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3D Lenticular Imaging for Art

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Abstract

3D lenticular printing technology can be used to display three-dimensional art objects on a flat medium. Such pictures can be viewed naturally without any aids or impediments, and be easily duplicated. This makes them a very attractive alternative to making physical sculptures in displaying three-dimensional art objects. In principle, any object, real or virtual, can be displayed in a 3D lenticular picture.

This paper outlines how artwork can be submitted for lenticular print and describes the main characteristics of 3D lenticular depth imaging.

Introduction

Practitioners of two-dimensional (2D) visual arts have many readily available and inexpensive options to present their art. This is not the case with practitioners of three-dimensional (3D) visual arts.

Traditionally, art objects with 3D presence are displayed as sculptures. To make a sculpture one needs a studio, tools, and materials. The sculpture itself may be heavy and bulky; it requires a big storage space, and cannot be hung on a wall. Nowadays, there is an option to create sculptures with a 3D printing machine. However, such sculptures are limited in size, and suffer from inadequate surface finish and coloring.

3D lenticular technology offers another alternative, which is particularly attractive for artistic applications. It uses a flat medium which can be easily stored, shipped, and hung on a wall. The artistic part of 3D lenticular picture making requires only a PC and suitable software. There are no gravitation constraints; it is possible to display unbalanced, and even floating in space objects. The color quality of the picture is the same as in conventional 2D print.

The main characteristic of a lenticular picture is its ability to display different images for different viewing angles. Such images were created before the advent of the lenticular technology. Back in 1692, a French painter G. A. Bois-Clair made a viewing-angle dependent picture using triangularly cut strips of wood [1], a technique which is still being used in art. At 1902 F. E. Ives has proposed a method to be known later as "Parallax Barrier" [2] and was utilized commercially. As high-quality and mass-produced lenticular sheets became available, it was replaced by lenticular print technology.

Probably the first application of lenticular lens sheet for stereoscopic imaging was proposed by W. Hess [3]. This idea was soon generalized and significantly improved by C. W. Kanolt [4], who proposed to record a sequence of pictures instead just two (as in a stereoscopic pair). The use of an image sequence to create a 3D picture allows comfortable viewing in a relatively large angle, thus enhancing significantly the viewing experience. This method became the cornerstone of modern lenticular 3D technology.

The goal of this paper is to help those artists who would like to try the 3D lenticular printing technology to display their art objects. The actual production of a lenticular picture requires expensive equipment and technical expertise that takes months to acquire. Instead of trying to produce such pictures themselves, artists may use the services of established lenticular printing studios for this task. The question is: how to submit 3D art to a lenticular printing studio?

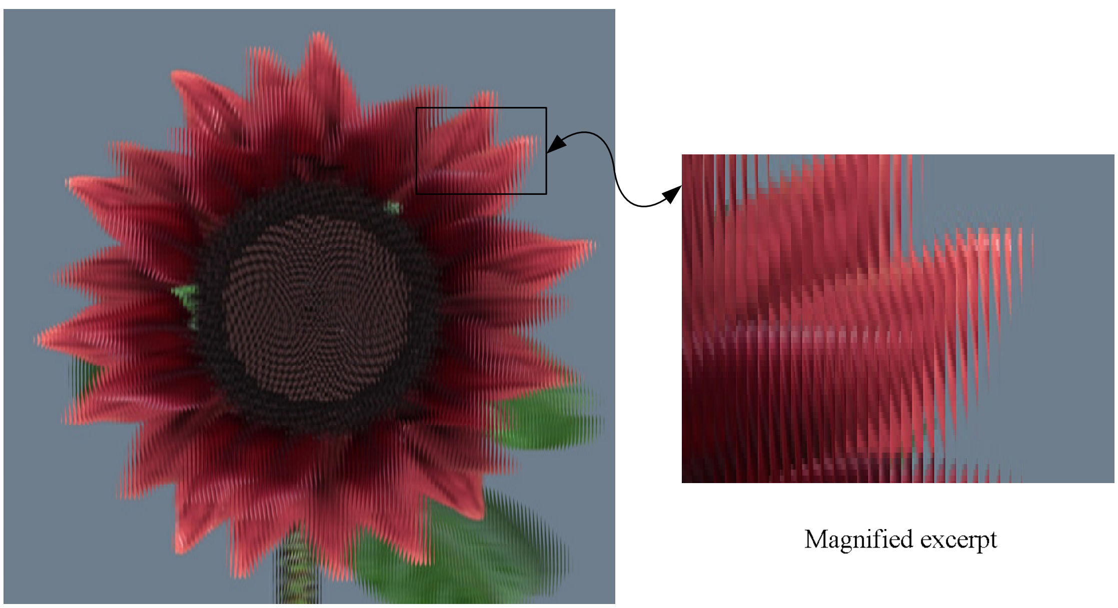
For lenticular print the object must be converted to a special sequence of images, which we call "lenticular sequence". This is accomplished by real or virtual photography for physical or virtual objects respectively. Either one requires equipment, software and expertise normally not found in lenticular printing studios. This unfortunate situation denies the access of 3D lenticular print to the art community.

