Advances in holography

Full colour holography shows great potential on high security document market

by Martijn van Heerden

Holography dates back to 1947, when Hungarian/British scientist Dennis Gabor working at British Thomson-Houston in London discovered the principle of holography while working to improve the resolution of an electron microscope. Gabor coined the term hologram from the Greek words: ὅλος (holos; 'whole') and γραφή (graphḗ; 'writing' or 'drawing'). Holograms still offer the easiest method for the general public to determine if a product is authentic. Unfortunately, due to the increased availability of hologram origination technology worldwide, fake products including counterfeit holograms are no longer an exception.

To combat counterfeit holograms, the forefront of the industry has been researching innovative techniques in holography that offer new features and are therefore more difficult to master and produce. A promising new technique is full colour holography, which can create the most realistic image of an object that can be obtained today.[1] This type of holography is also known as Lippmann colour holography, named after Gabriel Lippmann, the Franco-Luxembourgish physicist and inventor who, in 1908, won the Nobel Prize for Physics for the first colour photographic process on a single emulsion.

Background

A Lippmann colour hologram (LCH) is a full colour, 3D volume reflection hologram. For decades such a hologram could only be produced one at a time, but in the last few years copying of these images has been perfected. At first only small series were possible; nowadays they can finally be mass-produced. Lippmann colour holography is now commercially available for both display and security holograms. It offers realistic 3D full colour images and with full horizontal and vertical parallax. An image recorded in such a holographic plate represents the most technically advanced representation of an object that can be produced today (see figure 1 next page).

Access to this new technique is currently very limited, whereas the technology used to produce monochrome and rainbow holographic masters is relatively accessible. The main difference between an LCH and embossed or stamped holograms is the sheer complexity of producing or counterfeiting a full colour, 3D volume reflection hologram. In effect this raises a significant new set of technical barriers that will be extremely difficult and costly for counterfeiters to overcome.

The earliest successful Lippmann colour hologram, an image of a Japanese doll, was made in 1986 by Japanese holographer Toshihiro Kubota. As the time he did not have access to a suitable panchromatic emulsion, Kubota's Lippmann colour holograms were obtained by combining three component holograms recorded in different materials.[2] He used an AGFA 8E75HD silver halide glass plate for the red and dichromated gelatin glass plates for the blue and the green components. When completed he sandwiched the plates together in order to achieve full colour.[3]

Optical cloning of artefacts

Nowadays, LCHs are also used in museums for the optical cloning of artefacts. These holograms are used for restoration and documentation purposes and in virtual object presentations (see figure 2). An LCH is recorded 1:1 from an actual object that is placed inside the camera. These museum holograms are often unique or small series of handmade copies. The museum display versions of these holograms, which can range up to 40 cm x 60 cm in size, are so realistic that people often mistake them for the genuine physical object.

Dr Hans Bjelkhagen, one of the pioneers in the field, has recorded the earliest artefact from Wales, the Kendrick's Cave horse jawbone, for the British Museum.[4] Auction house Christie's has successfully used holograms to show their clients' objects simultaneously in both London and in Hong Kong. The client in Hong Kong bought the object based on a viewing of the hologram alone. In both the UK and Greece several museums have recorded their artefacts as full colour holograms. With this technique museums can safely record their objects and eventually sell holograms of their often unique objects to collectors, lend holograms to other museums and document their restorations, all in full colour 3D.

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Figure 1
Full colour Lippmann security hologram of the Union Jack by Bowater Holographic.

The British company Colour Holographic has carefully developed the optical cloning technique over the last fifteen years. They have succeeded in creating their own recording material: a holographic panchromatic emulsion.[5] Worldwide around ten companies now offer the LCH technique, which is mostly used in display rather than security applications. Colour Holographic UK, the Hellenic Institute of Holography in Greece and Yves Gentet Holography in France have all built a portable holographic 'camera' capable of recording the holograms in situ rather than transporting the museum objects to their laboratory.

Other applications

Applications of this technique are not limited to museums alone. We may see them on the high street very soon when jewellers use them to replace the expensive watches in their shop windows at night. They might even appear on our banknotes as security holograms.

Technical overview

Lippmann colour holography is an analogue optical technique that uses lasers, optics and panchromatic recording materials. The most important factors to consider when mastering in full colour are:

- The wavelengths of the lasers.
- The recording material and processing.
- The camera set-up.
- The final replay conditions.

