

Ultra-realistic imaging and *OptoClones*TM

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ABSTRACT

Recent improvements in solid state CW lasers, recording materials and light sources (such as LED lights) for displaying color holograms are described. Full-color analogue holograms can now be created with substantially better image characteristics than previously possible. To record ultra-realistic images depends on selecting the optimal recording laser wavelengths and employing ultra-fine-grain, silver-halide materials. The image quality is improved by using LED display light with improved spatial coherence. Recording museum artifacts using mobile holographic equipment is described. The most recent recorded such holograms (referred to as *OptoClones*TM) are the Fabergé Eggs at the Fabergé Museum in St. Petersburg, Russia.

Keywords: Holographic Display; Color Holography; Display Holography; 3D Imaging, Museum Display;

1. INTRODUCTION

Analogue color holograms of the Denisyuk type are the ones which really create the illusion of viewing a real object behind the plate rather than an image of it. The possibility to record ultra-realistic holographic color images¹ depends on selecting the optimal recording laser wavelengths. Three (RGB) wavelengths are a minimum, but four or five are required for better color rendering.² It is necessary to use extremely low-light-scattering panchromatic recording materials, which means the use of ultra-fine-grain, silver-halide emulsions. The third factor is the light source used to display the recorded color holograms. Progress in illumination technology, by employing the new LED lights, is leading to a further major reduction in display noise and to a significant increase of the clear image depth and brightness of the holograms. The light and the illumination arrangement (source size, distance and angle of illumination) play a very important part in creating ultra-realistic 3D images. The new RGB-LED lights have contributed to the progress in displaying color holograms. What do we mean by an ultra-realistic image?

- It looks “identical” to the real object observed by eye
- Very accurate color rendition
- Same scale – no magnification
- Image resolution corresponds to the eye resolution
- No detectable image blur
- No field of view limitations
- Image light reflections move like they do on the object
- In principle – recording light waves reflected off an object, store and recreate them later
- ONLY DENISYUK HOLOGRAPHY can accomplish this

The early monochrome large-format Denisyuk holograms recorded in the former USSR were very impressive. The bright, high-contrast holograms were recorded using red-wavelength lasers on ultra-fine-grain, silver-halide emulsions. Such holographic materials were not produced by Agfa, Ilford or Kodak, which made it difficult to record such holograms in other parts of the world. Because of the high-quality of the Denisyuk reflection holograms in the former USSR; museums in these countries were keener than western museums to study and test holography.³⁻⁵ A selection of these holograms was brought to the West at the 1985 exhibition ‘*Holography – Treasures of the USSR*’ at the Trocadero Centre in London. One rare museum monochrome hologram recorded in the West was the *Lindow Man* who died sometime in the first century AD. It was made in 1987 for British Museum in London.⁶⁻⁷ These early monochrome holograms looked very realistic, but not being able to reproduce the artifact’s color was unacceptable for most museum applications. In addition, museums hesitated because of the expense and the need for special recording laboratories.

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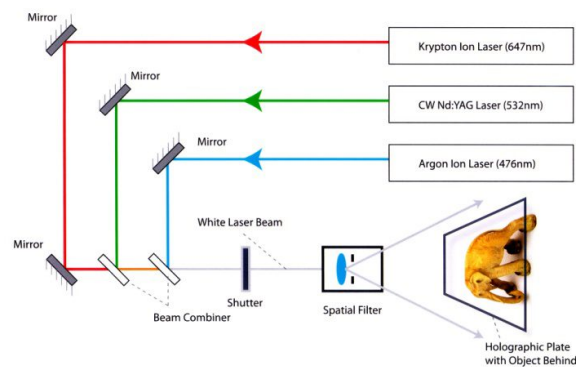


Figure 1. Setup for recording analogue color reflection holograms

2. COLOR HOLOGRAPHY

The principle of recording analogue color holograms of the Denisyuk type is shown in Fig. 1. In the setup, only three lasers are indicated, but it is possible to add one or two more lasers using additional beam combiners. This is the setup which have been used in holographic laboratories equipped with large, often water-cooled argon-ion and krypton-ion lasers. The analogue color holograms of the Denisyuk type have been coined by the Hellenic Institute of Holography (HiH) as *OptoClones*TM partly caused by the incorrect use of the word “hologram” in modern versions of Pepper’s Ghost display technique and similar so called “hologram” applications. In addition an *OptoClone*TM needs to be displayed in a fixed installation, using a new type of LED illumination as explained in the following, which guarantee that a distortion-free, ultra-realistic image will be on display.