Unlike the production of lenticular pictures, many artists can master the procedure for deriving the lenticular sequence from their art. Most lenticular printing studios will accept such sequences for printing. In this paper we give a brief outline on how lenticular sequence can be created and what are the main design parameters of the process.

The Principle of 3D Lenticular Imaging

The uniqueness of a 3D lenticular picture is its ability to present a different image depending on the viewing angle. These images are the members of the lenticular sequence. If they are the projections of a three-dimensional object corresponding to the respective viewing angles, the picture creates an illusion of displaying a realistic replica of the object including an authentic 3D sensation. Essentially, lenticular imaging is a simplified (one dimensional) implementation of integral imaging [5]. Typically, the number of images in the lenticular sequence is about 20.

In order to print the lenticular picture we need to encode the lenticular sequence into a single, printable image. This process is known as “interlacing”. After printing the encoded image is bonded to a lenticular lens sheet, which is a fine array of cylindrical lenses. This sheet is capable of decoding the encoded image and present the corresponding projection for each viewing angle. Each eye of the viewer sees the picture from a slightly different angle, and therefore sees a different image. If the two images are the correct projections of the object, a 3D sensation is invoked.



Magnified excerpt

Encoded (interlaced) image

Figure 1: *The encoded (interlaced) picture*

Creating the Lenticular Sequence

The lenticular sequence is created by shooting the object from a series of points which lie on a common trajectory, as shown in Figure 2. The subfigures labeled (a) and (b) show linear and circular trajectories correspondingly. Although technically there are some differences between the two methods, both are valid, and with the correct design and processing should lead to identical results.

One of the parameters which characterize the sequence is its span, which is the angle subtended by the sequence extreme shooting points relative to the object center. The span controls the depth of the displayed object, which is normally different from the depth of the real object. To reduce the displayed depth we reduce the span; to increase it we increase the span.

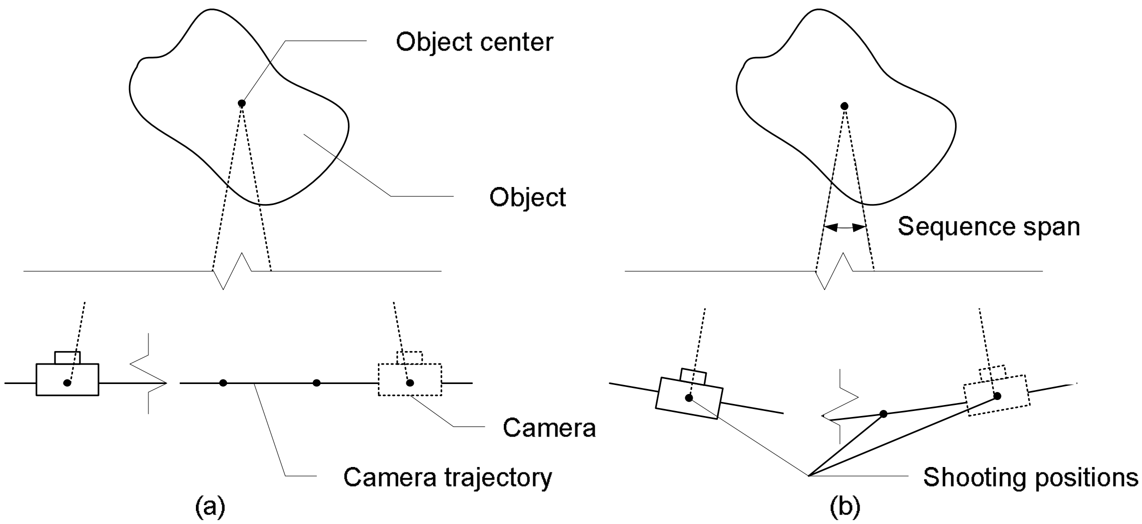


Figure 2: *Shooting the object from multiple locations to make the lenticular sequence. (a): linear trajectory, (b): circular trajectory*

