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# A transportable system for the in situ recording of color Denisyuk holograms of Greek cultural heritage artifacts in silver halide panchromatic emulsions and an optimized illuminating device for the finished holograms

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# A transportable system for the in situ recording of color Denisyuk holograms of Greek cultural heritage artifacts in silver halide panchromatic emulsions and an optimized illuminating device for the finished holograms.

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**Abstract**. In this paper we will present the Z-Lab transportable color holography system, the HoLoFoS illuminator and results of actual in situ recording of color Denisyuk holograms of artifacts on panchromatic silver halide emulsions. Z-lab and HoLoFoS were developed to meet identified prerequisites of holographic recording of artifacts: a) in situ recording b) a high degree of detail and color reproduction c) a low degree of image distortions. The Z-Lab consists of the $Z3^{RGB}$ camera, its accessories and a mobile darkroom. HoLoFoS is an RGB LED-based lighting device for the display of color holograms. The device is capable of digitally controlled intensity mixing and provides a beam of uniform color cross section. The small footprint and emission characteristics of the device LEDs result in a narrow band, quasi point source at selected wavelengths. A case study in recording and displaying '*Optical Clones*' of Greek cultural heritage artifacts with the aforementioned systems will also be presented.

## 1. Introduction

Holography is a form of optical information storage method that can record our three-dimensional world on a two-dimensional recording medium and playback the original object or scene to the unaided eyes as a three dimensional image. Holographic image differs from photographic image as it has perspective and depth and can be viewed from various angles. In 1948, Denis Gabor invented the technique of recording phase information by means of a background wave, which converts phase differences into intensity differences. The general principles are described by Leith et al [1] and holography theory and its applications are well described in the literature [2]. In 1962, Dr. Y.N. Denisyuk from Russia combined holography with 1908 Nobel Laureate Gabriel Lippmann's work in natural color photography. Denisyuk's technique produced a reflection hologram which, for the first time, could be viewed under ordinary incandescent bulb light [3]. By using 3 or more laser lines, one can record color Denisyuk holograms of artifacts [4].

### 1.1. *HoloCultura: Color holograms of cultural heritage artifacts*

Current technological progress in various disciplines such as solid-state lasers, panchromatic emulsions, LED illumination etc., allow for the first time the use of display holography in cultural heritage in a practical and tangible manner. A renewed interest in applications of display holography for Museums and worldwide activities in this sphere have ensued [4].

In response to a public call for proposals financed under the EU Structural Funds and involving display holography issued by the Greek State General Secretariat for R&D in Sep 2009, the Hellenic Institute of Holography submitted its proposal titled 'HoloCultura' specifying -among other- a transportable recording system and LED illuminating devices for Denisyuk color holograms of objects of Greek cultural heritage [5]. Unfortunately, no project involving holography was financed in spite of the explicit specifications of the original call.

Nevertheless, the Hellenic Institute of Holography and its partners decided to embark into this project on their own capacity. During Phase I of the 'HoloCultura', the necessary transportable equipment, processes and software for the in-situ recording of artifacts and their subsequent interpretation in either analog or digital display holograms have been developed. The project is now in Phase II where experimental work is done by using different materials for producing display holograms of acceptable standard by the prospective end-users. Results of Phase I and Phase II (May 2012) will be discussed in the next sections.

## 2. The $Z3^{RGB}$ and HoLoFoS : Theoretical and Practical Considerations

In theory, true color Denisyuk holograms of high quality can be recorded in silver halide emulsions and subsequently be displayed reproducing life-like three-dimensional images, if certain prerequisites are fulfilled [6] [7] [8] [10] e.g. :

- Suitable selection of three or more laser wavelengths
- Panchromatic recording plates with mean grain size well below 10 nm
- Optimized processing of the exposed plates
- Suitable recording geometry to eliminate dispersion
- Mechanical and thermal stability
- Optimized illumination of the color hologram to enhance depth reconstruction, color rendition and minimize blur

Moreover the transportability of a holographic camera for the in situ recording of artifacts introduces more challenges to the overall optical and mechanical design of such a system. We will elaborate on the aforementioned prerequisites in the following sub sections.

