

## Scratch holograms drawn by computer using a laser engraver system

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Recibido el 15/05/2009. Aprobado en versión final el 10/06/2010.

**Abstract.** A computing generalization of the non-conventional holographic technique, well-known as Scratch Holography or Hand Drawn Holography, is developed. It is presented an alternative technique that allows to code three-dimensional virtual objects (3D) as two-dimensional (2D) multiple circular-scratch drawings, using a software program for 2D encoded representation of 3D-models. Using this software like an assistant, several scratch holograms of variable complexity were hand drawn, generated by software templates. A CO<sub>2</sub> laser engraver system, driven by computer, was used for drawing more complex holograms directly onto suitable surface. Different types of plastic material are employed. Reconstructed images from all these holograms are shown.

**Resumen:** Se desarrolla una generalización computarizada de la técnica holográfica no convencional, conocida como Scratch Holografía u Holografía Dibujada a Mano. Se presenta una técnica alternativa que permite codificar objetos virtuales tridimensionales (3D) en dibujos bidimensionales (2D) de rayados circulares múltiples, usando un programa de software para codificación 2D de modelos 3D. Usando este software como un asistente, varios hologramas Scratch de complejidad variable se dibujaron a mano, generados por las plantillas del software. Un sistema de grabado a láser de CO<sub>2</sub>, gobernado por un ordenador, se usó para dibujar hologramas más complicados directamente sobre la superficie del material conveniente. Se emplearon diferentes tipos de material plástico. Se muestran imágenes reconstruidas de todos estos hologramas.

**Keywords:** Scratch holograms 42.40.Kw, computer generated holograms 42.40.Jv, laser engraver systems 42.62.-b

### 1 Introduction

The non-conventional holography, known as Hand Drawn Holography, or Scratch Holography was reported in the Web by Beaty [W. J. Beaty, "Hand-drawn holograms", <http://www.amasci.com/amateur/holo1.html>] in 1995, when most optics community was not be familiar with it. In his paper he refers some previous works that mention the synthesis of such 3D images<sup>1, 2, 3, 4, 5</sup>, because the phenomenon has been repeatedly discovered, receiving different names. The first version of this technique was patented by the artist and inventor Weil<sup>1</sup> in 1934.

Beaty's paper has been actualized in<sup>6</sup>. Theoretical considerations can be found in<sup>2,6,7</sup>.

Unlike the conventional holography, for making this type of hologram by hand, neither a darkroom with isolation table and expensive laser, nor highly photosensitive film plates are necessary. Scratch holograms can be directly drawn upon a suitable material, by using an appropriate tool. For drawing this type of hologram by hand, only a compass with two points and an adjusting screw to precisely set the spacing between the points is needed. Alternatively, one can also uses transparent half-circular masks and a steel point for drawing fine scratch lines onto the plastic plate.

Some ingenious instruments for drawing scratch holograms were also reported in <http://www.instructables.com/id/Make-a-Tool-to-Draw-Scratch-Holograms/>

This technique is able to encode a 3D image, by using a multiple circular-scratch representation. The image can be observed using white light and an appropriate illumination. Complicated 3D designs can be encoding by varying the radius of circular-scratch, for obtaining deep effects.

Due to its simplicity, a logical generalization of this type of hologram is to generate it by means of a computer. Using a computer for writing the code, it will be possible to represent much more complicated 3D-designs, generated by the appropriate software.

Beaty comments in his Web paper saying that “the scratch-hologram technique might be very useful in reducing the amount of data required for computer-generated holography”.

Usually, all techniques used for making computer generated holograms produce a mathematical description of a virtual transparency, which constitutes the hologram. In all cases, a diffraction pattern must be calculated and, because no method can be easily achieved for producing this hologram directly because of the high resolution required, the calculated diffraction pattern has to be first plotted on an expanded scale and later photographically reduced. Unlike this, a scratch-engraved hologram is the generalization of hand made holograms, but generated by computer from a 3D virtual object and directly laser “scratched” onto the appropriate material with an engraver-laser system.

For making this computer generated scratch hologram, neither diffractive optics, nor mask pattern or photo-reduction of a transparency onto a high resolution film plate are needed.

As in the traditional holography, the two-dimensional representation on the used material it can be considered like a type of 2D-code which allows, having the appropriate illumination, to obtain the 3D images.

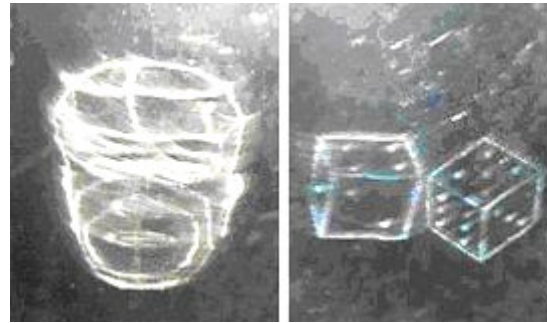
Any available tridimensional virtual object, also named 3D model, can in principle to be represented in this 2D-code, but it is necessary to use some type of tool for drawing directly those “scratches” on the suitable material. The methods usually used in scratch holography are based on “mechanically generated” holograms. Unlike this, in our work we made scratch holograms, which are not mechanically generated.

