Stephen Benton (1941 - 2003) – a pioneer in holography

This monograph is written in remembrance of Steve Benton and discusses a few major holographic applications that his inventive mind made possible.

Steve Benton –a pioneer in holography together with Emmeth Leith and Yuri Denisyuk–, is renown as the inventor of white light transmission holography or *Benton holography*[1], also called *rainbow holography*. Benton holograms are produced by means of an optical technique that sacrifices the vertical parallax of the holographic image in favor of a sharp monochromatic reconstruction by a white light point source, in other words: a *parallax limited* holographic image. On tilting a Benton hologram about a vertical axis, the usual horizontal parallax is observed in a relatively narrow spectral band, rendering the holographic reconstruction monochromatic and, as a result, sharp. However, on tilting a Benton hologram about a horizontal axis, no vertical parallax is observed, but the image is perceived in the successive colors of the visible spectrum, hence the alternative name *rainbow hologram*. This pioneering holographic technique rendered holography an invaluable impulse, making the reconstruction of Leith type holograms possible without illumination by a monochromatic point source such as a laser. Benton's patent US 3,633,989, was filed on October 21, 1969 and published on January 11, 1972 and provides an excellent explanation of both the *one-step* and *two-step* rainbow holographic technique. Figure 1 shows Benton's famous 1975 "Holography Blocks" phase hologram[2] as a brilliant example of the technique he invented; the holographic film is extremely transparent, amazingly clear of diffusing noise and displays an exceptionally bright holographic reconstruction of a scene of acrylic cubes.

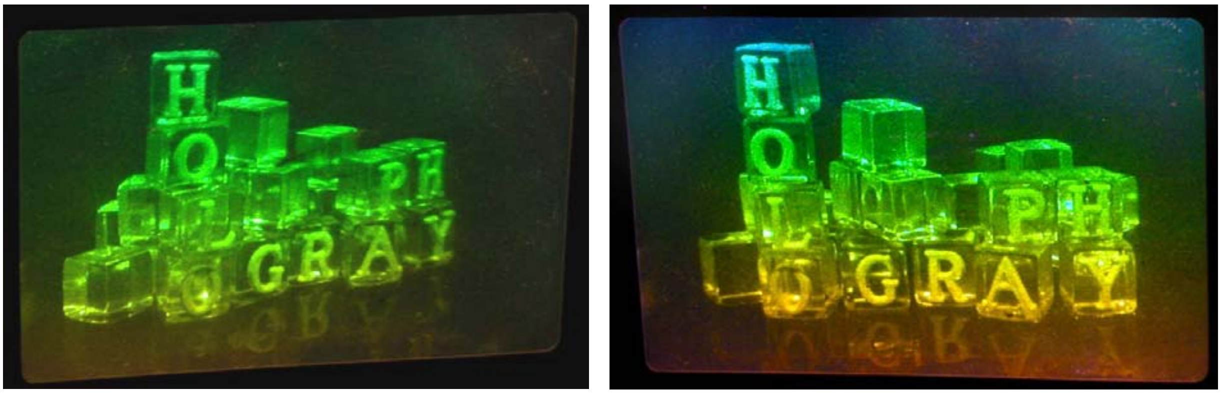

Figure 1 – "Holography Blocks", the famous 1975 transmission rainbow hologram that Steve Benton made of a few tens of 1 inch transparent acrylic cubes. I photographed the hologram from the left and from the right to demonstrate its three-dimensionality. Hologram size 115 x 175 mm.

Further, the development of (1) photosensitive resins (photoresists) that yield surface relief gratings on exposure and subsequent application of solvents, (2) the technique of embossing this relief into suitable polymers, and (3) depositing a reflective layer on the embossed relief added to the world wide use of Benton holograms.

Steve Benton had a significant influence on me and my career. I met Steve Benton for the first time in May 1979 in Boston, after he invited me to present a paper on my work on holographic bleaches and emulsion scatter at the 32nd Annual Conference of the Society of Photographic Scientists and Engineers.[3]

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[1] Benton, Stephen A., "Hologram Reconstructions with Extended Incoherent Sources", *J. Opt. Soc. Am.*, Vol. 59, October 1969, 1545-1546.

