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Winchester School of Art

An Investigation into Three Dimensional Mutable 'Living' Textile Materials and Environments

by

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ABSTRACT

FACULTY OF LAW, ARTS AND SOCIAL SCIENCES
WINCHESTER SCHOOL OF ART

Doctor of Philosophy

AN INVESTIGATION INTO THREE DIMENSIONAL MUTABLE 'LIVING' TEXTILE MATERIALS AND ENVIRONMENTS

By Ki-Hoon Kim

My research aim concerns questioning how we can generate environments suggestive of nature fused with built environments through textiles. Through literature reviews and experiments with available the 3D imaging techniques of Holography, Lenticular and 3D Integral Imaging using Fresnel Lens Arrays, I have researched towards finding the most effective method for 3D imaging techniques for textile applications. Furthermore I have investigated the practicality of generating a textile material capable of achieving three dimensional mutable 'living' textile materials in combining the Lenticular technique with the 3D Integral Imaging Technique using Fresnel Lens arrays. The advantage of the combining technique is to create the possibility of seeing a number of different floating 3D illusory images, depending on the viewing angle.

Introduction

The research aims to discover how images of materials seen in science fiction films such as Minority Report (2002), Ultraviolet (2006), Bee Season (2005) can become a reality as textiles. Descriptions of films relevant to the research are included in the Images of Context chapter.

To identify my initial idea, the use of the term 'living' in the research title is not used to describe actual 3 dimensional living forms in a biological sense, rather it refers to 3 dimensional illusory effects applied to 2 dimensional textile substrates. Also, the term is used to indicate verisimilitude or lifelike appearances.

Currently examples of mutable materials exist either as fictional narratives or through three dimensional image techniques such as holography. Traditionally, holographic materials are made as thin films and are generally for graphical applications only. My aim is to explore the potential application of the illusions created by various 3D imaging techniques and develop textiles to create new environments where reality and fiction are fused.

The key question I would like to answer is how close textiles can be to the kinds of imaginative visual sensations demonstrated by the examples of the films above. Can we generate environments capable of fusing nature with built environments through textiles? Can this be proven theoretically and technically within the scope of contemporary textile technologies?

A Holographic textile has been developed by Dr. Munzer Makansi but the material has yet to be realised as a realistic material product. According to Textile News[1] (August 13, 2001), Dr. Munzer Makansi (Signal Mountain TN) has developed and patented a way to create such a material. The article states that the process is only a few steps away from being developed commercially but through my research I have found no evidence that this has been achieved. Dr. Munzer Makansi calls his invention "holographic fabric technology," featuring direct embossing of rainbow and hologram images on fabrics with heat and pressure. Using existing holographic film embossing equipment, the fabrics are produced with a thermal embossing process at elevated pressures. The article claims that the fabric is unique in that, upon exposure to light, the fabric projects coloured images that are bright and also shimmer, just as conventional hologram images do.

"This technology provides a third method for colouring fabrics, beyond dyeing and printing," Makansi explained, "without using dyes, pigments, adhesives, film or laminates. It's an environmentally friendly process. The colours and images that are

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[1] Bea, Q., Fabric technology moving ahead, Textile news, August 13, 2001.

produced through this technology are dynamic as they appear to move and are also three-dimensional."[2]

Makansi said he believes the potential market for his holographic fabric technology is large. Among potential applications are sportswear, fashion apparel and accessories, interior furnishings and fabrics for outdoor uses. These potential applications are fascinating and almost overwhelming. However the fact that such fabrics remain a few steps away from being developed commercially through existing manufacturing technologies has led me to focus on technologies which are readily available and to research their potential in creating alternative and achievable three dimensional mutable 'living' textile materials.