An appropriate software for 2D representation from 3D-models was developed. Using the software, some scratch holograms were computer generated and drawn by a computer driven laser engraver on several plastic materials. Each laser trace, as the hand drawn scratches, must be polished inside like a mirror.

Using the same software like an assistant, several scratch holograms of variable complexity were hand drawn on acetate pieces.

In the case of engraved holograms, a commercial CO<sub>2</sub> engraver-laser system was used. The beam was focused

by a lens in a focal spot of few  $\mu\text{m}$  in diameter. The intensive beam can vaporize the surface on the material leaving an engraved image. The engraver laser systems are usually used for engraving 2D non-holographic drawings.



**Figure 1.** Reconstructed images of computer assisted holograms. **Left:** 3D Head. **Right:** a pair of 3D dices. The images were observed in reflection mode by halogen illumination.

**Figure 2.** Photograph of 3D cube holographic image obtained using sunlight illumination in reflection mode. Scratch hologram was engraved by the laser system on acrylic sheet.



**Figure 3.** Stereoscopic pair from the 3D image of a polyhedron obtained at two different angles. The scratch hologram was laser engraved on a transparent acrylic piece. The image were obtained using sunlight illumination in reflection mode.

## 2 A computer program for encoding scratch holograms

**3D Silhouette program.** It was written with the initial purpose of supplying an aid for the creation of hand drawn scratch holograms. Three dimensional virtual objects, represented as files in 3D format, are used as input data. These objects may be transformed by means of simplifying or searching the best point of view, before processing them.

Program creates a set of templates that may be used as a guide for making hologram by hand, using a divider with sharp tips. Otherwise, output may be redirected to the printing device for printing scratches, or to the laser engraver for drawing scratches directly onto appropriate

material surface. Program can read files in .3ds (3D-Studio) or .mcl (MarbleClay) formats. Here objects are represented as polygon mesh data. A polygon mesh or unstructured grid is a *collection of vertices, edges and faces* that defines the shape of a polyhedral object in 3D computer graphics and solid modeling. The *faces* usually consist of triangles, quadrilaterals or other simple convex polygons, since this simplifies rendering, but may also be composed of more general concave polygons, or polygons with holes.

There are several 3D Object Modelers-Editors based on polygon mesh data structure. 3D Studio, Rhinoceros 3D, Maya, Wings3D, are among most popular. Marble-Clay is a freeware polygon mesh editor that can be freely downloaded from Internet.

**Building scratches and simplifying objects.** 2D object rendering is performed basically on polygon edges. They form a set of paths displayed as finished hologram. Edges are broken in sets of even spaced points, each of them corresponding to one scratch. Regarding the chosen output form, every point is represented as a line carrying information about point position and radius, or as an arc shaped trace directed to printer or plotter.

Polygon mesh object models may be very complex. They usually contain tens of thousands of faces or more. This could impose some difficulties to the task of rendering these objects as scratch holograms.

Very complex pattern templates are hard to work manually. On the other side, extreme densely packed scratches could deteriorate working media, and destroy hologram. In order to avoid handling with this complexity, in most cases, models should be simplified. The program has an embedded simplifying procedure that uses a different approach to deal with model complexity taking advantage of Principal Features Searching Method. Principal features may be interpreted as a group of model details, which lead to differentiate it from others. As the program only needs polygon edges to perform object rendering, it tries to find most outstanding edges on the model. These edges are searched using a local extremum finding algorithm that looks for extremal vertexes on model surface.

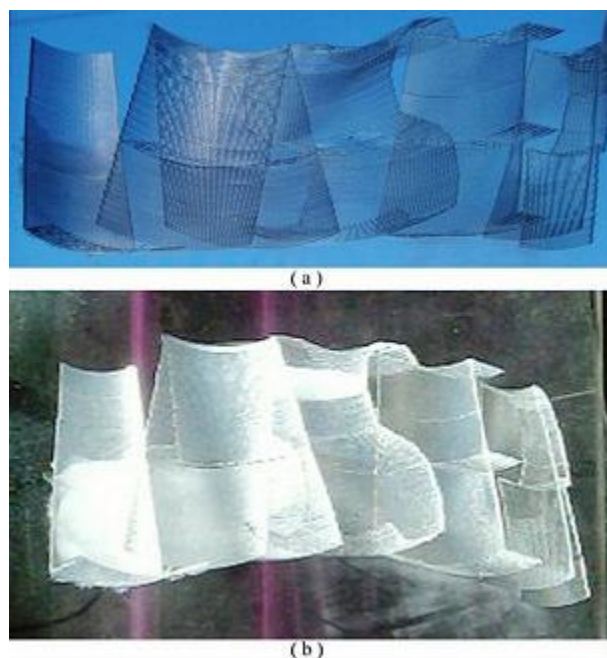
**Working with the program.** It presents a very simple interface for managing 3D objects. They may be rotated, moved and scaled. A special feature allows editing object by deleting or adding edges. These features allow accommodating object on the screen for easy handling. The program also allows saving edited object in .mcl format file. The available options contain the *Render Options*. Here may be modified some parameters, as minimum and maximum scratch radius, scratch spacing, scratch angle, accuracy level and others, that determine final performance.

