifting toward

the blue. Multilayer coatings produce interference effects over a very narrow band giving very bright, quickly changing colours at certain angles, while completely transparent at others. These coatings require very careful control of the deposition process.

The two types of film are available as either transfer films or laminates. Transfer films are carrier supported coatings, transferred from the carrier to a substrate by heat and pressure, similar to traditional hot stamping foil. The adhesive layer must obviously be as transparent as possible and no air bubbles formed in the application process. The material the film is applied to will often determine the adhesive used.

Laminate films have either an embossable base or an embossable coating, the whole of which is applied to the substrate via adhesive, using heat, pressure or both. Application of transparent holographic foils depends on whether the application is to finished cards, or as an intermediate in a longer process. It will also depend on the underlying substrate (e.g. card or plastic) and the form of transparent film or laminate. Pre-cut laminate is suitable for the encapsulation of documents and cards that have to be personalised and issued on a local basis. Office laminating machines are suited to this. Individual transparent holograms can be applied in register by vertical reciprocating machines such as the Kurz MM3000. Specialist card personalisation machines are also available.

From reading the above, it is obvious that much thought and planning is involved in a job using transparent holograms. The process involves close co-operation between originator, manufacture and converter.

While most transparent holograms currently used are embossed, it is worth noting that photopolymer holograms are automatically transparent, but are usually black backed to make them more viewable. A typical application of photopolymer holograms would be to laminate, using optically clear adhesive, a hologram at 90 degrees to the document. For example, a security card for a bank could be a normal card when viewed horizontally, while revealing a hologram when positioned vertically.

Holographic giftware

A wide range of products which have holographic imagery as the key component already exist. The simplest and most common are those using off the shelf patterns. This includes pencils, watch faces, wrapping paper and simple bookmarks.

Many holographic stock images are available. These are in the form of stickers, in the case of embossed holograms or packaged and pre-mounted holograms for wall decoration in the case of silver halide and photopolymer holograms. There remains a market for holographic jewellery using both embossed and dichromate holograms. The latest craze has been for holographic sunglasses, using photopolymer and embossed holograms for promotion and retail.

Search on the World Wide Web for information on all types of holographic products.

Stock images

There are several holographic stock image libraries, offering a wide range of generic imagery from globes to eyeballs. The use of stock holograms can be a very cost-effective way of integrating holography into a project. The client will see exactly what they are paying for and there are no set-up costs. While less suited to some applications (such as security), stock holographic images are a growth area in holography.

Packaging

In recent years, holographic packaging has moved from a small niche area to almost an industry in its own right. Products, such as toothpaste are now branded with holographic material, whereas in the past it was only used for special promotions. Packaging almost exclusively uses diffractive material that is bright and can be seen

in any light. The material is produced in vast quantities and is available off the shelf. If sufficient material is purchased, the cost becomes competitive with other forms of specialist packaging.

Promotion stationary and publishing

The holographic techniques described above can be used for a variety of applications. Because of their method of manufacture, photopolymer and embossed holograms are most commonly used for promotion, stationary and publishing. After the method of manufacture, application is probably the biggest issue, (and stumbling block).

Several specialist holographic foil stampers can foil block holograms in register. Alternatively the images can be produced as stickers and using pressure sensitive application machines, stick the holograms on. The third option is to hand apply the stickers, and there are companies who provide this service. For small runs (<10,000), hand application is actually often the cheapest route.

Many books have been published using holograms as the central theme. The first significant example was the Mirror Stone that led to a series of similar children's books by the publisher.

Holographic CD's

Holographic CD manufacture is now well established with several examples on the market. The CD manufacturing process fits very well with the holographic production process.

A shim is grown and a lacquer applied to the CD surface. The holographic shim is embossed into the lacquer and dried. The result is a full playing CD on one side with an overall holographic image on the reverse. Alternatively, the hologram can be applied to specific areas of the CD, for example an inner band round the hole in the centre as a security device.

The result is dependent on good design as well as production capability and the final result can look stunning. The addition of a hologram can add only a small amount to the production cost of the entire CD.

Holographic clothing

Holograms can be applied to fabric. The first method involves bonding diffractive foil to the fabric as a direct process. A patented process is now available using special adhesive, which allows the garment to be washed many times. The second method is to encapsulate the hologram in a plastic coating, which is then sewn onto the garment. Holographic thread is also available. Although several examples have reached the market, holographic clothing is still in its infancy.