3. PANCHROMATIC RECORDING MATERIALS

The main key to succeed in recording color holograms is to have a suitable panchromatic, low-light-scattering materials. Currently, the main two material types are silver-halide emulsions and photopolymer materials.

3.1. Silver Halide Materials

There are only a few companies producing ultra-fine-grain emulsions for holography, *Slavich*⁸ located in Russia, has a panchromatic emulsion for color holography. *Sfera-S*⁹ is another Russian company manufacturing large-format panchromatic rolls of film and glass plates for color holograms. The UK-based *Colour Holographic Ltd*¹⁰ is a manufacturer of panchromatic ultra-fine-grain emulsions. The company also records color holograms of museum artifacts under the name *TruLife*TM. Recently Yves Gentet of *Ultimate Holography* demonstrated that it is possible to produce a panchromatic emulsion with a grain size of 4 nm.¹¹ This new *Ultimate* material has been introduced on the market. Commercial silver-halide materials are listed in Table 1.

3.2. Photopolymer Materials

The panchromatic photopolymer materials from *Covestro* (former Bayer MaterialScience),^{12,13} *DuPont*^{14,15} and *Polygrama*¹⁶ are alternative recording material for color holograms. Although, being less sensitive than the ultra-fine-grain, silver-halide emulsions, the photopolymer materials have their special advantages of easy handling and dry processing (only UV-curing and baking.) However, the photopolymer materials are more suitable for copying color holograms rather than using them for recording an object.. The photopolymer materials are of high quality and can be supplied in large quantities on film. *DAI Nippon Printing Co., Ltd.* (DNP)¹⁷ in Japan was the first company with mass-produced color holograms recorded in DuPont's panchromatic photopolymer material. Today DAI Nippon manufactures its own photopolymer material for their holograms. They make decorative holograms called TRUE IMAGETM and security color holograms, marketed under the name of SECURE IMAGE.TM *Bowater Holographics Ltd*¹⁸ in UK is in the process of developing security color reflection holograms on *Covestro* photopolymer materials.

Table 1: Commercial panchromatic silver-halide holographic recording materials

| Material | Spectral sensitivity [nm] | Resolving power [line pairs/mm] | Grain size [nm] | Substrate |
|----------------------------------|---------------------------|---------------------------------|-----------------|------------|
| <i>Colour Holographic</i> | | | | |
| RGB: BB-PAN | 440-650 | 6000 | 10 | Glass |
| <i>Slavich</i> | | | | |
| Pan: PFG-03C | 450-700 | 6000 | 10 | Glass/Film |
| <i>Sfera-S</i> | | | | |
| Pan: PFG-03CN | 435-665 | 6000 | 9 | Glass/Film |
| <i>Ultimate</i> | | | | |
| Pan: 08-COLOR | 460-650 | 10000 | 8 | Glass/Film |
| Pan: 04-COLOR | 460-650 | 15000 | 4 | Glass/Film |

4.2. Recording Holograms in a Museum

Considering security problems when bringing artifacts to a holographic lab, personnel needed for transportation and the need to be present during the recording, it was clear that mobile recording equipment was necessary. The only possibility to make display holography accepted as a new imaging technique, popular and safe; the recording has to be performed inside museum buildings. The first described mobile equipment for recording color holograms was presented in 2009 by Gentet and Shevtsov.¹⁹ The system was equipped with a red ($\lambda = 639$ nm) semiconductor laser and two solid-state lasers, a green ($\lambda = 532$ nm) and a blue ($\lambda = 473$ nm). In 2013 *Colour Holographic Ltd* recorded color holograms of several specimens from the Grant Museum of Zoology in London using their newly developed mobile equipment.

HiH has developed the *ZZZyclops*TM equipment²⁰ which is shown in the principle drawing of the recording setup shown in Fig. 1, with an inside view. Two DPSS lasers (*Cobolt* lasers)²¹ and one stabilized DL system (developed by A. Sarakinos) are currently used in the equipment with TEM₀₀ emissions and coherence lengths of more than five meters each. The three lasers:

- Red laser: 638 nm at output power 90 mW (*Hellenic Institute of Holography HiH-R100* DL laser);
- Green laser: 532 nm at output power 100 mW (*Cobolt Samba* DPSS laser);
- Blue laser: 457 nm at output power 50 mW (*Colbolt Twist* DPSS laser).