In this Ph.D. thesis I have focused on the working title *'An Investigation into three dimensional mutable 'living' textile materials and environments'*. Emphasis is on using the available technology to express my artistic vision rather than be dazzled by the power of amazing hardware and software. In this sense, the realities of technology are fundamental to the processes of experimentation, production, expression, and interpretation within my research. My objective is to produce intriguing textile patterns and images in which the objects and colours change as viewpoints change. To realise

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[2] Bea, Q., Fabric technology moving ahead, Textile news, August 13, 2001.

this objective I have investigated and tested the use of three dimensional imaging technologies such as Holography, Lenticular, and other new 3D imaging technologies.

2. Research Aims

1. Investigate and compare different methods to produce three-dimensional textiles using Holography, Lenticular and new technologies.

2. Conduct contextual research and gain an in-depth insight into the applications where the research outcomes will be expressed.

3. Investigate different graphic software applications, including Photoshop, Illustrator, Painter, and 3-D Max to determine specific graphics for which the method of digital printing is most suitable.

4. Have a greater and a more detailed understanding of the methodologies of holographic and lenticular materials in the context of textiles.

5. Investigate further into different lenticular materials and determine what are most suitable for specific fabrics.

6. Integrate novel artistic and technical approaches to the determination of textiles through integrating technological advances.

7. Make an original contribution to the development of future textiles and predict how my research can affect different environments.

3. Research Methods

The information on various three dimensional (3D) imaging technologies was collected through literature searches in original manuscripts, books, internet resources and also through attending workshops, meetings and interviews arranged with experts in the field. Information has been saved by audio and visual recordings. The research has focused on imaging techniques that have the potential to be applied theoretically and practically in textiles expression such as Holography, Lenticular and other new technologies.

Theoretical inquiry and practical experiments in the materials of Holography, Lenticular and new technologies have been conducted to extend knowledge and understanding of these technologies. The main objective of the practical experiment was to gain experience and understanding of 3D imaging technologies and investigate potential applications for expressing three dimensional moving images in textiles. Experimental work was carried out in collaboration with professional textile researchers, scientists, artists and designers conducting research in this field.

4. Research Context

The concepts and approaches I believe are important in my research are expressed in the following quotation by the innovative designer Issey Miyake.

'Once again our society is poised to make dramatic changes based upon developments in science and technology. Will fashion be able to afford to keep the same old methodology? I believe that technology can function only as long as we have the ability to imagine, a sense of curiosity and a love for our fellow men.'[3] (Issey Miyake).

This view that there must be imagination to successfully apply technology within cultures is central to my research. However it was through popular film rather than fashion or textiles that my interest in the research was first inspired.

Everyone remembers a popular Sci-Fi movie sequel in the late 80s, "Back to the Future 2" (References for films mentioned in this thesis are easily accessible through any popular internet search engine such as Google or Yahoo). Steven Spielberg with his unique creative imagination captured people's hearts internationally into the world of science fiction. I think that may have been the first film to inspire my interest in 3D imaging. There is a particular scene where the central character played by Michael J. Fox goes into the future with a time machine. He then stands in front of a

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[3] Suzanne, L., Warren D. P., Nick T. J., Sep 2005, Fashioning the Future: Tomorrow's Wardrobe, Thames & Hudson, p 59.

future cinema complex where there is a huge poster for Jaws 8. Suddenly a shark as a 3D image comes into life from the poster and appears to come out to attack him. At that time I thought this kind of 3D technology could truly happen in the future; transforming popular culture. I felt this new technology would be very effective in advertising, in particular as it certainly allows the viewer to experience 3D imagery in an ordinary surrounding space. Furthermore, I came to think it would be fascinating and worthwhile to see if there could be a textile material in which pattern and colour could change with different intensity of light and viewing angles. This would allow the viewer to incorporate such 3D imaging techniques into fashion, fabrics and other related products, including sportswear.