Three dimensional pictures

Humans, along with many animals, have the ability to see three-dimensional images through the use of stereoscopic (also referred to as stereoscopic) vision.

Stereoscopic vision involves the use of both eyes. Three-dimensional movies and pictures work by supplying each of your eyes with a different image. These two "flat" images can look three-dimensional.

When you focus on an object each eye has a slightly different view of it. Your left eye tends to see a little of the left side of the object, while your right eye sees a little more of the right side. Your brain automatically uses this information, plus the angle your eyes have to turn to focus on the object, to supply you with an estimate of the distance of the object.

With the exception of reflection holography, all 3D techniques only allow horizontal parallax to be seen; that is three dimensions horizontally, not vertical dimensionality.

The most basic method is to get each of the eyes to focus on different images. The two images are placed side by side. The viewer, by crossing their eyes, can interpose one on top of the other to generate the 3D picture. The advantage of this method is that the image has full colour. The disadvantage is that it takes some practice to get the necessary co ordination to do it unless you have a device called a stereoscope. This is the basis for traditional stereoscopic photography. In recent times, the use of computers have taken an idea originally proposed in the 1960's and created elaborate stereo pairs and integrated them into a single image. There are many names for these auto stereo pairs, such as Magic Eye and 3D Eye. At the time of writing this technique is currently out of vogue, but achieved large coverage during the early 1990's. Two more traditional methods of seeing in stereo are anaglyph pictures and polarised light.

Anaglyphs

Anaglyph is the technical name for the familiar red/blue (or green) pictures viewed with red/blue (or green) glasses. With this method, the images to be shown to the right and left eyes are either encoded in shades of blue or red then combined. Since the coloured lens of the filter out any colour but their own, the left eye, which has a red lens, only sees the red shades and the right eye, which has the blue lens, sees the blue shades. The brain combines them to give you the three dimensional images. The disadvantage with this approach is that only monochrome images can be seen this way. Books and software packages available allow one to generate anaglyph pictures. One shows how to use the popular bit-map editor Photoshop[®] to do this. While anaglyph pictures require only traditional printing techniques, they are hindered by the necessity to wear the glasses.

Polarised light

3D films (including IMAX) often use a method similar to red/blue. Instead of separating the images by using colour filters, they depend on "polarisation." Special filters are used to polarise the light differently between the left and right images.

A polarisation filter is a transparent sheet of plastic or glass, on which tiny lines have been etched. They run like blinds usually from the top to the bottom of the filter or left to right. Once light has been polarised, it will only pass through a filter with the same polarisation orientation, but not one with an opposite orientation. The viewer uses glasses with one lens polarised top to bottom and the other, left to right so each eye sees only the correct image. The advantage of this method is that it allows full colour pictures to be seen, but does require both special glasses and projection equipment.

Lenticular photography

Lenticular photographs, and their animated counter parts, sometimes called Virtual Video, work by splicing images together either using a computer or photographic optics. Splicing in this case means taking a thin strip from the first image and pasting it beside a strip of the second image. The next strip of the first image is then pasted next to this and so on.

A lens array, usually a plastic sheet known as a lenticular screen, is placed over the spliced images. The lens array causes one eye to see all the strips from the first image with one eye and all the strips of the second image with the other eye. This creates a dimensional picture. If several images are combined in this fashion, each being the frames from a movie, a moving image can be created.

Because our eyes are positioned horizontally, the three dimensional lenticular photographs have the screen running vertically, relative to the viewer. This allows the lenses to direct the correct images to the left and right eye. If a sequence with fast motion were used, there would be a great disparity between the left and right eye view.

For animated lenticular images, the screen is placed horizontally and movement is seen by tilting the image up and down. This way, there is no stereo cross over and the pictures (although two-dimensional) appear to move.

The field of lenticular photography has developed rapidly over the past few years, enabling more pictures and finer screens to be used. The modern lenticular is very different from the simple "flip images" found in cereal packets of the 1970's.

Barrier screen lenticulars

Instead of using a plastic lenticular screen, there is another simple way of presenting each eye with a different image using what is known as a barrier screen. Take two pictures that make up a stereo pair, and splice them together in a similar way to a normal lenticular print. Instead of placing a screen over the final image a piece of plastic, about 3mm is laid over the top. On this is a printed screen with fine black lines on it. When positioned with the correct images, the correct sheet width and the correct line spacing, the black lines block out the correct view for each eye, so that the left eye sees the left eye view and the right eye sees the right eye view.