### 2.1. *Selection of Laser Wavelengths*

The human eye has photoreceptors (called cone cells) for photopic vision, with sensitivity peaks in short (420–440 nm), middle (530–540 nm), and long (560–580 nm) wavelengths. Thus, in principle, three parameters describe a color sensation. These tristimulus values of a color can be conceptualized as the coordinates of three primary colors in a tri-chromatic additive color space like the CIE XYZ.

Two light sources made up of different mixtures of various wavelengths may appear to be the same color; this effect is called metamerism. Such light sources have the same apparent color to an observer when they produce the same tristimulus values, no matter what the spectral power distributions of the sources are. In this aspect researchers in color holography have aimed at choosing three suitable wavelengths for recording a true color hologram, which would cover a sufficient area of the CIE chromaticity diagram.

Thornton [9] found that the reflectivity of an object at three well-specified wavelength bands (near 450, 540 and 610nm) have a disproportionately high color rendering index. Using these wavelengths, a wide range of highly saturated colors can be produced. Hubel and Ward [11] in 1989 recorded color reflection holograms using 647, 528 and 458nm lasers with a wide color gamut. In 1991 Hubel and Solymar [12] found another good practical choice of wavelengths in using a combination of 442, 532 and 633nm. Bjelkhagen and Mirlis [6], Peercy and Hesselink [14] and Kubota et all [13] claim that

more than three wavelengths are needed for true color rendition. In our transportable $Z3^{RGB}$ holography camera we use 457, 532 and 638nm solid state lasers with space provision to add more.

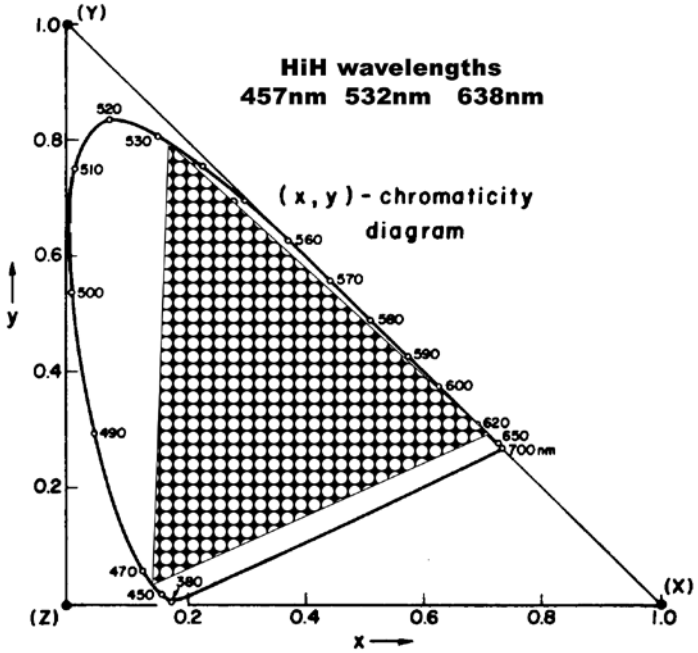


**Figure 1.** Color gamut of the $Z3^{RGB}$ laser wavelengths.

This combination of wavelengths gives a gamut (figure 1) that includes yellow, purple, dark blue and violet as the Hubel and Ward one, and overlaps the Wintringham data. An important reason for this specific selection of wavelengths was the close matching to the emission characteristics of available power LEDs for the HoLoFoS hologram illuminating device.

### 2.2. *Recording Media and Chemical Processing*

To be able to record high quality color Denisyuk holograms, it is necessary to use panchromatic emulsions with mean grain sizes less than 10nm. Grain size affects the maximum spatial frequencies that can be recorded, the signal-to-noise ratio and the exposure energy required. Currently two commercially available emulsions, the Slavich PFG-03c and 'Ultimate' 08 by Yves Gentet [15], have suitable characteristics for color reflection holography. 'Colour Holographic' have recorded on their BBpan emulsion high quality holograms but the emulsion is not commercially available yet. Bjelkhagen [4] has recorded museum artifacts on the experimental Silver Cross emulsion

There are many formulae for suitable developers and bleaches described in the literature [16]. The chemical processing of the exposed plates has to be carefully adjusted to an emulsion in order to achieve high diffraction efficiencies and low level of scattering, especially towards the blue end of the spectrum.