I think it is probably safe to state that many ideas that have developed through technologies to enhance culture generally came from wild imaginations first featured in fantasy or science fiction novels. Technologies such as video phoning shown in futuristic movies between late 80s and early 90s have now become widely available and with extensive developments in internet and mobile phone technologies we can now enjoy sharing information wherever and whenever we want. Difficult works in terms of load and accuracy for people have been taken over by popular use of robots already and robots in the form of human beings for the use of personal assistance may not be so far off in the future as shown in a film such as "I Robot". We are still being surprised by how far imagination can affect future research. More recently the "Transparent Cloak" featured in the Harry Potter film is apparently going under research for development. There has also even been an auctioning on Ebay for a personal flying vehicle which does not require a pilot's license to operate and can be operated similarly to normal automatic vehicles. Advances in technology, triggered by imagination, are truly amazing.

Textiles have also gone through many changes and can be expected to continue to evolve. According to Raymond Loewy, it seems that the important improvements and innovations in clothes for the "World of Tomorrow" will be in the fabrics themselves. It is reasonable to assume that new types of fabrics will be developed which will greatly affect the design of clothes. Such fabrics, might, for instance, be constituted of microscopic cellular construction, made of a contracting and expanding fibre. When affected by atmospheric variations, the cells would automatically open or close and regulate air penetration. In other words, fabrics would be air-conditioned. Stitching will probably be replaced by some cementing or moulding process.'[4]

If a fabric can be wiped and rewritten with a fresh image, like a computer screen, what would be the need for textile and fashion designers? And, more importantly,

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[4] Suzanne, L., Warren D. P., Nick T. J., Sep 2005, Fashioning the Future: Tomorrow's Wardrobe, Thames & Hudson, p 147.

what would be the need for more than one garment in that shape? Textile designers may soon be required to reinvent themselves and seasonal print collections could become obsolete. Also, consumers might access a designer's or a brand's online portfolio to download new collections of surface design into their 'digital' garment as and when they choose.

Human lives today are controlled by electronic communications as there is an overemphasis on seeing and hearing, numbing the other senses by light and sound from cinemas, videos and computer screens. The future in textile will lie on developing sensory faculties for touch, taste and smell, experience new emotions and experiment with new forms of expression.'[5] Innovative developments and highly advanced technology are now being combined in the laboratory to create such exciting new textiles whose aesthetic quality is as important as their performance. Advanced technology will be the basis for the future of materials, and in years to come we may be able to work with mutable, flexible, almost 'living' materials. Imagine a girl wearing a T-shirt featuring a fairy and the fairy's wings are actually moving on the T-shirt as she walks. Or imagine a woman wearing a textile with photographic images of that change as the light hits the material at different angles. That day may not be as far off in the

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[5] Pompas, R. Textile design training at the Nouva Accadmia Di Belle Arti in Milan. Textile Forum 1/2000.)

future as you might think. Technology will take us from our old familiar world to a future which offers a very different environment.

Inspiration from the power of Rosamond Wolff Purcell's compelling photographs lies in their ability to evoke memory and create illusion. Complex, multi-faceted, magical, her work blends portraits of men and women with images of plants and animals to form a world on the edge of reality. Likewise, I'd like to use human or nature movement to bring textiles to life, which, on a second level, is optically patterned with allusive, magical works.

When inventions and technological development are working together to be in harmony they can come closer to having a wider affect on our lives. For example, cloth has fluid, flexible and sensual like 3D qualities. Fabrics are not seen through a digital screen but are actually tangible and can be held, and worn, next to the skin. They have the ability to make us rediscover the childhood delight of tactile pleasures and physical sensations. It is quite sad to see today's computer kids who will never know the delights of playing with mud, having dirty, active, energetic hands and directly experiencing and learning about matter purely through touch. Computers and mobiles are condensed with information, and although it may be visually stimulating, the images are simply digitised without any sensually stimulating sensation such as touch and smell. Through patterning textiles with shapes inspired by plant forms, organic and living touch is immediately injected and found appealing. Careful selection of responsive and sensitive visual imagery is therefore vital in future development in textiles.