Laser wavelengths

The virtual colour image recorded in an LCH holographic plate represents the most advanced image of an object that can be produced today.[6] To record an LCH a minimum of three lasers is required. These lasers emit red, green and blue light (RGB). Combined they form a more or less white beam (see figure 3).

A 'standard' set-up for full colour holography:

- An argon ion laser emitting at λ 457 nm for the blue light.
- An argon ion laser emitting at λ 514 nm for the green light.
- A helium neon laser emitting at λ 633 nm for the red light.

However, this combination of wavelengths will not always result in a perfect colour replay in the final hologram depending on the chosen object, so the final hologram will be in colour but not necessary in natural or true colour. There has been intense debate within the scientific community about what wavelengths are most suitable for true colour images. Some scientists think the answers can be found in holography and early colour photography whereas others point to colour science. Based on colour science, the ideal wavelengths would be λ 450 nm, λ 540 nm and λ 610 nm.[7] Since suitable lasers are not available in all wavelengths, the nearest wavelengths should be selected for the recording set-up. For example: the Argon Ion laser emitting at 514 nm for the green light can be replaced with a frequency doubled Nd:YAG laser (neodymium-doped yttrium aluminium garnet laser) at 532 nm. This wavelength is closer to the optimum wavelength so should give more natural colours in the final hologram when deployed. Several good-quality true colour holograms have already seen the light but true colour holography is still being developed.

Recording material

LCHs are produced on panchromatic recording materials. These materials are sensitive to all

Figure 2
Museum display: full colour Lippmann hologram by Colour Holographic.

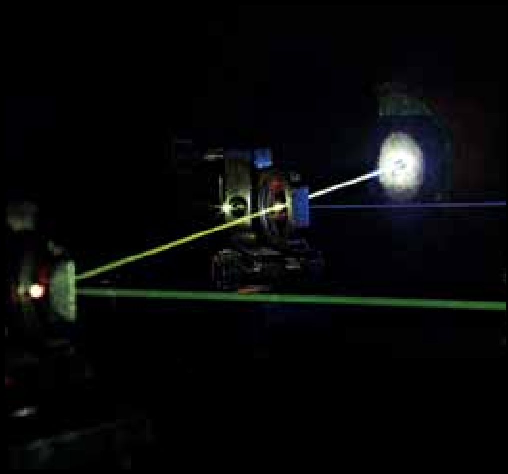


Figure 3
Laser beams are combined into a white beam inside the camera for full colour Lippmann holograms. (source: Colour Holographic UK)

wavelengths of visible light. An LCH is produced by recording a holographic interference pattern in a panchromatic photosensitive emulsion coating on film or glass using a white beam. Several recording materials are suitable for full colour holography: panchromatic photopolymer, multiple layer dichromated gelatin and panchromatic silver halide emulsions.[8] Silver halide is preferred for larger holograms such as analogue museum displays. Dichromated gelatine was crucial in the development of the principle of Lippmann colour holography but the technique is less practical because different colours have to be recorded in different plates. Photopolymer is the material of choice for both security holograms and digital display holograms.

Camera set-up

The camera set-up for the recording of LCHs is frequently based on the simplest holographic recording geometry, known as the Denisyuk or single beam-set-up. In the standard Denisyuk set-up there is only one laser beam that acts as both reference and object beam. The Denisyuk set-up uses the minimum number of optical components, yet produces holograms with full horizontal and vertical parallax so the images have a wide viewing angle and look very realistic. The complicating factor for Lippmann colour holography is that instead of just one laser, a minimum of three lasers is now used (see figure 4). The holographic set-up suitable for creating an LCH uses continuous wave lasers. Such a set-up is an optical system placed on a vibration isolation table. The elements within the optical system have to be stable to fractions of a µm during the recording of the hologram. Instead of the single beam set-up, split beam holography could in theory also be used, but is more complex to install and therefore not common practice yet.