At the current phase of the 'HoloCultura' project, we decided to follow the developing processes proposed by the manufacturers of the test plates. Practically all of our experimental recordings, while testing the $Z3^{RGB}$, have been carried out, so far, on the 'Ultimate' 08 emulsion and processed with the 'Ultimate' developer and bleach. It is our aim, at this phase of the project, to test in comparison all commercially available emulsions and publish our results in the near future. Some characteristics of the PFG-03c and 'Ultimate' 08 as published by their manufacturers are summarized in Table 1.

In our short experience with the 'Ultimate' plates we have confirmed the exposure energy levels quoted, high diffraction efficiencies and tolerable scattering in the blue if exposed properly.

**Table 1.** Characteristics of Slavich and 'Ultimate' emulsions.

| | | |
|---|---|---|
| Silver halide material | PFG-03c | 'Ultimate' 08 |
| Grain size | 10nm | 8nm |
| Resolution | 10000 lines/mm | 10000 lines/mm |
| Blue sensitivity | 2mJ/cm2 | 120-150 μJ/ cm2 |
| Red sensitivity | 3mJ/cm2 | 120-150 μJ/ cm2 |
| Green sensitivity | 3mJ/cm2 | 120-150 μJ/ cm2 |

### 2.3. *Recording geometry*

Color reflection holograms exhibit less dispersion than transmission holograms due to their inherent sampling over the illuminating source frequencies. It is possible to minimize dispersion by using a reference angle of 30 degrees while keeping the plate inclined at 15 degrees [7]. This arrangement results in 45 degrees illumination angle during playback, a situation where the reflection of the illuminating source just misses the line of sight of an observer. However, not all objects can be displayed in this configuration, as the object appears inclined relative to the plate's surface.

### 2.4. *Mechanical and Thermal Stability*

Although the Denisyuk setup is less susceptible to mechanical disturbances, we prefer to heavily isolate the object and the plate using a Thorlabs 60 by 60 cm passive isolation platform on which we place a thin aluminium optical breadboard sitting on Sorbothane™ legs. We use a specially designed mobile tent chamber that encloses the object/plate space in order to minimize air currents and ensure thermal stability during the exposures. Both the isolation system and the chamber are standard parts of the Z-Lab holography system.

### 2.5. *Optimized illumination*

Though reflection holograms do filter the illuminating light, variable bandwidths of the recording frequencies may occur. Image blur due to dispersion is heightened in a broadband plate under a broadband illumination. On the other hand, image blur due to the finite dimensions of the illuminating source forces the placement of the light source inconveniently far from a hologram. The HoLoFoS LED RGB, a narrow band and quasi-point illuminating source, was designed as a device which addresses these problems.

## 3. The $Z3^{RGB}$ Transportable Color Holography Camera

The $Z3^{RGB}$ is actually a light mixing device built with transportability in mind and using high quality optical and mechanical parts (figure 2, figure 3). At the moment it incorporates three solid state lasers emitting at 457, 532 and 638nm with corresponding powers of 50,100 and 80 mW of single mode $TEM^{oo}$ radiation. The coherence lengths of the lasers are more than 5 meters each. The camera is PC-driven by software developed in house (figure 4). The lasers and optics are mounted on a 60 by 60 cm honeycomb optical breadboard which in turn is enclosed in a fibber glass protective housing which contains the DAC boards and power supplies. The housing (figure 5) stands on three removable pneumatic legs allowing height and tilt adjustments and serves the thermal stability of the camera.

At early camera development stages we encountered laser jitter and mode hoping due to thermal instability. To overcome this behavior we had to build optimized TEC driving electronics for one of the lasers and fit the layout in a housing to ensure thermal stability. At the same time we added a Fabry–Pérot scanning interferometer to continuously monitor the laser beams and coupled the lasers monitoring and control lines to the Z3 controlling software. A thermistor was also fitted inside the camera housing and coupled to the software in order to read the temperature inside the housing compartment. In this way we now have continuous monitoring and control of the lasers which ensure

mode-hop-free exposures except under extreme humidity and temperature gradients (as in one particular case of a windstorm when our red DL substituted our barometer!).