'A fragrant green bouquet makes us feel perky, happy, even rejuvenated. Fresh greens are synonymous with well being. The flower is a health filled creature that emanates a soothing presence on man.'[6] The need for sensitivity with nature is slowly being realised. Textiles designed to feed our senses through sight and smell have a major role to play in helping counteract the expanding and for some the numbing technological world.

Through this research, I would like to advance textiles further, not by only creating a new form of textile using the technologies I have identified but also emulating the transient, ethereal beauty of nature. The basic idea is to develop a textile that fuses nature and technology within a whole and an inseparable environment. Thus I am investigating textiles, in which the objects and colours change as the viewpoint changes like 3D moving images.

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[6] Baude, D. M., Bloom: A view on flowers. Issue 2.

5. Contextual Images

'Technology essentially broadens my language as a designer. I'm interested in languages that allow you to go beyond consideration of the body of 'normal' clothing to create new ways of looking. The importance of technology in my work is that it presents a fresh means of expression.'[7] (Hussein Chalayan)

In this section I plan to go through a variety of visual expressions, from different mediums (films, fashion and photography), that have inspired this investigation.

5.1 Inspirational Films

Fig.1 Tom Cruise monitoring future crime scenes in pre-crime department.
Minority Report (2002)

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[7] Suzanne, L., Warren D. P., Nick T. J., Sep 2005, Fashioning the Future: Tomorrow's Wardrobe, Thames & Hudson, p 95.

Minority Report (2002), directed by Steven Spielberg is the first inspirational film I identified as relevant to the research. To summarise the film, it is set in the future 2054, Tom Cruise works for a crime prevention programme, called a pre-crime department, as a policeman arresting people who have a 100% probability of committing crime. This film shows many interesting scenes of imaginary future impressions of our built and technological environment.

In this film the special 3D effects from different forms of technologies captured my attention. For example, a transparent monitor was used in the "pre-crime department" showing images and texts floating in mid-air (Fig.1). Similarly, portable flash memory is also transparent and reveals its content on the surface. Other interesting technologies include cereal packaging with cartoon characters that create an animation and sound whenever the package is being used, posters in the entrance of an underground would have 3D images that would actually come into life and interact with the people passing by. The newspapers read in the underground are not just limited to text and photos but also show video clips, which seems to be dynamic. In this Science Fiction film the future society uses various 3D visual techniques to transfer information and to develop products. The close relationship between 3D technology and the society can be clearly seen.

Fig. 2 *Bee Season (2005)*

The second inspirational film is Bee Season (2005), directed by Scott Mcgehee. To summarise the film, the main character Eliza Naumann spells words which are relatively difficult and long but with effortlessness and understanding that surprises everyone around her, including her teachers, her fellow students and her family. Bee Season is the kaleidoscopic portrait of a modern American family whose picture-perfect surface conceals an underlying world of secret turmoil.

My special interest in this film is particularly focused on the scene where Eliza Naumann (Flora Cross) trains for the ultimate test of her spelling powers, in the pressure-packed National Spelling Bee in Washington D.C. When she concentrates to correctly answer a question, such as spelling the name of a flower, the clothes she wears shows a flower pattern which starts to grow as if the fabric becomes alive. (Fig. 2, video clips are also available online; follow the web link in the Appendices)

Fig. 3 *Ultraviolet (2006)*

The third inspirational film is Ultraviolet (2006), directed by Kurt Wimmer. To summarise the film, a subculture of humans have emerged who have been modified genetically by a vampire-like disease, giving them enhanced speed, incredible stamina and acute intelligence, and as they are set apart from 'normal' and 'healthy' humans, and the world is pushed to the brink of worldwide civil war aimed at the destruction of the "diseased" population. In the middle of this crossfire is an infected woman

"Ultraviolet", who finds herself, protecting a young boy who has been marked for death by the human government, as he is believed to be a threat to survival of human society.