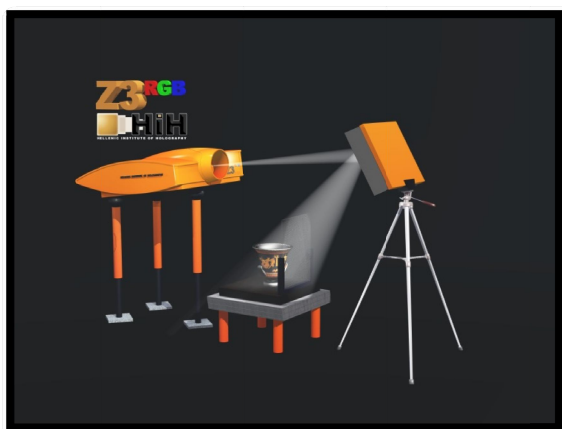


Figure 2. Setup for recording *OptoClones*TM in a museum



Figure 3. The RGB lasers inside the *ZZZyclops*TM

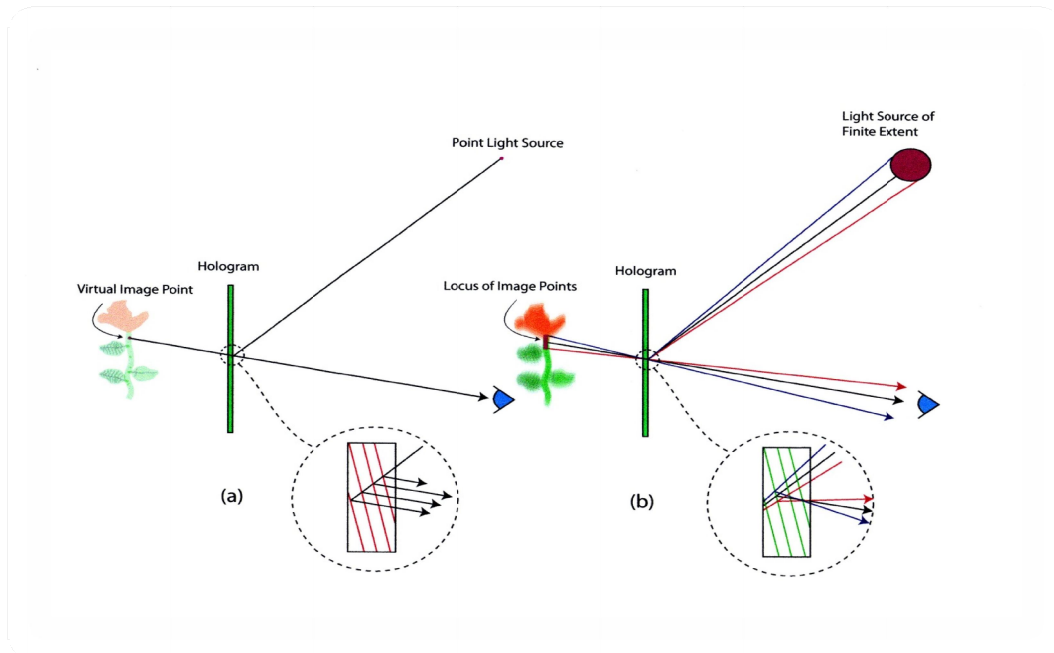


Figure 4. Image blurring in a reflection hologram when illuminated with an extended light source

