

REPRINT



SPIE—The International Society for Optical Engineering

Reprinted from

Holography 2000

31 July–1 August 2000
San Diego, USA



Volume 4149

The Art of Colour Holography (Pioneers in Change)

Martin Richardson & Hans I. Bjelkhagen
The Holographic Image Studio,
1.18 OXO Tower, Southbank, London SE1 9PH
De Montfort University, The Centre for Modern Optics
Hawthorn Building, The Gateway, Leicester LE1 9BH
United Kingdom

ABSTRACT

The possibility to easily record full colour holograms, (simply *colour holograms*) has opened new possibilities for art holographers. This paper includes details concerning preparation of subject matter and its practical suitability for colour holographic recordings from practical working sessions at "ARTCAPI" Atelier de Recherche Technique et de Creation Artistique en Physique et en Informatique in France. Martin Richardson as invited artist and Hans Bjelkhagen as scientist holographer describe colour holography to a wider public audience through artistic display. Both directly recorded 'true colour' images and computer-generated images based on the ZEBRA printing technique are be presented.

1. INTRODUCTION

1.1 A Journey into True Colour.

'True Colour' holography is enjoying a resurgence which will produce an interesting number of commercial and industrial products during the next decade. We now have the technological tool's for this from work at ZEBRA Imaging and Atelier de Recherche Technique et de Creation Artistique en Physique et en Informatique in France, further defining true colour holography and making it a science more assessable then ever before. Both the ZEBRA Imaging and A.R.T.C.A.P techniques are based on the principles of the Denisyuk hologram which maximises both vertical and horizontal parallax.

By way of chance, when I was a student at the Royal College of Art in London circa 1984, my works were all Denisyuk multi-coloured holograms. The colours in these holograms were bought about in the processing by altering the acceptable concentrations of Sulphuric Acid in a Dichromate bleach process. fig 1. So it seemed quite natural for me to explore the virtue of these new techniques and, to this end, the past two years have seen a turning point in my development as an artist, away from the monochromatic standard toward concerns focused on designing and making three dimensional holographic images in true colour.

Correspondence: Email: easyhologram@easynet.co.uk; www.holograms.uk.com
Telephone: +44 (0)20 7928 3331; Fax: +44 (0)20 7928 6980

Over the years, various technics of obtaining different colours in holographic images have been introduced and certain methods became popular with holographic artists. Such holograms are often referred to as *pseudo colour* or *multicolour* holograms. For historical purposes, these may be placed into two main groups.

Group One.

To the first group belong white-light pseudo colour transmission holograms based on Benton's original rainbow technique.¹ The pseudo colour transmission technique is based on multiple white-light rainbow holograms in which different spectra are superimposed at the position of the observer. By using a single-wavelength laser and combining different holograms recorded with different reference angles it is possible to create artificial colours in the final rainbow hologram. One problem with these holograms is that the colours vary depending on the vertical observation position. Being transmission holograms they are sometimes mirror-backed for reflection reconstruction. The multicolour technique for rainbow holograms was introduced in 1977 by Tamura.^{2,3} Grover and Tremblay⁴ demonstrated the possibilities of creating natural colour rainbow holograms. Benton *et al.*⁵ and Benton⁶ gave detailed descriptions of the transmission pseudo colour recording technique. This technique was mastered by the artist Crag Newswanger in the United States, a holographer I had the pleasure of working with on three images the most successful titled '**Rocker**'. Indeed, the multiplex movie film I recorded for '**Rocker**' was later used on loan by Mike Medoria to produce a 50 x 60cm multi coloured transmission hologram to test a holographic transfer camera he had developed in London with Nigel Robiette. Fig 2.

Group Two.