What drew my attention in this film was the special clothing of the central character. There is an endless changing of colour and pattern of clothing which reflects the character's mental state and her surrounding environment. It resembles a chameleon camouflaging itself in response to external visual stimuli. Most people are aware of temperature sensitive fabrics which change their colour as the temperature changes. However the clothing in this film shows a more creative variety of changes that could be possible smart fabrics of the future. As mentioned previously there is no doubt that technologies introduced in futuristic films are now becoming available in reality and such films are inspiring scientists to further develop technologies.

The final inspirational film is John Mc Tiernan's 1987 "Predator". In the movie an alien warrior visits earth to kill a team of highly skilled military special force for recreational reasons. By the time the movie ends, the alien predator has killed off two complete and highly-experienced U.S. Special Operations teams, except for one survivor (played by Arnold Schwarzenegger), with extreme prejudice.

Fig. 4 Camouflage technology, from the film *Predator (1987)*

While the alien is bigger, stronger, faster, and much more mobile in the dense jungle environment than its human prey, it also has another major advantage; superior technology. One weapon in particular stands out because of its power of invisibility. The figure of the Predator, an alien creature in the jungle, demonstrates the tactical advantage of being invisible to his enemies, as the Predator is concealed by reflecting its surrounding environment. Not surprisingly, the concept of invisible clothing has huge appeal to the military, which is the principal driver of chameleon camouflage research and development. Until now, electronic fashion existed only in science fiction, but as the enabling technologies begin to emerge from laboratories so these fictions can become reality.

5.2 Inspirational Fashion

Fig. 5 Victor & Rolf's Autumn/winter 2002 ready-to-wear

Optical camouflage in addition to being decorative or capable of broadcasting information, a dynamic fabric might reflect its surroundings. If a garment mirrored its environment it would render its wearer invisible. Victor & Rolf's Autumn/winter 2002 ready-to-wear collection created the illusion of a fabric that research laboratories over the world are working on which has variously been described as chameleon camouflage, digital cloth or a textile display. As the models passed the audience, the fabric of the clothes streamed with film footage of traffic in the street and clouds racing across the sky. Brilliant blue detailing in the outfits was replaced by digitally projected images, a process known as blue-screening. Blue-screening is a special effect more commonly used in film and television, where anything painted in a brilliant blue pigment can be digitally isolated and replaced with another image.

Fig. 6 'transparent coat' by Professor Susumu Tachi

Professor Susumu Tachi of the University of Tokyo demonstrated the principle of optical camouflage with his 'transparent' coat. A masked object has a background image (captured with a video camera) projected onto it. This makes it appear transparent and the viewer is fooled into thinking they are seeing 'through' the wearer. The art of camouflage is to make the garment and its wearer mimic their immediate environment so that one becomes indistinguishable from the other. (The 'transparent coat' is further discussed in more detail in the case study.)

5.3 Inspirational Photography

Fig. 7 Photographs by Rosamond Wolff Purcell

Born in Boston in 1942, Rosamond Wolff Purcell is a contemporary photographer whose work has been collected by museums such as the Museum of Fine Arts, Boston, the Victoria and Albert Museum, London and the Delaware Art Museum. The power of Rosamond Wolff Purcell's compelling photographs is in their evocation of memory and illusion. Through complex, multi-faceted and magical qualities, her work integrates portraits of men and women with images of plants and animals to form an illusory world.

Many of the images in her photographs belong to states of mind rather than to realities. The title of the book on her photography 'Half-Life' refers, in many cases, to hybrid or interrupted identity. From a photographic point of view, 'Half-Life' can refer to anything not fully recorded but blurred or layered. The term implies a glancing-off of subject matter rather than an embracing of it, something seen out of the corner of the eye rather than trapped in all its detail by the film or by the mind. For Wolff-Purcell "every object has a potential 'whole life' which, of necessity, must be diminished in order to remerge as an allusion to ideas rather than as merely a glorified version of itself."[8]

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[8] Rosamomd, W. P., 1980, Half-life, Godine.