3. DISPLAY OF COLOR HOLOGRAMS

Often the term "*reconstruction*" is used to describe the display of a hologram. This refers to the fact that if the reference beam, which was used to record the hologram, is used to also illuminate the processed hologram plate, the wavefront emitted from the object during recording, will be faithfully *reconstructed* generating the holographic image. This underlines the critical fact that in order to obtain a faithful holographic reconstruction, the properties of the reference recording and reconstruction beams must usually be identical. The illumination of holograms is nevertheless a topic which is seldom included in books on holography; but it is as important as techniques to record holograms. Remember that holography is a *two-part process* where the holographic plate, with its recorded interference pattern, constitutes only one of the two parts needed to create the holographic image. The second part is the reference light which is used to display the hologram. The characteristics of this reference light fundamentally control the display process. Only if the properties of the reference and replay lights are identical (spatial coherence, ray divergence, angle of incidence and wavelength) will a distortion-free, correct holographic image be generated. In most practical situations it is rare that the replay light is *absolutely* identical to the recording light. In particular conventional broadband white-light sources are frequently used to illuminate reflection holograms. Here one uses the wavelength selective properties of the reflection hologram to filter out light having a different wavelength to that of the recording light. Illumination by a broadband source will bring with it chromatic blurring and in general the clear image depth of the hologram will be compromised. One of the most important properties of any light source used to illuminate a hologram is spatial coherence. When a hologram is recorded, the reference laser light emanates from a spatial filter having a diameter of between 10 and 25 μm . This is several orders of magnitude smaller than the source size of current popular illumination sources. For example, halogen spotlights commonly used to display reflection holograms, have source sizes from one to several centimetres. A finite spatial coherence in the reconstruction source leads to source-size blurring (see Figure 4), which limits the clear image depth of the hologram. For ultra-realistic holographic imaging a rough rule is that the reconstruction source size must be less than 1mm in diameter for every 1m of diagonal distance which separates the illumination source and any point on the hologram. This ensures that any residual source-size blurring will be below the perception level of the standard human observer - as the average human eye can resolve image details of about one millimetre at a distance of 1m. Many applications of color holography require that the display and illumination techniques are carefully considered to display ultra-realistic images. The new LED lights make it possible to reduce the image source-size blurring as well as to improve color rendering.

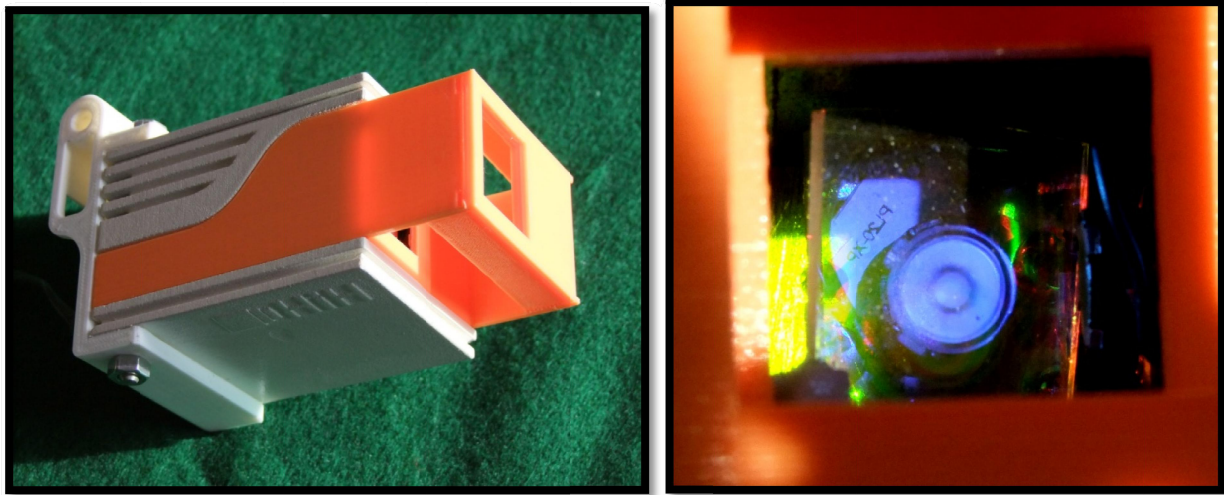


Figure 5. The *HoLoFoS* model (λ) RGB LED spotlight and the 2 mm diameter light-emitting area

3.1. Light-Emitting Diodes (LEDs)

The past few decades have seen a continuing and rapidly developing race among manufacturers of LEDs to produce ever cheaper and ever more efficient illuminants. This rapid progress in solid-state LED lighting has opened up new possibilities to illuminate color reflection holograms. A significant advantage of LEDs is that they possess a much smaller bandwidth than broadband white-light sources. Although typical bandwidths are much larger than those commonly associated with lasers and laser diodes, LED light sources should nevertheless be matched to the recording laser wavelengths (or vice versa). This guarantees that only the white light from the LED source (which is a mixture of the primary LED wavelengths) contributes to creating the holographic image. Using a halogen spotlight, a large part of the light spectrum emitted illuminates the surface of the plate without having any impact on the intensity of the image. Instead this light is scattered, lowering the image contrast. The lack of this scattered light in LED illumination can lead to significantly higher image fidelity. In addition LED light sources have considerable advantages over halogen and other traditional lighting sources, such as long life, small size, small étendue, high durability and robustness to thermal and vibration shocks, low energy usage/high energy efficiency, no IR or UV in beam output, directional light output, and digital dynamic colour control – white point tuneable.