The second group contains white-light pseudo colour reflection holograms. The technique of creating different colours is based on the fact that colour in a reflection hologram is obtained by the reflection of light from the recorded interference layers within the emulsion. The distance between these layers will determine the colour. The distance between the interference fringes generated during the recording of a reflection hologram can be manipulated in many ways by various processing methods, which means that different colours can be obtained in the finished hologram. Typically, a single wavelength laser is employed for the recording. Pre-swelling the emulsion before the recording will result in a shrinkage after processing, which will create colours of a shorter wavelength in the hologram than the colour of the laser light used. Often triethanolamine (TEA) is used as the swelling agent. The first note concerning the possibilities of obtaining different colours by double exposure and emulsion thickness manipulation in between exposures was presented in 1979 by Blyth.⁷ Hariharan⁸ described the pseudo colour reflection process in finer detail. Walker and Benton⁹ introduced an interesting technique for obtaining pseudo colour reflection holograms.

From its beginning "group one" became popular within the Art circles and in particular, the work by Rudie Berkhout^{10,11} was highly recognised. One artist who has used colour as a main part in his transmission holograms is Dieter Jung. He explains that: "Holographic colours appear as 'freed' light-colours that are no longer buried in translucent matter. They illuminate a space that is different from the coordinated three-dimensional arrangement, modulate light chambers in elusive hues and tones, form spatial pellucid superimpositions and create dimensional fusion."¹²

Lon Moore and John Kaufman published several papers on the reflection pseudo colour method and its artistic possibilities.¹³⁻¹⁷ Julie Walker Parker's work based on techniques developed at MIT has been described in a paper by her.¹⁸ An artists perspective on the pseudo colour technique was provided by Melissa Crenshaw.¹⁹ Larry Lieberman²⁰ explained how he could "paint with light" using this technique. For some time he produced several commercial pieces all based on pseudo colour techniques. However, one piece *Primary Man* was made together with the artist Margeaux Lucas in Florida. As regards, this piece, Lieberman mentions: "Not only are the colours used in an expressive way, but the image composition, theme and content have a certain magical quality that says: I am fine art."²¹ In a recent publication by Oliveria *et al.*²² accurate colour control techniques were presented. It should also be mentioned that the emulsion thickness manipulation techniques described above can be used to create achromatic and black-and-white images as well. Indeed, In 1985 Edwina Orr and David Trayner,²³ Richmond Holographic Studios, England, produced some large black-and-white holograms, e.g. *Kate McGougan & Stephen Jones hat*. In this case only two colours are necessary in order to create white and grey levels.

2. Colour Holography.

Sometimes lifelike holographic images have been referred to as full colour, natural colour, or true colour holograms. The most logical name for these holograms that comes to mind by analogy with colour photography, colour movies, and colour television would be *colour holograms*. In the following we are using this term to describe these types of holograms.

Even if pseudo colour techniques can meet some artists ideas of creating holographic images, such techniques are rather troublesome and labour intensive. Therefore, the introduction of direct recording techniques to generate colour holograms has opened new opportunities for artists. In 1986, Kubota²⁴ demonstrated that high-quality colour holograms of the reflection type can be obtained. His sandwich hologram (silver halide and DCG plates) of a Japanese doll really proved that scattered light waves could be recorded and permanently stored in holographic plates. When illuminated with white light, the recorded wavefronts are regenerated as long as the light illuminates the plate. The large field of view and the colour permanence associated with the Denisyuk technique adds to the realism of such images. However, Kubota's technique is difficult to reproduce and not until panchromatic recording materials for holography were introduced, colour holograms could be made much more easily as demonstrated by Bjelkhagen *et al.*^{25,26}

Today, Slavich produce panchromatic silver halide emulsions and Dupont has a panchromatic Photopolymer material on the market. Three laser wavelengths are employed for the recording, e.g., 476 nm, provided by an argon ion laser, 532 nm, provided by a cw frequency-doubled Nd:YAG laser, and 647 nm, provided by a krypton laser. Two dichroic filters are used for the combining of the three laser beams to create "white" laser light. The impact of colour holography as a 3D imaging technique is obvious for displaying museum artifacts, for product displays, advertising, security, and other commercial applications. However, artists may find that colour holography can offer advantages over monochrome or pseudo colour holograms. Colour offers the possibility of emotional expression or the cold logic of colour theory - hue's, scales and saturation. Colour is life, for the world without colours appears lifeless.