[2] A *phase hologram* is a hologram consisting of a diffractive grating that is phase modulated through variations in refractive index rather than in variations in absorption. This significantly contributes to the diffraction efficiency of the hologram (the brightness of the holographic reconstruction).

[3] R.L. van Renesse, "Scattering by fine grain bleached emulsions", *32nd Annual Conference of the Soc. Photogr. Sci. Eng.*, May 13-17, 1979, Boston, Mass.

Inspired, in June 1979, using the 514 nm line of the argon laser available in my lab at Technisch Physische Dienst (TPD) in Delft, I started experimenting with Benton's magical invention and, amongst others, recorded a multicolor two-step rainbow hologram, having the reference beam under different angles for each of the three objects, depicted in Figure 2. In making the hologram I went by Tamura's 1978 paper in Applied Optics.[4] This is about as far as my experimental endeavors with Benton holography reached, but it helped me understand the huge significance of Benton's new technology.

Figure 2 – a three-channel multicolor rainbow hologram that I shot in 1979 after I learned to make rainbow holograms according to Steve Benton's invention. The color rendition is of the "false color" type.
I made it a point to show that the three separate objects "TPD", "optics" and "1979" could be displayed in colors countering the ordinary spectral order observed when tilting a rainbow hologram. The different objects are floating in space between 3 and 10 cm behind the hologram.

Material: 4 x 5 inch Agfa-Gevaert 8 E-75 glass plate.
Processing: bleached to silver ferrocyanide after development, in order to obtain a phase hologram with high diffraction efficiency.

I had the good fortune of meeting Steve Benton several more times, starting with the 1995 SPIE conference on Practical Holography IX in San José (CA), where I presented a paper invited by him[5]. At this occasion, referring to the 1st edition of my book "Optical Document Security" that had seen the light in 1994, Steve proposed that I might consider organizing SPIE conferences on Optical Document Security. The result of Steve's suggestion was the first conference on "Optical Security and Counterfeit Deterrence Techniques" in San José in 1996, which subsequently became a biannual SPIE conference. Until the 2002 conference I had the pleasure to meet Steve, attend his conferences on Practical Holography, watch the fascinating hologram exhibits that invariably accompanied his conferences and enjoy the lively Japanese dinners that he organized. Steve organized and chaired the Practical Holography event 16 times: another of his many memorable achievements.

The first Benton holograms to appear on security documents were the 1983 Master Card hologram and VISA dove (shown in Figure 3). The typical characteristics of a Benton hologram, horizontal parallax and vertical color shift are demonstrated in Figure 4. The VISA dove has since been decorating the VISA card for decades and, while the ability to apply Benton's technology steadily proliferated, a definite security value remained inherent: the uniqueness of the object. Successfully reproducing a tiny and detailed object of only a 9 x 13 mm size and producing an embossed Benton hologram of it, is by no means a sinecure. Holograms of unique objects therefore possess an intrinsic security value.
The holograms were made by Kenneth Haines of Eidetic Images, Inc. (Elmsford, NY) a subsidiary of American Banknote Company (New York, NY). Both holograms are an admirable accomplishment regarding novelty and quality. For an interesting account of the realization of these holograms you may wish to visit Jim Trolinger's website: http://www.worldsworsttourist.com/personalinterest.htm.

[4] Tamura, P.N., "Pseudocolor encoding of holographic images using a single wavelength (ET)", *Appl. Opt.*, Vol 17, No. 16, 2532, August 1978.
[5] R.L. van Renesse, Ordering the order, a survey of optical document security features, Proc. SPIE Conference on Practical Holography IX, San José, CA, USA, 5-10 February 1995, vol. 2406, pp. 268-275.

Figure 3 – Mastercard Benton hologram (image courtesy of Holophile, Inc., USA: http://www.holophile.com/html/history.htm) and the VISA Benton hologram, appearing in 1983.

Figure 4 – The Visa hologram observed with horizontal parallax on rotation about a vertical axis (top) and without parallax on rotation about a horizontal axis, but displayed in successive spectral colors (bottom). Hologram size 15 x 20 mm, object size 9 x 13 mm.

Figure 5 – The Benton hologram of an eagle on the cover of National Geographic of March 1984. This is essentially a single channel hologram, having only a foreground and no background. Hologram size: 62 x 102 mm.