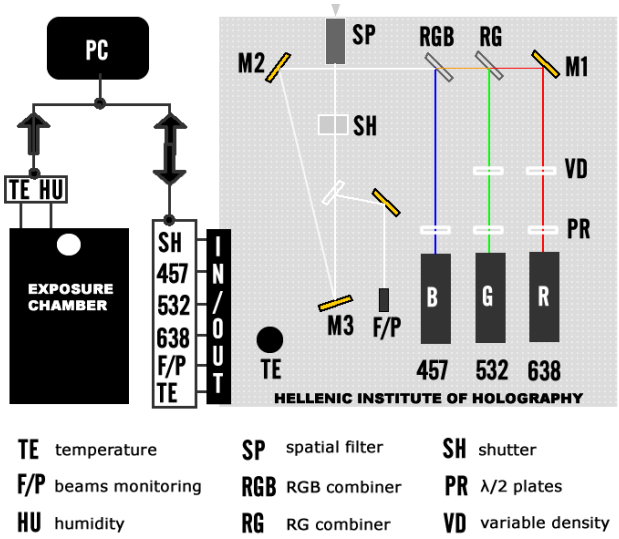


**Figure 2**. Z3 $^{RGB}$ Schematic.

Testing the camera under actual or simulated varying environmental conditions, with the camera being thermally stable to a high degree, we realized that we had to enhance vibration and thermal isolation in the plate-object space. So we assembled our two layered isolation platform where we place the object and the plate and manufactured our light-proof exposing chamber to enclose the plate/object space. The chamber is fitted with temperature and humidity sensors which feed their data to the Z3 controlling software. The Z3 software creates a record of each exposure including emulsion type, exposure energy, temperature inside the camera and the exposing chamber as well as humidity in the exposing chamber.

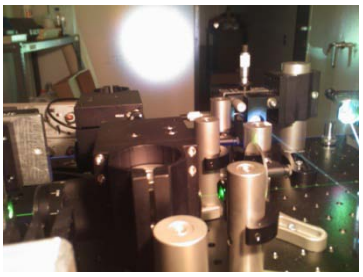

**Figure 3.** Inner works & beam.

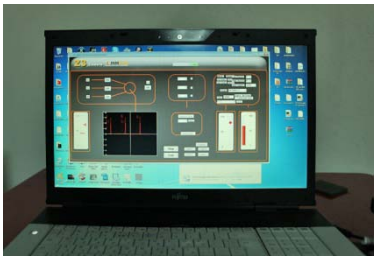

**Figure 4.** PC control software.

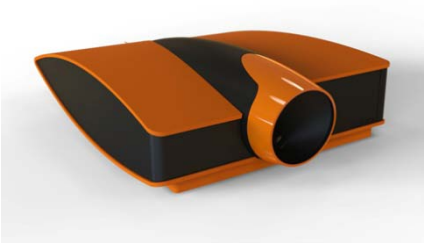

**Figure 5.** The Z3$^{RGB}$.

The camera's 'white light' output beam can be directed to the plate either by adjusting the housing's legs or by using a relay mirror, which is our preferred method. Typical times to reach thermal stability inside the camera are 30 to 60 min while typical exposure times for a 30X40 cm 'Ultimate' 08 plate are 6 to 12 seconds.

An autonomous and easily assembled darkroom completes the Z-Lab setup for the in situ recording of artifacts. The darkroom is equipped with vertical development tanks to save space and chemicals,

can be connected to an external water supply and sink or -alternatively- use the fitted water and waste collection tanks.

## 4. HoLoFoS: An Optimized Light Source for Color Holograms Display

For decades display holograms have been illuminated either by cumbersome theatrical lights or simple halogen spots. This kind of illumination has many drawbacks including -among other- image blurring, high power consumption and thermal degradation of the illuminated hologram. On the other hand, an RGB-LED illuminant is characterized by narrow bandwidth per color to a high degree and small size of source, which minimize blur [8], while power consumption and thermal effects are reduced. Consumer available RGB LED fixtures suffer, from holography's view, of non-axial placement of the RGB LEDs and poor spatial mixing of the discrete beams.