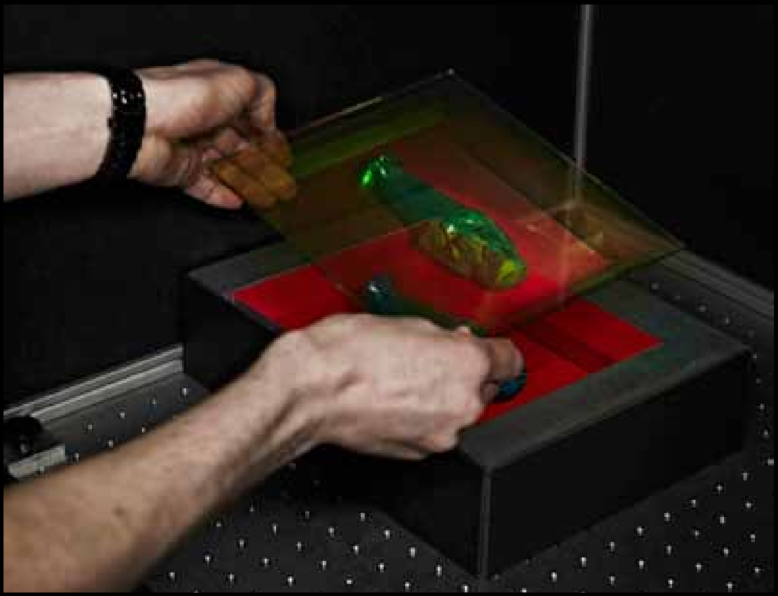


Figure 4
Camera for full colour Lippmann holograms with the object and hologram inside. (source: Colour Holographic)

Final replay conditions

When designing the hologram, one has to take into account what the final replay conditions of the hologram will be. In the case of security holograms, playback will often be in ambient light conditions. As visibility is key, images with limited depth will work best. Colour display holograms can be lighted with halogen spotlights, but for more accurate reproduction of the colours recorded in the hologram a full colour LED spotlight works best. For true colour replay a full colour LED is essential.

Security holograms in full colour

An LCH is not only a significant new tool for museum documentation or advertisements, but it is also a potential game changing security device which is extremely difficult to copy, manipulate or simulate due to its unique properties. Now images can finally be displayed in a hologram with their natural colours and full parallax. In the past a common problem in holography was a coloured logo that was reproduced in full 3D in the hologram but with a monochrome green colour or as a rainbow transmission lacking vertical parallax. Combining the properties of an LCH with standard document security protection techniques such as serialisation, microtext or covert laser readable information could produce a unique security feature which could be applied in brand and product protection, high value document security and banknote design.

Because the substrate on which the security holograms are recorded is based on a photopolymer, applications of full colour holograms on photopolymer banknotes

Figure 5
Full colour Lippmann hologram of a tiger on a card by Dai Nippon Printing (please note that the card is much larger than credit card size).

will also be feasible in the near future. There are already nine countries that print all their banknotes on photopolymer. The Bank of England has also announced that it will be printing the next generation of GBP 5 and GBP 10 notes on photopolymer. Two companies that focus on the security applications of LCH are Bowater Holographics from the UK and Dai Nippon Printing (DNP) from Japan. Since both companies have successfully copied security LCHs, they have started to offer industrial replication. In Japan DNP has successfully launched mass production of full colour holograms. These holograms can be produced embedded in cards or as foils and are used for security documents such as passports and ID cards (see figure 5). DNP is also producing larger size display LCHs. One of many obstacles they had to overcome to achieve mass production in full colour was the brightness of the final hologram. Early copies were apparently quite dim, but now DNP reports it has doubled the peak brightness of their earlier efforts.

The GBP 6 holographic banknote

The UK based company Bowater Holographics was founded in 2012 and now employs several of the world's best holographers. Bowater has successfully registered a number of patents focusing on security LCHs and the mass replication of holographic images as a means of optical encryption. They have set up mastering facilities and have successfully developed replication facilities. Bowater conducted a feasibility study to commission their new photopolymer mass production system for Bayer film. Part of this involved designing a full holographic GBP 6 banknote. Their photopolymer copies of the banknote hologram are in full colour and have two channels.

Bowater's Chief Technical Officer, John Wiltshire explains: "The GBP 6 banknote hologram we created has the approximate size of a banknote to demonstrate the feasibility of colour reflection holograms as a security feature. There is a two channel vertical switch between two images representing Queen Elizabeth II and Winston Churchill (see figures 6 and 7 on the next page). There is considerable depth in the images: The background plane to Churchill is a London panorama with a foliage overlay and in the area of the GBP 6 denomination both channels show digits floating in the film surface. The rear plane to the main channel consists of a graphic array with an animated guilloche pattern and a circular logo to the left."