Figure 6 – The Benton hologram of the fossil African Taung Child (a 3 million year old Australopithecus variety) on the cover of the National Geographic of November 1985.

Note that this is a multicolor hologram of the 2-channel type: foreground and background reconstruct with different colors. Hologram size 100 x 127 mm.

In due course it became acknowledged that security holograms had to be more complex in order to counter the steady proliferation of the Benton holographic technique and the resulting risk of counterfeiting. One approach was the expansion of the number of "channels" that composed a hologram, which made the production of Benton holograms significantly more involved. An example of such an advanced multi-channel Benton hologram was the 4-channel multicolor Beethoven hologram on the 1992 Euro debit card. The production of this security hologram involved the recording of 4 separate objects in different channels, applying 4 different reference beam angles: (1) the image element depicting the year of issue "92", (2) the image element "EC 92", (3) Beethoven's head and (4) its background. The result is illustrated in Figure 7. Note that the Beethoven image is derived of a tiny model that fits within the space covered by the 15 x 17 mm hologram and like the VISA dove, this object renders inherent security because of its uniqueness.
Although these high-tech holographic features undoubtedly have a security merit, it must be recognized that –considering the relatively small size of the holograms– the obviousness of the various optical effects is somewhat marginal and does not adequately serve inspection by the general public.

Figure 7 – A four-channel multicolor rainbow hologram of a tiny model of Beethoven's head on the 1992 Eurocard, photographed at 4 different angles while rotated about a horizontal axis. No changes in vertical parallax are observed, but the color of the separate image elements change with the vertical angle of observation. Hologram size 15 x 17 mm.

Meanwhile, in 1979, Steve Benton and his co-workers William Houde-Walter and Herbert Mingace Jr. at Polaroid Corp. made a next step by developing a true color (or full-color as Benton calls it) one-step rainbow hologram using red, green and blue laser lines. Such laser lines, for instance, could be the 633 nm line of a He-Ne laser, and the 514 nm and 488 nm lines of an argon ion laser. An even wider color gamut can be obtained by using the red 647 nm line of a krypton laser, the green 532 nm line of a frequency doubled Neodymium-YAG laser and the blue 422 nm line of a He-Cd laser. The patent US 4,415,225 was filed on November 10, 1980, and published Novemeber 15, 1983. Benton's famous true-color "chessmen" hologram, is depicted in Figure 8.

Figure 8 – "Chessmen" the first true-color, one step, white light transmission rainbow hologram made in 1979 by Steve Benton, William Houde-Walter and Herbert Mingace Jr. of Polaroid Corporation. Hologram size 4 x 5 inch.

Source of photograph:
Holography, May 2004, Vol. 15, No. 1, erroneously referring to this hologram as "the first ever rainbow hologram: made by Steve Benton in 1969."

Another expansion of the Benton technique was the "pseudocolor"[6] rainbow hologram, which hologram also displays colors more or less faithfully matching the colors of the original object seen in white light. The technique is based on the use of three grayscale RGB color separations of a colored object, of which three separate hologram strips H_R, H_G and H_B are recorded. Real images of these three strips are subsequently projected and a final color hologram is recorded of these real image projections, whereby the angles between the reference beam and the respective object beams of the strips are adjusted so that the R, G and B reconstructions are superposed in register[7]. As a result, the reconstruction –at a certain viewing angle and distance– is in what is often denoted as "true-color", "full-color" or "real-color", but it is also called "pseudocolor" by other holographers because the reconstructed colors are not the natural broadband material colors of the original object, but colors synthesized of R, G, and B spectral bands. In my view this distinction is irrelevant because the human eye is trichromatic and cannot distinguish between (1) the "natural" white light broad band spectral response of material colors and (2) the narrow band color simulation by the true-color hologram. An early, and probably the first, example of this type of a true-color Benton hologram is presented in Figure 9. I have no knowledge of Benton true-color holograms having ever been applied as document or product security features and I'd appreciate references to any such applications.

An uncomfortable limitation of holographic displays was that object size and hologram size were tightly connected. A hologram of a large size object –say a 3D portrait of a live person– could only be realized if either or both the hologram and the object-to-hologram distance were large enough. For example, a small hologram of a dove was only practicable if a small model of a dove was made. Precise model making thus became part of the early holographic handicraft, the VISA dove being an example, and as mentioned, the making of such unique and finely detailed models added to the security value of the holograms made of them.