The first holographic artist to take advantage of the direct colour recording technique using 'white' laser light was Anait Stephens in the USA. Her two 8" by 10" pieces were recorded at Lake Forest College, Illinois, in cooperation with Hans Bjelkhagen. The first piece was '*Flag*' and the second one was '*Cave*', both recorded in 1995. Anait created two pseudoscopic sculptures for these holograms. Her intention was to be able to generate the image as a projected Denisjuk image in front of the holographic plate.

3. The Rationale of Colour Holography.

Colour sensitivity within culture is a potent means of identity. As Anait's hologram of a flag only become a potent symbol through its identity use of the red, white and blue. Yet its strength as a symbol of global power is undermined by the impression of the soft material from which it is made, a fragility highlighted by its transpiration into the ephemeral holographic form. It is a gentle female statement, incredible potent, incredibly thought provokingly and intrinsically beautiful. fig 3.

At this point the pursuit for true colour holograms may be distinguished between the scientist and artist thus:- "The physicist studies the nature of the electromagnetic energy vibrations and particles involved in the phenomena of light, the several origins of colour phenomena such as prismatic dispersion of white light, and the problems of pigmentation. He investigates mixtures of chromatic light, spectra of the elements, frequencies and wave lengths of coloured light rays. Measurement and classification of colours are also topics of physical research. The artist is interested in colour effects from their aesthetic aspect, and needs both physiological and psychological information. Discovery of relationships, mediated by the eye and brain, between colour agents and colour effects in society, is a main concern for the artist. Visual, mental, and spiritual phenomena are multiply, interrelated in the realm of colour and the colour arts." 26.1.

3.1 Directly Recorded Colour Holograms, (works in progress).

Prior to this paper being published, works are being carried out at the Holographic Image Studio in London with experimental subjects such as fluorescent colour charts and different metallic surfaces such as silver and gold. Test charts have been designed accordingly and form a series of compositions with the intention of demonstrating the full range of colours achievable using the ARTCAPI system. Other subject matter includes a range of different coloured human hair, an array of different coloured glass eyes and textured surface maps. (see '*Space, Time, Colour Test Chart*'), fig 4. Apart from creating some very beautiful compositions, these act as practical charts that may be used to calibrate light intensity. This is a crucial necessity for accurate true colour recordings because different batches of recording materials differ in their exposure requirements. The '*Space, Time, Colour Test Chart*' series is also preparation for full colour portraiture. A long term project started at the Holographic Image Studio which at present uses a 10 jw Ruby linked to a 3 jw double frequency neo dinium jag to make dual coloured images. Also the studios are presently in communication with GEOLA regarding the design of a blue pulsed laser to complete the full colour range.

4. Computer-Generated Colour Holograms.

The development of new techniques for generating large full colour, full parallax computer generated holograms at Zebra Imaging in Texas is now open to artists to take advantage of. The technique has been developed by Klug *et al.*²⁷ and Ford Motor Company has supported the new company in the USA. Large 3D images are made in 60 cm