'HoLoFoS' is our intelligent LED illuminating device that can supply to a hologram the necessary narrow bandwidth in red, green and blue light with peaks near the recording wavelengths . At the same time the small footprint of the HoLoFoS LED dies (2mm by 2mm per color) allows placing the HoLoFoS at a closer distance to a hologram while retaining image sharpness and enhanced depth. Electronic remote control of the LEDs driving current permits the accurate intensity mixing of the emitted red, green and blue bands in order to fine tune the colors of a hologram. The HoLoFoS provides coaxial mixing of the LEDs beams with the use of dichroic combiners (figure 6).

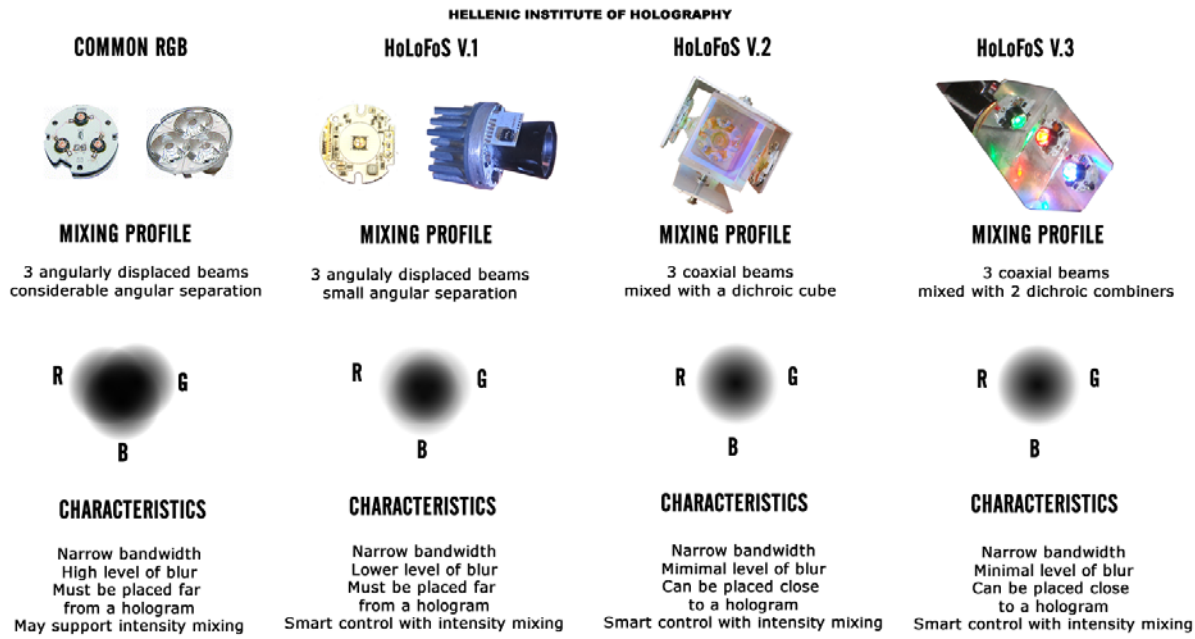


**Figure 6**. Evolution of HoLoFoS smart LED lighting for holograms.

The 'HoLoFoS' can be fitted with any combination of 3 or 4 LEDs in various wavelengths. Qualitative inspection of color reflection holograms under HoLoFoS illumination show a dramatic increase in image crispness while RGB intensities mixing help to 'correct' many faults in color rendition.

## 5. The 'Chios Epitaph' : An Actual Recording with the $Z3^{RGB}$

The 'Chios Epitaph' proved to combine all the requirements for testing our equipment : original artifact, natural multi-level depth, bright natural colours, wooden 'breathing' substrate, lots of fabric cloth, free-standing 'vibrating' metal flowers, ideal size and a fragile nature.

Several alternative layout setups were tested for the final hologram and various slightly different holographic images were thus obtained. What has been selected to go on public show has been recorded with the object artifact contained within a wooden box featuring a yellow-painted background in order to enhance colour contrast. The recording setup is depicted in figure 7.

