Autostereoscopic Photos–Old and New

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Abstract

The history of three-dimensional display only slightly predates the history of photography itself, and the history of autostereoscopy, or "3D without glasses" only slightly post-dates than that of photography. Autostereoscopy is a field that has attracted some of the most creative minds in optics and photography, yet the field still struggles to find a practical solution to the many problems that arise. This paper will outline the history of autostereoscopic display research, with an emphasis on its photographic applications, leading up to the holographic displays of today.

Introduction

Long before photography was invented, writers of fiction described the marvelous image communication that was someday to be. Besides being moving and in full color, of course the images were to be three-dimensional! This last part of the promise of photography has yet to be kept, especially if no viewing aides (such as spectacles) are allowed.

There is some debate among stereographers over exactly what is meant by "autostereoscopic" photography – whether just two views can be presented, or a sequence of distinct views, or a smooth progression of varying perspective angle. But there is no debate over what the result should be: an easily-seen image of remarkable depth and realism. Here, the term will apply to all three modes of imagery, and to possibilities yet to be realized. Of course the difficulty of the challenge depends on how many images are to be incorporated, and the complexity of the system can be distributed between the viewer's aids and the technology of the display itself. In autostereoscopic displays, the complexity is embodied in the display rather than with the viewer.

This discussion will omit one large category of autostereoscopic display, which we refer to as "slice stacking" displays. In these, slices or sections of the imagery are presented, usually serially in time, either as a stack of sections, or sometimes as a radial array of slices. Although these displays are well-suited to some applications, they are not capable of presenting photographic-style images. That is to say, they cannot present solid-shaded opaque surfaces, which are typical of photographic scenes. Here, we will emphasize instead the "multiple perspective" systems, which present a variety of discrete side-to-side views (and perhaps up-to-down views) as the viewer moves about. Each of these views can represent solid-shaded surfaces that are opaque, and all the cues leading to photographic-style realism. Indeed, they can be photographs taken by an array of cameras, or by a single camera moving through a variety of positions.

Types of Displays

The goal of the multiple-perspective type of display is to "aim" the bundle of rays containing any one perspective view to a particular point in the area of the viewer, or perhaps to a vertical line in the case of horizontal-parallax-only displays. Thus there is a two-fold optical challenge: 1) to maintain the quality of the perspective view itself (without vignetting, distortion, or other corruption), and 2) to manage the creation of the viewing zone for each perspective view. In the early history of autostereoscopic displays, optics as large as the image were used to focus light toward one eye or the other (and to locations in between and beyond the eyes for multi-view systems). Later, the viewing surface was subdivided into many small "cells" (what we might now call "pixels") with separate small optical components for each. We will refer to the former as "macro-optical displays" and the latter as "micro-optical displays." The cost of macro-optical displays grows quickly as larger image sizes are contemplated, because the optical quality of the large positive lenses or concave mirrors must be maintained over larger diameters (the cost of an optical component typically grows as the third power of its diameter). Micro-optical displays can be cheaper to make, especially in large quantities, but impose technical limits on the precision of "aiming" of the viewing zones due to the diffraction limit imposed by their small width or diameter. A tradeoff between image resolution (cell size) and image depth (due to intermingling of perspectives) is thus inevitable. Both types of displays continue to play their appropriate roles in the history of autostereoscopic displays, depending on the various constraints on the engineering of the systems in which they are incorporated.

A Brief History of Three-Dimensional Displays

The first stereoscope was built to the design of Charles Wheatstone in 1832, but the first familiar design is that of David Brewster, from 1849. The response to the resulting images was immediate and highly positive, upon their public introduction in 1852 (perhaps reflecting a unconscious disappointment that photographs had been flat at the outset). The hood and slidebar type of stereoscope that survived well into the 20th century was designed in the mid-'60s by Oliver Wendell Holmes and Roger Bates. An outline of the subsequent progress is reflected in a collection of papers soon to be published, edited by this author[1].