by 60 cm tiled increments. So far, the largest image created at Zebra was of Ford's P2000 Prodigy concept car in which ten such hologram tiles make up one very large computer-generated colour reflection hologram. This was unveiled by the United States President Bill Clinton at the winter 1998 Detroit Motor show to much acclaim. Digital technology is changing holography. It's liberating those who make a living from the medium the restrictions of their 18th century darkrooms. For me the importance of **'Digital Head'** is best understood against this back drop of twenty two years endurance with the traditional dark room, starting with the Royal College of Art summer shows in London 1980, where I exhibited fourteen 30 x 40 cm multi coloured reflection holograms, on to the very precise intensive monochromatic work made with ruby pulsed portraiture and the large format display holograms, around which I have since built my reputation. 'Digital Head' is the first in a new generation of holograms made possible by the good work of 'Zebra Imaging'. Upon first seeing the completed hologram I was amazed because I had never seen anything like in Art or holographic Science. It made me feel nauseous but intuitively I knew this was an image a new generation of artists could relate to, and one which I feel deeply content with. The head scans were made in the U.K by 'Cyber Site Ltd' based in Hays, Middlesex, and the background image is a photograph I made taken of the Arizona desert at sunset - a fitting backdrop considering the actual hologram was to be made in Texas. It's content is not deeply thought provoking, spiritually embodying, philosophical or prophetic. But its image power can be measured in megatons. Grotesquely ugly but also insanely funny, uniquely original, totally uncommercial and utterly banal. Like the head of the great 'Oz' projecting before Dorothy in 'The Wizard of Oz', your eyes will not be able to resist looking behind its hollow again and again. fig 5.

5. Conclusions and Summary

History will determine which colour technique is will survive and which falls to the side walk on this long journey into holographic hyper reality. That said, the holographic system which utilises actual white light as its primary source, and ultra high resolution LCD screens as receiver via Internet broadcast, will out live all the above mentioned regimes. Whatever the outcome, we can not remove ourselves from one fact which is entirely astonishing. That it is part of human creative nature to evolve a timeless form of illusion that will no doubt go on to fascinate and influence millennia after millennia and true colour holography takes us one step closer to this.

6. Acknowledgments

Dalibor Vukicevic, Université Louis Pasteur, Strasbourg, France, is acknowledged for his assistance and for access to the ENSPS colour holography laboratory in Illkirch. **Zebra Imaging Inc**, PO Box 81247, Austin, TX 78708 is acknowledged for their assistance in the rendering and printing of the digital hologram titled 'Digital Head', and continuing to chart the constructive waters of holographic technology.

7. Illustrations

Figure 1. 'Mobius', 1986, by Martin Richardson. Pseudo colour reflection hologram size 30 x 40 cm.

Figure 2. 'Biker', 1990, by Martin Richardson. Stereogram Transmission copy by M. Medora and Nigel Robiette.

Figure 3. 'Flag', 1995, by Anait Stephens in cooperation with Hans Bjelkhagen. 8 x 10 inch "True Colour"

reflection hologram. **Figure 4.** Design for true colour hologram **'Space, Time, Colour Test Chart,'** 2000, by Martin Richardson. **Figure 5. 'Digital Head'**, 2000, by Martin Richardson in cooperation with Zebra Imaging. 50 x 50 cm digital reflection hologram on DuPont Photopolymer.