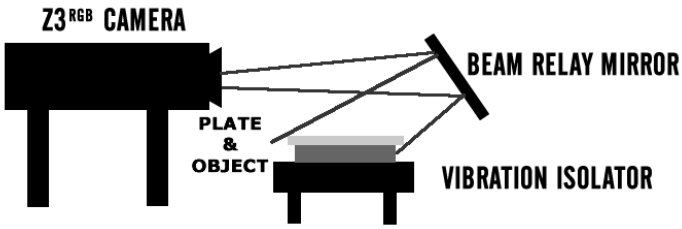


**Figure 7**. Setup for the 'Chios Epitaph' hologram recording.

The hologram was recorded on 30x40 cm 'Ultimate' 08 plate with an exposure time of 12 seconds. The object has been previously left to acclimatize for one day. Standard 'Ultimate' developer and bleach were used and the plate was left to air dry after soaking in distilled water in which a few drops of PhotoFlo were diluted. The hologram exhibits saturated colors and fine details under HoLoFoS illumination (figure 8).

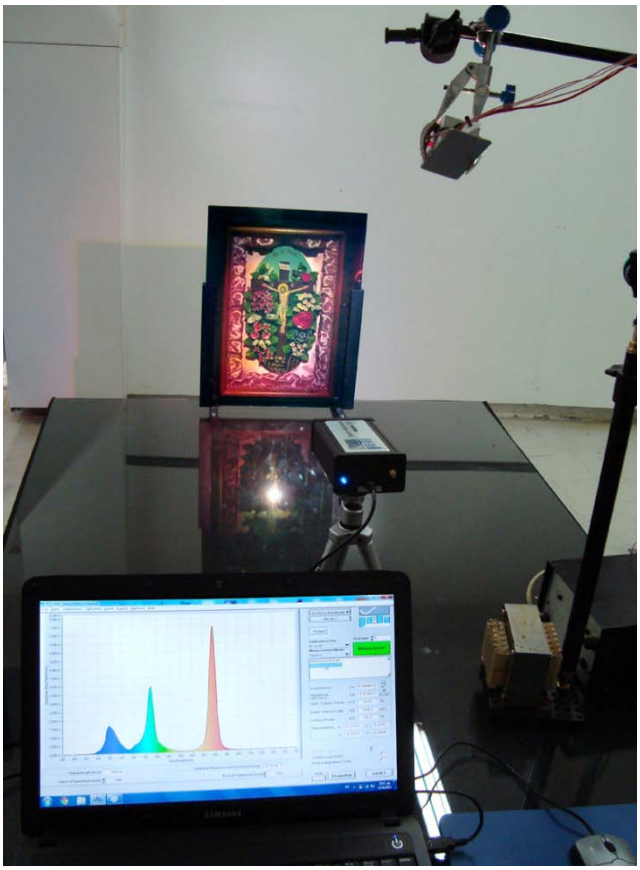

**Figure 8**. Spectrum from the 'Chios Epitaph' hologram, under HoLoFoS illumination, measured with our Jeti Specbos 1211 spectro-radiometer.

## 6. Conclusions

We have designed and tested a transportable camera for the in situ recording of color holograms of cultural heritage artifacts and an RGB LEDs illuminating device to illuminate the holograms.

The $Z3^{RGB}$ is stable under adverse environmental conditions and is capable of exposing 30x40 cm 'Ultimate' plates with short exposures of 6 to 12 sec. The HoLoFoS provides narrow bandwidth quasi-point source illumination that enhances colors and reduces blur.

Our experience with the 'Ultimate' emulsion is limited and we have to further quantitatively investigate the emulsion's characteristics to ensure repeatable results using spectro-radiometric measurements. At the moment we get remarkable results though not consistently due to the emulsion's high sensitivity to humidity.

Finally, we have to investigate the option to add more laser lines to enhance color reproduction.