3.2. LED Spotlights for Color Holograms

HiH has developed a special LED spotlight²² for the display of *OptoClones*TM as shown in Fig 5. The *HoLoFoS* model (λ) LED spotlight is based on Cree LEDs. The illuminating head contains the RGB LEDs, mixing optics and lenses. The optics incorporated in the unit provide for an axial mixing of the LED beams resulting in a homogeneous color mixing over the full extent of the projected beam. The small footprint of each LED die (approx. 2 mm) is small enough to produce clear and deep holographic images even at small illuminating distances. The illuminating head can be fitted with a variety of LEDs at selected wavelengths and more than three different LEDs can be fitted to match various recording wavelengths. The current product *HoLoFoS* model (λ) uses three aligned LEDs with spectral characteristics which correspond to the lasers of the *ZZZyclops*TM recording equipment. The dominant wavelengths for the LEDs are 620 – 630 nm, 520 – 535 nm, and 450 – 465 nm. The new LED lights have been incorporated in a custom-made, free-standing display cabinet, as shown in Fig. 6. It is important that there is a fixed installation of the light source in relation to the plate to guarantee a distortion-free, sharp and color-correct 3D image. The display cases have a window on the side showing that there is no real object inside.

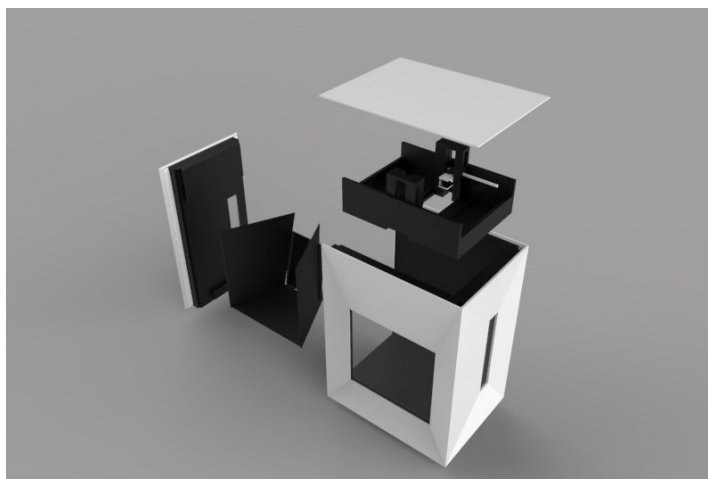


Figure 6. The display case with integrated RGB LED light

4. RECORDING MUSEUM ARTIFACTS WITH COLOR HOLOGRAPHY

Holography now offers the possibility to essentially duplicate valuable and rare artifacts - and to a point where an observer practically cannot tell whether he is looking at the real exhibit or at a holographic recording. Although such holographic reproduction can never match the value of actually possessing the real artifact, it can allow the museum to fulfil one of its most important functions - to maintain display of the exhibits. Analogue holography does offer a means to preserving a faithful visual recording of unprecedented microscopic detail. Holography can also help museums with travelling exhibitions. It is difficult for some people to travel to museums and as a result there is pressure on museums to take exhibits to the people. But transporting priceless artifacts is both hazardous and expensive. Transporting *OptoClones*TM on the other hand is not. A reason why ultra-realistic color holograms are useful to museums is related to insurance costs of even exhibiting within a museum. Most museums have large collections "downstairs" which they do not exhibit. The reason is that it generally costs more to exhibit something than to securely store it - as the risk of damage or loss is greater when an exhibit is on display. Again holography can help solve this problem. If the *OptoClone*TM is indistinguishable from the real exhibit, why not just securely store the real item and display the *OptoClone*TM?