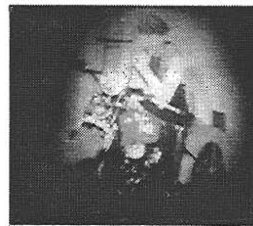
8. References

1. S. A. Benton: Hologram reconstructions with extended incoherent sources. *J. Opt. Soc. Am.* **59**, 1545-1546 (1969)
2. P. N. Tamura: Multicolour image from superposition of rainbow holograms, in *Clever Optics*, ed. by N. Balasubramanian, J. C. Wyant. Proc. SPIE **126**, 59-66 (1977)
3. P. N. Tamura: Pseudocolor encoding of holographic images using a single wavelength. *Appl. Opt.* **17**, 2532-2536 (1978)
4. C. P. Grover, R. Tremblay: Multicolour wave front reconstruction in white light. *Appl. Opt.* **19**, 3044-3046 (1980)
5. S. A. Benton, H. S. Mingace, W. R. Walter: One-step white-light transmission holography, in *Recent Advances in Holography*, ed. by T. C. Lee, P. N. Tamura. Proc. SPIE **215**, 156-161 (1980)
6. S. A. Benton: Topics in advanced display holography. Workshop Notes, Lake Forest Holography Workshops, Lake Forest College, IL 60045, USA (July 1989)
7. J. Blyth: "Pseudoscopic" moldmaking handy trick for Denisjuk holographers. *Holosphere* **8** (No.11), 5, (1979)
8. P. Hariharan: Pseudo colour images with volume reflection holograms. *Opt. Commun.* **35**, 42-44 (1980)
9. J. L. Walker, S. A. Benton: In-situ swelling for holographic colour control, in *Practical Holography III*, ed. by S. A. Benton. Proc. SPIE **1051**, 192-199 (1989)
10. R. Berkhout: Holography: exploring a new art realm - Shaping empty space with light. *Leonardo* **22**, 313-316 (1989)
11. R. Berkhout: Investigating the use of HOEs in the holographic image making process, in *Practical Holography X*, ed. by S. A. Benton. Proc. SPIE **2652**, 204-212 (1996)
12. D. Jung: Holography space: a historical view and some personal experiences. *Leonardo* **22**, 331-336 (1989)
13. L. Moore: Pseudo-color reflection holography. Proc. *Int'l Symp. on Display Holography*, ed. by T. H. Jeong, Lake Forest College, IL 60045, USA, Vol.I (1983) pp.163-169
14. J. A. Kaufman: Previsualisation and Pseudocolor image plane reflection holograms. Proc. *Int'l Symp. on Display Holography*, ed. by T. H. Jeong, Lake Forest College, IL 60045, USA, Vol.I (1983) pp.195-207
15. J. A. Kaufman: Update of Pseudocolor reflection techniques. Proc. *Int'l Symp. on Display Holography*, ed. by T. H. Jeong, Lake Forest College, IL 60045, USA, Vol.III (1989) pp.367-378
16. J. A. Kaufman: Large format Pseudocolor reflection holograms on film, in *Int'l Symp. on Display Holography*, ed. by T. H. Jeong. Proc. SPIE **1600**, 38-43 (1992)
17. J. Kaufman: Life in the lab - a working visit to a holographic studio. *Leonardo* **25**, 497-502 (1992)
18. J. Walker Parker: Exploring holography through science and art. *Leonardo* **25**, 487-492 (1992)
19. M. M. Crenshaw: Pseudo-color reflection holography - An artists perspective, in *Practical Holography II*, ed. by T. H. Jeong. Proc. SPIE **747**, 104-107 (1987)
20. L. Lieberman: "Paint with light" - Artistic manipulation of colour in multicolour reflection holograms, in *Int'l Symp. on Display Holography*, ed. by T. H. Jeong. Proc. SPIE **1600**, 224-228 (1992)
21. L. Lieberman: Holo madness and the search for the 'Hologenic' image. *Leonardo* **25**, 481-485 (1992)
22. R. M. Oliveria, L. Carretero, R. Madrigal, M. T. Garzón, J. L. Pinto, A. Firmia: Experimental study of colour control on reflection holography, in *Practical Holography XI and Holographic Materials III*, ed. by S. A. Benton, T. J. Trout. Proc. SPIE **3011**, 224-230 (1997)