## 7. Epilogue

Since its inception, display holography offered the highest hopes for recording objects of cultural interest and using the resulting holograms as *Virtual Artifacts*. However, mostly on account of the limitations of the technology (such as monochromaticity, unavailability of consistent commercially available emulsions, size and performance of LASERs, etc.) such hopes never really materialized in a publicly acceptable way despite the early promising applications and the occasional successful implementation of holograms as a medium for creating optical replicas of the original artifacts.

In our view, these efforts also lacked an important angle to their approach to Museum curators, conservation scientists and decision-makers: the proposed holograms were considered mainly on their properties for replicating quasi-realistically the selected objects or were assessed on basis of their subjective aesthetic and artistic value. Our proposal is that the new generation of ultra-realistic display holograms or ***Optically Cloned Artifacts*** - as termed by our Institute- should also serve as a means of **visually documenting** the cultural artifacts in addition to latest tendencies in museology such as digital modeling, multi-perspective imaging, digital virtual data-basing etc.

Within this framework, the novel approach of the Hellenic Institute of Holography to incorporate its techniques for creating display holograms with the scientifically-proven proprietary equipment for the analysis and diagnosis of works of art developed by the Institute of Electronic Structure & Lasers (Foundation for Research & Technology-Hellas) offers not only the necessary enhanced scientific credentials but also a complementary integrated approach described by the connoted term ***Hyper-Documentation™*** [17]. Such services, as marketed by **ArtGnomon**, a spin-off of FORTH-Crete and TAURUS SecureSolutionS Ltd., open a completely new approach to the study of cultural artifacts in which ultra-realistic display holograms have an important function to play.

## References

[1] Leith EN, Upatnieks J. 1965 *Scientific American* 212 6 24-35.
[2] Saxby G., *Practical holography* 2004 3rd edn Institute of Physics Publishing London.
[3] Denisyuk Y.N., 'On the reproduction of the optical properties of an object by the wave field of its scattered radiation', *Optical Spectroscopy* (USSR) 1963 **14** 279–284.
[4] Hans Bjelkhagen and Jill Cook, 'Colour holography of the oldest known work of art from Wales', *The British Museum Technical Research Bulletin* 2010 **4** 1-9.
[5] Anon., 'Greece plans Holograms of Antiquities', *Holography News* 2009 **23** 11 1-8.
[6] Bjelkhagen, H.I. and Mirlis, E., 'Color holography to produce highly realistic three-dimensional images', 2008 *Applied Optics* **47** 4 A123–A133.
[7] K. Bazargan, 'Techniques in display holography', 1986 *Phd Thesis* Optics Section Blackett Laboratory Imperial College of Science and Technology London.
[8] Arno Klein, 'Dispersion Compensation for Reflection Holography', 1996 *M.S Thesis* in Media Arts and Sciences M.I.T
[9] W. A. Thornton, 1971 *JOSA* **61** 1155-1163.
[10] K. Bazargan, 1989 *Proc. SPIE* **1051** 6.

[11] P.M. Hubel and A.A. Ward, 1989 *Proc. SPIE* **1051** 6.
[12] P.M. Hubel and L. Solymar,1991 *Appl. Opt.* **30** 4190-4203.
[13] T. Kubota, E. Takabayashi, T. Kashiwagi, M. Watanabe, and K. Ueda, 'Color reflection holography using four recording wavelengths' in Practical Holography XV and Holographic Materials VII, S. A. Benton, S. H. Stevenson, and T. J. Trout,eds., 2001 *Proc. SPIE* 4296 126-133.
[14] M. S. Peercy and L. Hesselink, 'Wavelength selection for true-color holography' 1994 *Appl. Opt.* **33** 6811-6817.
[15] Y. Gentet and P. Gentet,""'Ultimate'" emulsion and its applications: a laboratory-made silver halide emulsion of optimized quality for monochromatic pulsed and full color holography" 2000 Proc. SPIE 4149 56-62.
[16] Hans Bjelkhagen, 'Silver-Halide Recording Materials',1995 2nd edn Springer.
[17] Fotakis C., D. Anglos, V.Zafiropulos, S. Georgiou, V. Tornari, Ed. R. G. W. Brown, E. R. Pike, 'Lasers in the Preservation of Cultural Heritage; Principles and applications' 2006 *Taylor and Francis, New York.*