This technique requires special software such as Spatial Imaging's SPLICER program to create the images and the correct pitch screen. The advantages are that the only size constraint is the print itself and the screen size. The disadvantage is that the final image must be back-lit and that half the light is lost because the barrier screen obscures half the light. As more images are added to the final print, a correspondingly more opaque barrier screen is needed and this obscures more light.

Virtual reality and switching glasses

In a "virtual reality" (VR) helmet, each eye is given a small monitor of its own. The computer creates the correct left or right images for each. Since the computer can monitor the position of the helmet, it can continuously change the images seen by the viewer to match these movements. This can give the viewer the sensation they are moving in a computer-generated world, or reality, hence the name.

Some computer systems use special glasses that switch on and off to produce a 3D image on the monitor, e.g. Crystal Eyes system. As the viewer sees the screen, each lens of the glasses he wears alternates as a shutter to close off light so the viewer can only see out one side at a time. This blinking action is co-ordinated with the computer that displays the proper left or right image depending on the setting of the glasses. This way each of the viewer's eyes see the correct picture. The blinking action takes place so fast (usually at least 25 times a second) that the viewer does not notice the shutter action, and sees continuous images through both eyes.

Volumetric displays (swept-volume displays)

Volumetric displays are perhaps the first step towards a Star-Wars type "hologram".

Volumetric display devices are those in which 3D images may be generated within a physically three-dimensional display volume, rather than on a stationary surface. The images are therefore auto stereoscopic and may be viewed from almost any angle. The only restrictions are generally due to the display device itself.

Developing a volumetric display system requires a means by which the 3D-display volume be created, and a means by which the image data be generated inside it. In many of the systems currently under development, the display volume is swept repeatedly by the rapid periodic motion of a two-dimensional surface.

A voxel is a 3D image element, analogous to a pixel in 2D. Voxels are created by addressing this surface as it passes through the voxel positions in the display volume. The screen motion is sufficiently fast that the eye no longer perceives the surface itself. Such devices may be termed swept-volume displays.

The moving surface may be passive, in which case the voxels may be generated by addressing this target screen with electron or laser beams synchronised to the screen's rotation. The voxel generation in such systems is typically sequential. Several systems of this type were proposed in the 1940s and early 1960s.

Alternatively, the screen itself may be active, and comprise a 2D array of individually addressable voxel elements, such as LED's. These systems allow an increased parallelism in voxel generation - up to all the voxel elements on the screen may be addressed simultaneously.

Whereas most volumetric systems under development at present are of the swept-volume type, static-volume displays, which do not employ a moving component to sweep out the display volume, are also under development. One means of generating isolated voxels in a static volume is to utilise a stepwise excitation of fluorescence processes at the intersection of two invisible (usually infrared) laser beams. This requires that the display volume contain atoms, ions or molecules that exhibit this behaviour with suitable quantum conversion efficiencies, output fluorescence frequency and decay times. The most promising medium at present employs rare-earth ions doped into an infrared-transparent glass. An alternative static-volume technique has the display volume composed of a 3D array of individually addressable voxel elements. This method may thus achieve ultimate parallelism, with every voxel addressable each refresh.

Image quality considerations in volumetric displays

At the present stage of development of volumetric display systems, it is difficult to employ a single image 'quality' measure to quantify or compare the performance of different systems, in the way in which the Modulation Transfer Function, for example, is used with raster-scanned CRTs and flat-panel screens. In part, this is due to the wide variety of mechanisms employed in volumetric devices, but also to the fact that the non uniformity's inherent in many techniques have not yet been rendered transparent to the user. This is the ultimate aim.

Few volumetric systems can address every possible voxel location each time the image volume is refreshed - typically, only the visible voxels comprising the image are generated. This random-scan method may be thought of as a 'dot-graphics' technique, analogous in certain respects to the vector scanning once employed in graphics monitors. Thus, the number of voxels that can be generated each image refresh is an important image quality parameter.

There are other considerations such as the size of the individual voxels, how accurately and how densely they can be positioned, size of the display volume, image refresh rate, and the colour capability of the system. Current volumetric systems all generate translucent voxels in a small number of discrete colours - to the authors' knowledge, no system currently exhibits a full (true) colour capability.

Volumetric displays are currently very expensive and still in the research and development stage.