[6] The term "pseudo" in the area of color holography is used in the sense of "apparently similar" and not in the alternative meaning of the term "false" or "fake".
Note that in image processing the term pseudocoloring refers to the artificial assignment of colors to a grayscale image. The applied colors usually have no correspondence to the original scene. Such pseudocolor images, therefore are also referred to as false color images, according to the alternative meaning of the term "pseudo".
[7] McGrew, Steve "A Graphical Method for Calculating Pseudocolor Hologram recording Geometries", in Jeong, T.H. (dir.), *Proceedings of the First International Symposium on Display Holography*, Lake Forest, USA (Illinois), Lake Forest College, 1982.

Figure 9 – True-color hologram by Light Impressions, produced in the late 1980s or early 1990s. Because the hologram is made using RGB color separation films, it does not display in three dimensions and is actually a 2D “in-plane hologram”. Hologram size 110 x 130 mm.

Reconstructed image photograph courtesy of David Pizzanelli.
The image can be found in an article of David Pizzanelli titled: “Direct-write Digital Holography”, available at:
http://www.pizzanelli.co.uk/content/digitalholography.htm, and
http://www.holographer.org/articles/hg00001/hg00001.html

Thanks also to Mike Long (currently at Pacific Holographics Inc.), who was involved in recording 2D/3D true color holograms at Light Impressions at the time and who gave me an explanation of the recording process.

In fact, a hologram is the window through which the reconstructed object is observed and large objects can only be seen through small windows if they are at a large enough distance from that window. But in white light reconstruction with extended sources, the deeper parts of the object tend to reconstruct with a considerable lack of sharpness and this in turn calls for relatively shallow hologram object spaces.

However, already in 1972 Lloyd Cross adopted a different approach, when he started developing holographic stereograms, or “integral holograms” as he called them. The basic technique consists of shooting a movie of an animated scene on film, while the camera moves along the scene, or alternatively while the scene is rotated in front of the camera. This makes the holographic stereogram a fusion of holography and cinematography and it allows to convert motion picture footage of animated scenes into 3D holograms. Of each movie frame a rainbow hologram is made in the form of a vertical slit and all vertical hologram slits are mounted side by side to make the holographic stereogram. Lloyd Cross mounted the integral hologram in a semi-circle or circle, to display the animated object floating in its centre. When one walks by a semi-circular hologram, the animated scene unfolds. Cross’s famed example is the "Kiss II" integral hologram, recorded in summer 1974 in collaboration with Pam Brazier. This 180° “integral” was composed of hundreds of movie frames and displays Pam Brazier winking and blowing a kiss at the viewer, as shown in Figure 10; the scene unfolds by rotating the cylindrical set-up or by walking around it. Figure 11 shows an example of such a 360° cylindrical set-up.
The full 3D impression of these “integrals”, also referred to as “multiplex holograms” is based on the principle of stereo photography (stereography, stereoscopy): rendering the illusion of a 3D image by presenting a 2D image of the object to each eye, both 2D images being recorded at a slightly different angle. As both eyes observe the reconstructed image of the integral hologram through different vertical slits in the hologram, the object is presented to each eye under a different recording angle because the object rotated with respect to the camera during cinematographic recording.

A next step was the creation of holographic stereograms in full color by shooting a movie on color film and creating true-color Benton holograms of each movie frame by RGB color separation using R, G and B laser beams. Famous examples of such true-color holographic stereograms, applied in the document and product security branch, are the Shakespeare hologram used on UK Maestro credit cards, the Beethoven holographic stereogram depicted in Figure 12 and the famous Microsoft Windows 95 security hologram with a little boy pointing at a monitor screen (Figure 13). I further mention the well-known smiling clown which weeps over a broken rose, by Ken Haines depicted in Figure 14, not a security hologram. The technology requires precise alignment of three color separations of the original cine film and not many laboratories have the equipment and know-how in house, which makes such holograms interesting from a security point of view.