The *Get Silhouette* option implements the simplifying procedure, which performs Principal Features Searching algorithm. Other options allow selecting the kind of features to be sought, the size of the searched neighborhood

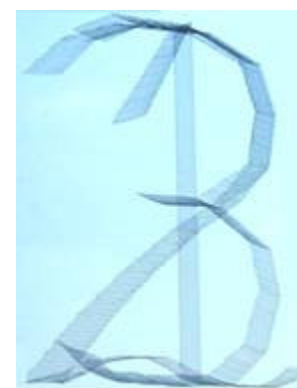
and searching rule strength.

Several outputs formats are available. *The Pattern template* output may act as a guide for drawing hologram by hand. It comprises a set of lines which length is the radius of corresponding scratch, where bottom end indicates coordinates for the compass tip. The *Scratch* output provides a set of raw scratches.

Resulting files may be obtained in .bmp raster format or .svg vector format. The last one may be used to draw scratches with a laser tracer directly onto working media.



**Figure 4.** (a) Image of scratches of word “Laser”, engraved on a piece of thermo-resistant acetate (b) photograph of the corresponding 3D reconstructed image, obtained from sunlight illumination in transmission mode.



**Figure 5.** Photograph of the coded objects-numbers 1-2-3, laser engraved on a transparent polycarbonate sheet.

### 3 Drawing scratches using generated templates

Using the *Silhouette* program like assistant, it is possible to draw by hand some 3D models of greater complexity than those drawn by hand without their help. Using sets of templates generated by the program, from provided

3D object models some scratch holograms of variable complexity were drawn by hand on acetate sheets. As example, in figure 1, (a) and (b), we show respectively the images of a 3D face, and of a pair of dice.

## 4 Drawing scratches using a CO<sub>2</sub> laser engraving system

**Computer generated scratch holograms.** By using the 3D Silhouette software, some scratch holograms were drawn by a computer driven laser engraver which was adequately arranged for performing this job. The holograms were engraved on different type of materials as acrylic and polycarbonate sheets and thermo-resistant acetate pieces.

All these scratch holograms were computer generated from 3D-models. Photographs of reconstructed images from some of these scratch holograms are shown in figures 2, 3 and 4.

The results were obtained using an engraver-laser system, from PINNACLE™ Lasers Engravers- that uses a CO<sub>2</sub> laser, with maximum power of 25 watt.

## 5 Multiplex-scratch hologram. Multiple image storage

Scratch holograms can be used as a multiple image storage medium, by encoding each distinct object with a different type of scratch. We engraved an image storage scratch hologram by varying the inclination angle of scratch corresponding to each object. By this way, if the reconstructing beam is fixed, the different objects can be observed separately by changing the observation angle. In figure 5 the coded objects -the numbers 1-2-3-, are shown on a transparent polycarbonate piece. Figure 6 shows the separately observed corresponding images. The observation variation angle in this case is small.

## 6 Conclusions

It has been shown a technique for generating by computer scratch holograms from 3D-models, by means of an appropriate software, with considerably widened scratch holograms possibilities. With the help of this software, the hologram can be drawn by hand, generated by software templates, or engraved with a laser on the suitable material. It has shown to be a significant improvement in working with 3D models of increased complexity. Drawing time was dramatically reduced, allowing to perform higher density drawings.

Engraver scratch holograms represent an alternative potential technology that allows a competitive use of the

three-dimensional images obtained by this technique in Art, Graphic Design, Visual Media for Education, Sciences, and others applications.

This technique may also allow making very interesting gigantic engraved holograms that could be recorded in separated parts and then assembled as the pieces of a puzzle. These images could be observed indoor, with appropriate illumination, or outside under sun illumination.

Further developing of this work will be aimed to find a way of increasing the hologram complexity without damage of recording medium. Suitable materials, optimal laser parameters and scratch shape are subject of researching.



**Figure 6.** Separately reconstructed images of numbers 1-2-3, obtained from sunlight illumination in reflection mode under small angle variations. Behind the support is observed.

## Acknowledgment

We gratefully acknowledge the invaluable collaboration and support of Dr. Luis Ponce, from Instituto de Ciencia y Tecnología de los Materiales (IMRE), Universidad de La Habana, La Habana, Cuba, for the use of his Laser-laboratory and materials. Specially, we thank Adalio Borges for his help and collaboration in the work with the laser engraver system.

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