LCHs and digital display holograms: a comparison

Lippmann colour holograms can only be created using analogue optical techniques. But a hybrid technique known as digital holography - hybrid, because it is based on holographic stereograms - makes full colour digital holograms possible. These display holograms look less realistic compared to LCHs because they have visible dots in the image known as holographic pixels or hogels. The size of the hogels or holopixels for display holograms is currently around 0.8 x 0.8 mm. Every hogel is individually exposed by an RGB pulse laser so a typical final image consists of tens of

Figure 6
Hologram channel 1 of the GBP 6 banknote: Queen Elizabeth II. (source: Bowater Holographic)

Figure 7
Hologram channel 2 of the GBP 6 banknote: Winston Churchill. (source: Bowater Holographic)

thousands of hogels. The hogels are a significant visual compromise, but because this system is digital, it allows us to create any image imaginable. LCHs are recorded 1:1 from a static object that is placed inside a camera, which has serious stability requirements due to the exposure time needed to record an interference pattern. This limits the imagery that can be recorded. This problem can be solved with digital holography as the use of RGB pulse lasers reduces the exposure time to a few nanoseconds. Unfortunately the RGB pulse lasers on the market today do not offer enough power to record entire plates at once, which is needed for LCHs.

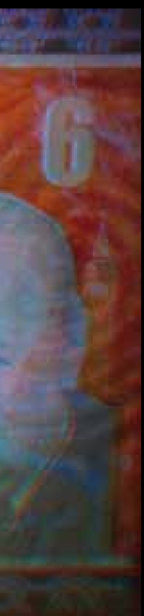
Accessible to the public

Two companies, Geola from Lithuania and US based Zebra Imaging, are selling full colour digital holographic prints. Clients simply send in their digitally prepared files and receive a digital holographic colour print. The digital holograms can be sourced from any computer-generated 3D scene. Files can be created in for example Autodesk CAD, 3D Max, Maya or Google Sketch up. It is also possible to use videos with parallax recorded on a linear track. Both Zebra Imaging and Geola have now developed lie-flat holograms that can be placed flat on a table and have a 100-degree viewing angle. This type of hologram is used by the military to create better situation awareness, by artists to create dimensional art works and by architects to print their CAD models into virtual scale models. Other common uses for these printing services are wall-mounted holographic portraits, holographic art prints and game scene previews (see figure 8). For the hologram enthusiast with little time it is even possible to record a full colour digital hologram with only the AutoDesk 123D Catch app installed on a smartphone and directly send it to Zebra Imaging for printing. Results may vary, but it is clear that anyone can now create a (digital) hologram without years of training and access to a costly laser laboratory. Digital holography does offer a much wider range of applications, but an LCH is visually superior to digital holograms because it has no holopixels/hogels and looks like the real object.

Colour 3D portraits on passports

Possible applications of full colour 3D digital holography include passports. Personalised full colour

Figure 8
A digital file prepared in Autodesk 3D max. The digital hologram, printed by Geola, is now on display at the MIT Museum in Cambridge, USA. (hologram design: Erik Swetter and Martijn van Heerden, 2012)



3D portrait holograms could be placed on the next generation of passports as an added security feature. Hologram Industries already offers a product called *HoloID*® featuring personalised colour designs with portraits. In Germany the Bundesdruckerei has used reflection volume holograms in the German passport for individualised identity purposes. With the possibility to mass-produce individualised holograms, we may well have to pose for a 5-minute parallax portrait recording session when applying for our next passport. If your new passport has your own full colour 3D holographic portrait inside, it will be worth the wait.

Conclusion

Full colour holography is now a mature technology with the possibility to produce high quality masters which can finally be mass-produced. Full colour holography is not only a significant new tool for museum documentation or advertisements, but now that mass production has started, there is great potential for full colour holography on the high security document market. Full colour holography can display corporate logos in the correct colours and has full parallax. Full colour holography can be combined with existing document security techniques. ID documents with individualised colour holograms are now feasible and not only a very attractive, but also a very secure solution.

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