The first autostereoscope was invented by Henry Swan in 1862, producing what was known (briefly) as the Swan Casket Portrait[2]. It relied upon the phenomenon of total internal reflection to selectively make either of two images visible to the right and left of an imaginary line focused at the viewer's distance. While generally considered an obscure (if pioneering) invention, it has been reprised in more recent years with lightweight plastic Fresnel optics as an optical toy[3].

The first autostereoscope that pointed the way toward future macro-optical displays was invented by James Clerk Maxwell, of electromagnetic equations fame, in 1865. It used a modified Brewster stereoscope to act as a pair of side-by-side projectors, converged to merge images on a large lens, which formed real images of the projection lenses at the viewers location[4]. Subsequent developments of twin-projectors into large field lenses and mirrors can be traced back to this simple but obscure development[5].

Parallax Panoramagrams

Probably the best-known autostereoscopic images of today are the 3D postcards and their ilk, commonly known as "lenticulars." The origins of these images, more properly known as parallax panoramagrams, can be found in the work on parallax stereograms by Frederick Ives[6]. The introduction of cylindrical plastic lenslets, or lenticules, by Hess made possible the inclusion of many more than two images, a direction explored by Clarence Kanolt[7,8]. In these images, each narrow lens directs light from an even narrower vertical strip behind it to a particular side-to-side viewing location. The resolution limitations of photomechanical image reproduction usually limit the number of distinct side-to-side views to less than a dozen, which limits the depth available without blurring to a centimeter or so. However, if camera-original imagery is used, or contact copies thereof, much better results can be obtained, as demonstrated by Maurice Bonnet up until the 1980s[9].

The holographic analog of a narrow cylindrical lens can be produced by interference between a wave focused by a larger cylindrical lens and a wave mimicking the intended illumination. The focused wavefront can have perspective information impressed upon it by an upstream photographic transparency or LCD screen, which results in different light fluxes being sent in the various viewing directions. An array of these imagewise-modulated holographic lenses can be combined to create an overall impression of a three-dimensional image of quite impressive depth, as described in the other papers in this session[10].

Integral Photographs

At about the same time that parallax stereograms were being developed, Gabriel Lippmann (best known for his invention of interference color photography) devised a system of photography with a grid of pinholes (replaced by an array of small spherical lenslets) spaced from a photographic layer[11]. It was Lippmann's hope that such a system could record and then reproduce a scene in three dimensions, offering a variation in perspective from up to down as well as side to side. Unfortunately, there were many technical difficulties in realizing Lippmann's vision, including a reversal of depth in the image. Many decades later, Roger de Montebello revisited the technique by introducing a second photo-optical stage to correct the depth reversal[12].

The optical effect of a small spherical lens can be created holographically by interfering a wave focused through a large spherical lens, and interfering it with a collimated reference beam. If the focused wave carries different intensities in different directions, corresponding to the variation of a pixel's brightness in various directions, then the combined waves from an array of holographic lenslets can produce an autostereoscopic image, just as Lippmann imagined. This too is further described in other papers in this session[13].

Conclusions

The history of autostereoscopic photography is rich with jewels of inventions and ideas, many of which have been lost in history. But as new optical technologies emerge, such as precision plastic optics and holography, they can take on new life if their underlying inspirations are understood and translated into contemporary terms. As the demand for high-quality autostereoscopic imaging continues to escalate, doubtless some of these updated and refined methods will find practical application, and perhaps even inspire further new inventions in the field.

References

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Biography

Stephen A. Benton is the Allen Professor of Media Arts and Sciences at MIT. He was educated at MIT and Harvard University. He was at Polaroid Corporation from 1961 to 1985, when he joined the startup team for the Media Laboratory at MIT. There, he and his students are developing three-dimensional visual interfaces to computer data. Recently, they invented the world’s first interactive holographic video system.