6. Theoretical Basis & Technical Experiments

An understanding of the technologies acquired from literature searches and related experiments will be described in this chapter. Furthermore, the feasibility of such technologies will be discussed in relation to the research aims.

Introduction

Coming from a background in design, there have been many difficulties in pursuing and continuing my research as it has involved understanding complex scientific technologies of optics and physics. However such difficulty should be expected when developing a new type of textile involving advanced techniques from other disciplines. Since understanding specific technologies is essential for developing a new form of textile, the history, methods, current applications and future potential of each technology has been described in this chapter. The chapter also considers briefly how certain artists understand and use such technologies.

At the end of each technology section a summary and analysis including the advantages and disadvantages are discussed. Also abbreviations and technical terms are explained in the Appendices. The technical elements in this chapter are key to understanding the principles of each technology. The focus of this chapter will be on

Holography, Lenticular and 3D Integral Imaging using Fresnel Lens Arrays. There are other 3D imaging technologies such as Anaglyph and Transparent Coat. However as these latter techniques cannot be seen by the naked eye but rely on supporting equipment, these technologies will be discussed in Chapter 7 case study.

6. 1 Holography

People are often uncertain about what holography really means and often confuse the technique with cinematic 3D projections, which are not a form of holography. Hologram makers are often asked to produce difficult illusions such as an image floating in the middle of a room or cinema, people walking around a room or herds of life-size animals running toward the viewer. However this is simply not possible with the current technology. Those who have seen 'Star Wars' and other science fiction films where the term hologram is used, often confuse science fiction with reality. Unfortunately, no one has found a way of projecting a fully three-dimensional image into space, remotely from the projection device.

The word hologram is derived from the Greek meaning "the whole image."[9] A hologram creates a real three dimensional image by reconstructing the light waves that

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[9] Smith, Howard M. (Howard Michael) Principles of holography, New York : Wiley, 1975

were reflected from the original scene or object.[10] Holograms are mostly made using lasers as the light source, and in general the image is recorded on photographic emulsions.

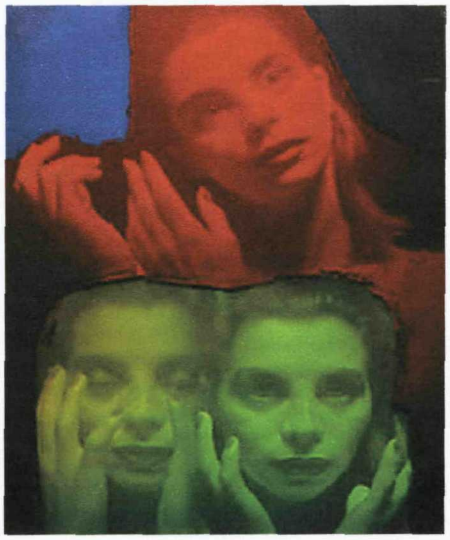

Fig. 8 Margaret Benyon, Split Benedict 1989, reduced reflection hologram collage.

Holography, which was developed in the 1960s, is very much a 21st Century visual medium.[11] The three dimensional holographic images show the remarkable possibilities that can be achieved through this manipulation of light. Only with holographic techniques can the artist display accurate, projected three-dimensional light imagery floating in space in front of the hologram with the same perspective, parallax, form and content as the original scene.

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[10] Kock, Winston E. Lasers & holography : an introduction to coherent optics New York : Dover Publications, 1981

[11] Vienot J.C., Smigielske P, H. Royer. Pref. de D. Gabor. Holographie optique: developpements, applications Paris, Dunod, 1971

The attraction of holography is that it has many facets, both metaphorically and literally. With a hologram it is possible to turn space inside out, cut it up, record the absence of objects, make the invisible visible, and make the solid transparent in paradoxical ways not possible in other media.