In the case of the linear trajectory, the shooting points are distributed equidistantly over the span interval. In the case of the angular trajectory the shooting points are distributed with the same angular interval between them. (Rigorously speaking the even angular distribution is an approximation, but correcting it has unnoticeable effect on the final picture.) The number of pictures in the sequence and the span depend on the lenticular lens that will be used for the picture and the printer resolution. The printing studio should recommend the values of these parameters.

The Depth Display Restrictions in Lenticular Imaging

Figure 3 shows a side view of a 3D picture with a protruding object at distance h_1 from the picture plane. This picture is imaginary, because this object can be seen in reality only when viewing the picture from front.

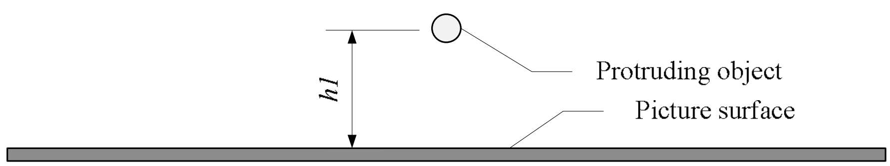


Figure 3: *An imaginary side view of a 3D picture showing a protruding imaged object*

It turns out that in order that in order to display the protruding object without any visual defects, h_1 must be smaller then a certain distance h, given by the following formula:

$$h = \frac{Nt}{n}$$

In this formula N denotes the number of images which can be resolved by the lens and the printer, t denotes the lens sheet thickness and n its index of refraction. Same formula holds for recessed objects, so the total depth which can be displayed is $2h$.

Figure 4 shows a schematic cross section of a lenticular lens sheet with the parameters n (the index of refraction), t (the thickness), and p (lenticular pitch). The parameter N requires some elaboration.

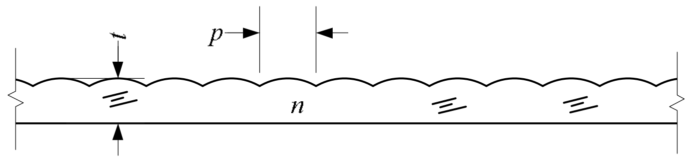


Figure 4: *Cross section of a lenticular lens sheet*

For small enough number of encoded images one can see each individual image from the sequence clearly when observing the picture with a single eye. When the number of encoded images is increased to a certain number, one starts to see in each image traces of the two adjacent images. Increasing further the number of encoded images will eventually make it impossible to see the individual images in the picture, and instead one will be able to see (with a single eye) only superpositions of two or more encoded images.

We define N as the maximal number of encoded images which still allows a distinct view of each image from its corresponding viewing angle. The limit on the display of depth in a 3D lenticular picture is directly proportional to N.

The number of resolvable images N depends on the lens and the printer resolutions. In most cases the lens resolution is better than that of the printer, so that the printer resolution is the bottleneck in displaying depth. The number of resolvable images N can be estimated, but the best method to determine it is by an experimental measurement.

Attempts to display objects with distances larger than h from the picture plane will give rise to one or both of the two following visual defects:

1. Blurring,
2. Discretization, or image break-up.

In a well designed 3D lenticular image the transition between adjacent views (as the viewing angle changes) is unnoticeable. Image discretization is manifested in discontinuous transitions between views, an effect which spoils the viewing experience.

One way to avoid discretization is to intentionally blur objects which are located further than h from the picture surface. This can be done by using image processing techniques, but also, to a certain extent, by using sequences with number of images exceeding N. The latter is a common technique for increasing the displayed depth by introduction of blurring.

For common lenticular lenses designed for medium to large 3D pictures, the displayable depth with inkjet printing lies in the range between 30 to 150mm. The span of the lenticular sequence should be chosen to comply with the depth imaging capabilities of the lens being used, in order to avoid visual defects.

Acknowledgements

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