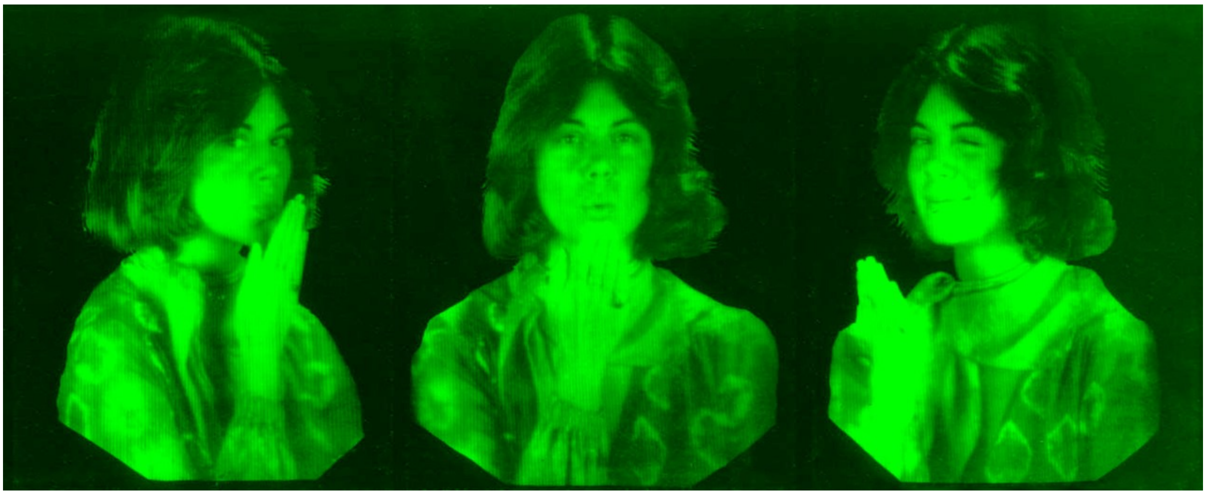

Figure 10 – Three views of Lloyd Cross's 1974 animated holographic stereogram of Pat Brazier: "Kiss II". After the 1977 photo by Daniel Quat, displayed on http://www.holophile.com/history.htm, which was probably taken from a 12 x 23 cm semi-circular version.

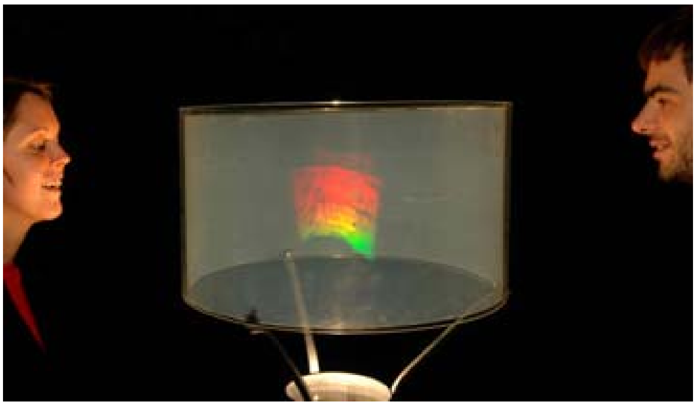

Figure 11 – Example of a 360° cylindrical holographic stereogram. Hologram size 10 x 50 inches, 40 cm diameter.
Artist: Eduardo Kac (1987/1988). Source: http://www.ekac.org/allholopoems.html

Figure 12 – A holographic stereogram on the 1999 Eurocard, photographed at 3 different angles while rotated about a vertical axis showing a true color reconstruction with horizontal parallax of a cinematographic animation of a live figure impersonating Beethoven. Apart from the stereogram channel, the hologram displays two separate channels: "EC99" and "99" (not shown). Hologram size 15 x 17 mm.

Figure 13 – Microsoft Windows 95 true color holographic stereogram (31 mm diameter).
On rotating about a vertical axis, the infant's arm rises and points at the screen. The movement is very fast and unsharp in reconstruction.

The original version of this hologram had an animation of a baby, sitting next to a computer and then pointing at the screen. The model was the infant son of the photographer, and did not wear a shirt, which led some people to believe that he was not wearing pants either, even though he was visible only from the waist up. After complaints from an offended government, Microsoft had to change the hologram to one that did not display "naked children".

Figure 14 – Clown 1991, True-color holographic stereogram, Ken Haines/ABNH (size 56 x 71 mm).

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