6. 1. 1. Brief Timeline of Hologram Development[12][13]

1947: Denis Gabor invents theory of holography

1960: Invention of laser helps hologram development

1962: Leith and Upatnieks make first laser hologram of toy train and bird

1977: Royal Academy stages Light Fantastic show

2003: Stephen Benton, inventor of credit card holograms, dies

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[12] Joanthan, D., 2004, Holograms: High art or just a gimmick?, BBC News, 23 Jun. news.bbc.co.uk/1/hi/magazine/3832361.stm

[13] Holophile, Inc. The History and Development of Holography retrieved from the World Wide Web: http://www.holophile.com/history.htm

6. 1. 2. Making a Simple Hologram

In normal light, such as that from a light bulb or the sun, the individual 'particles' or waves of light (called photons) move randomly through the air. A coherent light is a light in which the photons are moving together in an ordered way. Imagine that in sunlight the photons move like a crowd of people in a shopping centre, whereas in coherent light the photons move like a marching army. To make a hologram a source of coherent light is needed, in general. The best source is a laser. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.[14]

"A hologram is the recording of two sets of waves."[15] The first wave, called the reference beam, comes directly from the laser. The second wave hits an object, bounces off and interferes with the first wave (Fig.9).[16][17] The hologram records this very complicated pattern on a high quality photographic plate.

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[14] Kock, Winston E. Lasers & holography : an introduction to coherent optics New York : Dover Publications, 1981

[15] Leseberg, Bryngdahl Methods of Digital Holography, APPLIED OPTICS/ Vol. 23, No. 14, 15 July 1984

[16] Schnars U. and Juptner W. Digital Holography: Digital Hologram Recording, Numerical Reconstruction, and Related Techniques (Hardcover) Springer-Verlag Berlin and Heidelberg GmbH & Co. K (Oct 2004)

[17] Hariharan, P Optical holography : principles, techniques, and applications Cambridge ; New York : Cambridge University Press, 1984

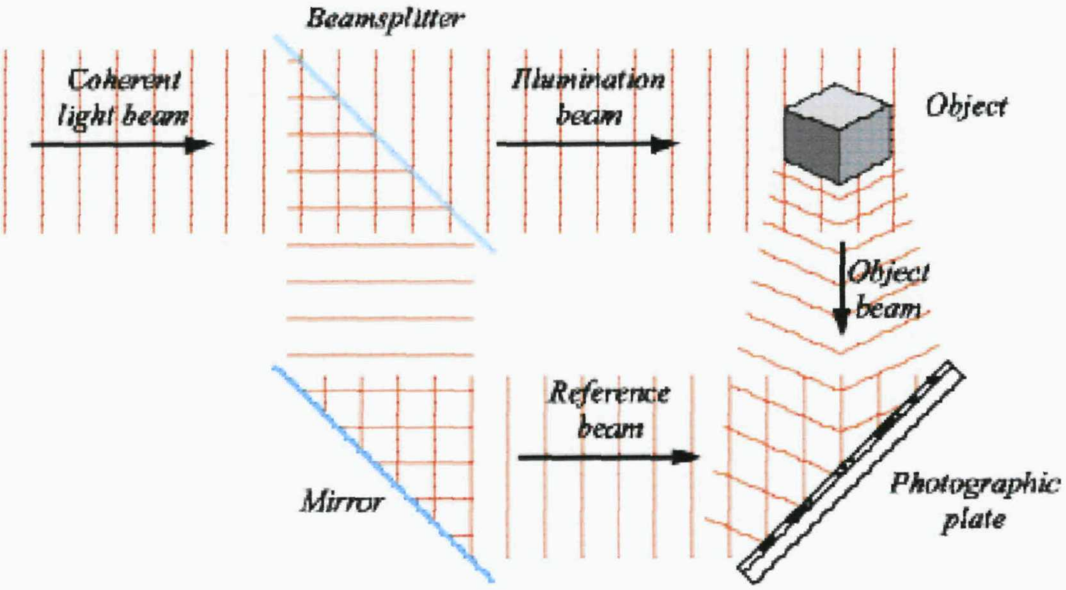

Fig. 9 Holographic recording process[18]