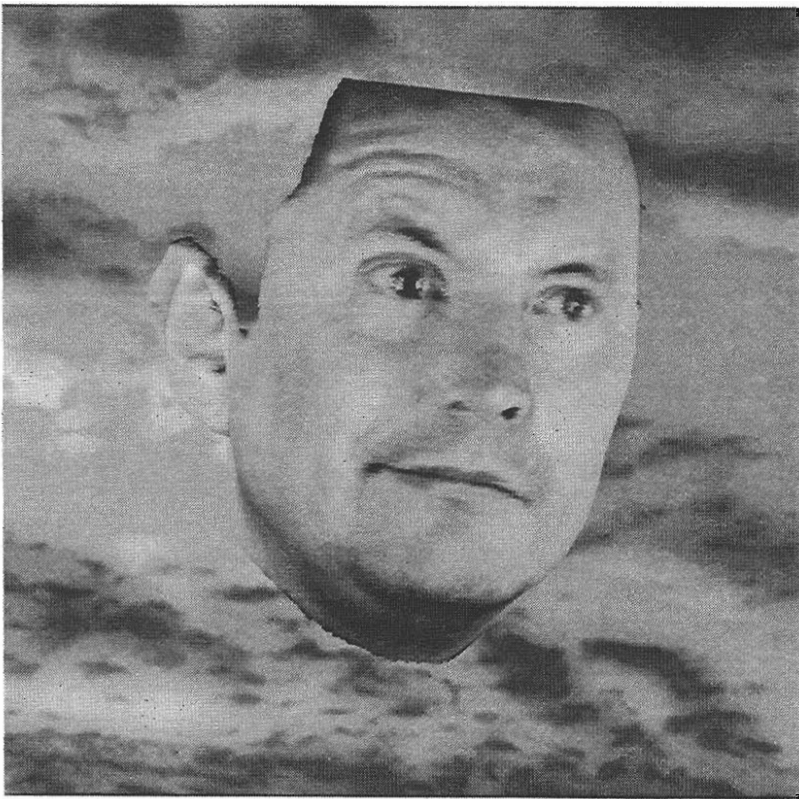
23. E. Orr, D. Trayner: Deep image reflection holograms in black and white and additional colours. *Proc. Int'l Symp. on Display Holography*, ed. by T. H. Jeong, Lake Forest College, IL 60045, USA, Vol. **III** (1989) pp.379-388
24. T. Kubota: Recording of high quality colour holograms. *Appl. Opt.* **25**, 4141-4145 (1986)
25. H. I. Bjelkhagen, D. Vuki_evi_: Lippmann colour holography in a single-layer silver-halide emulsion, in *Fifth Int'l Symposium on Display Holography*, ed. by T. H. Jeong. *Proc. SPIE* **2333**, 34-48 (1995)
26. H. I. Bjelkhagen, T. H. Jeong, D. Vuki_evi_: Colour reflection holograms recorded in a panchromatic ultrahigh-resolution single-layer silver halide emulsion. *J. Imaging Sci. Technol.* **40**, 134-146 (1996)
- 26.1. ITTEN, The elements of Colour. Translated by Ernst Van Hagen. Published by John Wiley & Sons, Inc. 1970
27. M. A. Klug, A. Klein, W. Plesniak, A. Kropp, B. Chen: Optics for full parallax holographic stereograms, in *Practical Holography XI and Holographic Materials III*, ed. by S. A. Benton, T. J. Trout. *Proc. SPIE* **3011**, 78-88 (1997)



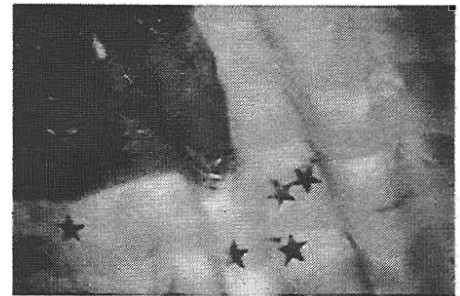
Möbius (fig. 1)



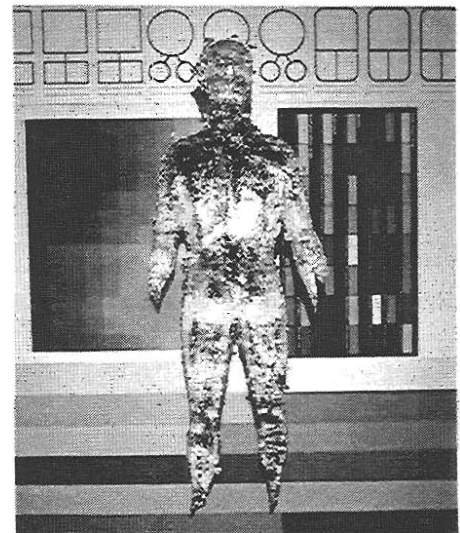
Rocker (fig. 2)



Digital Head (fig. 5)



Flag (fig. 3)



Space, Time, Colour Test Chart (fig. 4)