4.1. Holographic Laboratory Recordings

The first museum project, employing color holograms, was the '*Bringing the Artifacts Back to the People*' project.²³ For the first time holograms were used to provide 3D color images which were so realistic that they can stand in for the real thing in places where museum facilities are non-existent. The project involved collaboration with a number of major UK museums. The holograms of the artifacts were recorded at the Centre for Modern Optics located in OptIC Technicum in Wales, UK. The color holograms were on display in a travelling exhibition that was touring around north Wales and the borders. One of the recorded artifacts was the 14,000-year-old decorated horse jaw bone kept at British Museum in London.²⁴

4.2. Holographic Museum Recordings

HiH has recorded artifacts in the Athens Byzantine and Christian Museum as well as the Thessaloniki Museum of Byzantine Culture, using their mobile equipment.²⁵ The most ambitious HiH project was the recording of the Fabergé Eggs in 2015 at the Fabergé Museum in St. Petersburg, Russia.²⁶ The recording of thirteen Fabergé Eggs was performed by Andreas Sarakinos, Chief Holographer and Scientific Director of HiH. He spent long hours every day recording a total of about sixty-five *OptoClones*TM, which included several recordings of each Egg. Depicted in Fig. 7 is the recording setup of the 1911 *Bay Tree Easter Egg*. This beautiful Egg with leaves of the tree crown shaped like an egg is made of Sayan nephrite. The bright leaves are covered with amethysts, citrines, pink diamonds as well as white small enamel flowers. A bird with iridescent feathers is hidden inside the tree and when pressing a lever it appears and starts singing. Museum curator Alexey Pomigalov and Andreas Sarakinos are working on the setup in the tent. In Fig. 8 is a photo of the recorded *OptoClone*TM in the display case window and in Fig. 9, a viewer is admiring it in the display case as exhibited in the Fabergé Museum.



Figure 7. The artifact positioned in the recording box inside the tent by Pomigalov and Sarakinos

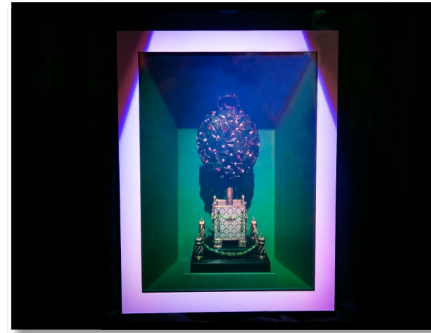


Figure 8. The 1911 Bay Tree Egg *OptoClone*™

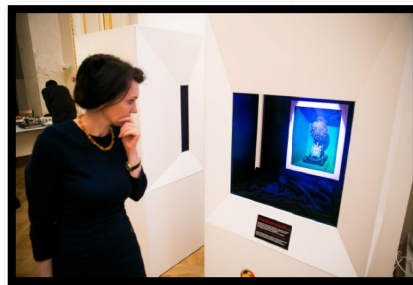


Figure 9. The *OptoClone*™ in the display case

7. CONCLUSION

The virtual color image behind an *OptoClone*™ represents the most realistic-looking 3D image of an object that can be recorded today. The extensive field of view adds to the illusion of beholding a real object rather than portraying a mere image. Good color rendering can be achieved through choosing the optimum recording laser wavelengths within the visible spectrum. The application of *OptoClones*™ in museums and the tourist industry alike could exploit this new 3D imaging technique. The mobile recording equipment is a necessity for recording artifacts like the Fabergé Eggs. Recorded museum *OptoClones*™ allows the image of an object to leave a museum, increasing the number of people who can experience the history of the object and its place within our culture. For example, since all of the still existing Easter Eggs are not in the Fabergé Museum but located in other museums and in private collections, it should be possible to exhibit all of the Easter Eggs in one place as *OptoClones*™. In addition it would be easy to send such an exhibition around the world without any worry about the artifacts themselves, being lost, damaged or stolen. It could be mentioned that another important application would be the recording of oil paintings.²⁷ Even if an oil painting is a 2D picture the ultra-realistic image will provide details about the micro structure of the painting such as brush strokes, signature, etc. Often in museums today, an oil painting is protected with a glass plate to prevent any potential damage to it. An *OptoClone*™ on glass of a painting looks identical to the painting itself, provided that more or less perfect color rendering is obtained, requiring four or five recording laser wavelengths.

ACKNOWLEDGEMENTS

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