Other ways of seeing

Along with stereo vision, brain can also use the "focal" distance of an object to estimate position. Like a camera, the eye must adjust itself to bring something into sharp detail (hold your finger in front of you about six inches and focus on it. Notice that objects farther out are blurry) The brain uses the amount the eye must change to estimate the distance of an object, too. The focal method is not as accurate as stereoscopic vision.

The brain can estimate the size and position of objects by knowing what they are or how big they seem in relation to other objects of known size. This is what permits us to see a normal two-dimensional picture as a three-dimensional scene, instead of just a bunch of colours slashed up onto a flat surface. It also allows us to understand

that the skyscraper in a picture is hundreds of feet high, although the photograph itself is only inches high.

Although all three-dimensional pictures have sometimes been referred to as "holographic" only images encoded by a laser are truly holograms. The holographic process allows much more of an object to be seen than the above stereoscopic processes. Reflection holograms allow objects to be seen as three-dimensional even as the viewer shifts his position from up and down as well as left to right. With stereoscopic images, the viewers' position is locked, side to side. Only in a hologram is true three-dimensional space represented. This is because of the unique way the image is made. With most dimensional imaging techniques, only two views are presented to the eyes. Other techniques allow as many as twelve views, or even more. A true hologram however contains many thousands of views, each small part of the hologram encoding a full three-dimensional representation of the whole scene.

Frequently Asked Questions

What is a hologram?

*Physically, it is a **piece of film or glass**. It has a recording of an interference pattern on its surface or in its photographic emulsion.*

How do you make a hologram?

See "Making a simple hologram"

How many layers are in a hologram?

Holograms are not made of layers. They are a recording of the light wave fronts from an object.

How many pictures are in a hologram?

In a conventional hologram there is one three-dimensional "picture" - In a stereogram, which uses a hologram as a three-dimensional viewing device there are normally 40 - 100 different pictures used. A stereogram is a holographic recording of sequential two-dimensional pictures. Holograms can incorporate channels which are images that appear at different viewing angles.

What is the largest size hologram you can make?

In short any size is possible, but it does depend on the type of hologram. For mass reproduced embossed holograms the largest size ever is 16" x 12" for a single image, but more common would be 6" X 6". For tiled embossed patterns 48" by thousands of meters. For conventional Photopolymer, 12" X 16" or in some cases 12" X 12" depending on the replicator. For silver-halide reflection display holograms, 100cm X 100cm and for silver-halide display transmission holograms 1m X 2m. These are not the absolute physical limits of production but holograms larger than these will require special set-ups and will be prohibitively expensive to the majority of clients. Zebra holograms can be made to any size.

I want 200 24" X 24" holograms for a point of sale campaign. Is this possible?

Yes, no problem. Contact Spatial Imaging. The cost can be as low as £200 per hologram.

I need 10,000 holographic CD's. Is this possible?

Yes. From supplied CDRom or audio data, a holographic CD with jewel case and paper insert can be supplied as a package.

We want a hologram for a new CD to be launched in three days time. We need 100,000 hot stamped holographic covers. Is this possible?

No. The hologram manufacturing process takes a minimum of three weeks. A more usual turn around time would be 5 to 6 weeks. Complex large run hot-stamping commissions may take 2- 3 months to plan and execute.

We have just launched an advertising campaign for our new soap. Can we have 200,000 holograms showing part of the video on loyalty credit cards for our major retailer?

Yes. A moving hologram showing 2 or 3 seconds of animation can be foil blocked onto credit cards, either plastic or paper.

How much will it cost to have 500 business cards with an animation of our logo on each one, overprinted in two colours, with full colour printing on the reverse.

Approximately £12 each. Increase budget or quantities to make such a project more affordable.

I want a 50 cm X 50 cm hologram of a ship sailing out of harbour. How much will this cost, and how long will it take? What do I need to supply?

It will cost about £5000 and take 5-6 weeks. Either a computer generated scene or pin registered film footage would be required.

I want a hologram of a life-size elephant "float" in the middle of a room as it charges towards you. I have a budget of £500.

Not possible. Our in-house levitators charge £150 per hour and 4 levitators are required to lift an elephant.

I want a hologram 6m X 1m. I have a budget of £100,000

Either use a Zebra hologram techniques or, for a conventional or laser viewable hologram, a large building would be hired and special optics and laser used. It would take several months to build the holographic camera. The entire budget would be required in either case.