The first thing to do is split the laser beam into two parts. Both beams must come from the same laser to make sure all the photons are in step with each other. To split the laser beam in two, a device called a beam splitter is used. A beam splitter can be as simple as a piece of ordinary window glass or a precision coated optical device.[19] Like most things in life, the more you pay, the better the result. The purpose of the beam splitter is to allow some light to go straight through and for some light to reflect off its surface. In this way, the single beam becomes two beams.

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[18] Frère, Leseberg, Bryngdahl, Computer-generated holograms of three-dimensional objects composed of line segments, Department of Physics, University of Essen Journal of the Optical Society of America A, Vol. 3, No. 5, May 1986

[19] Schnars U. and Juptner W. Digital Holography: Digital Hologram Recording, Numerical Reconstruction, and Related Techniques (Hardcover) Springer-Verlag Berlin and Heidelberg GmbH & Co. K (Oct 2004)

The next problem is that the laser beam is very small, only 3 or 4 mm in diameter. If we want to make a hologram of something, even as small as a matchbox, the beams must be spread out to cover the object. This is done with a set of lenses. Professional hologram makers use the lenses which are used in a microscope, often called microscope objectives.[20]

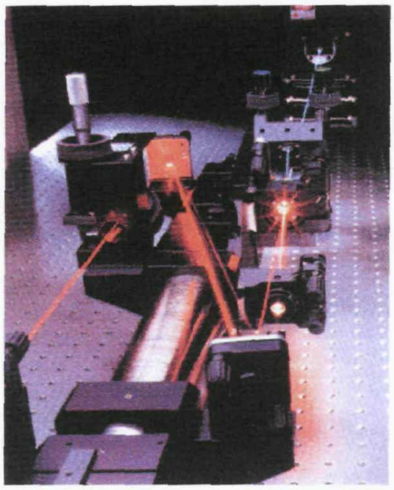

Fig. 10 Laser equipment on special, anti-vibration table

We now have a laser, a beam splitter and two beams that are spread out. Using some mirrors, the first beam (reference beam) is shone onto the holographic plate. The second beam is directed at an object. The recording plate is placed where these two beams meet. The whole set-up is called a holographic camera: If the reference beam and the beam bouncing off the object both hit the holographic plate from the same side, a transmission hologram is made. If the reference beam hits the plate from one side, while

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[20] J. Sheng, E. Malkiel and J. Katz. Digital holographic microscope for measuring three-dimensional particle distributions and motions Appl. Opt. **45**, 3893-3901 (2006)

the beam from the object hits the plate from the other side, the result is a reflection hologram.[21] There are many kinds of holograms, but all holograms fall into two basic categories, Transmission Holograms and Reflection Holograms.

6. 1. 3. Different Types of Holograms

A. Transmission Holograms

Most holograms you will see in every day life are Transmission Holograms. "The hologram is transparent to allow light to pass through from behind and reconstruct the holographic image."[22] The holograms found on credit and bankcards are of this type. They are called Transmission Holograms because ideally they are lit from behind, like a photographic transparency with the light being transmitted through the transparency. Often it is not possible to light the hologram in this way so a mirror or aluminized foil backs them. This is why bankcard holograms have a silvery appearance. The light then bounces off the mirror backing and effectively lights the hologram from behind, as on a credit card.

"Transmission holograms are also known as Rainbow Holograms as the light

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[21] Wenyon, M. Understanding Holography New York: Arco Publishing Company, Inc. (1978)

[22] Hariharan, P Optical holography : principles, techniques, and applications Cambridge ; New York : Cambridge University Press, 1984

being used to illuminate them is split into a spectrum, the hologram representing the 'correct' color(s) from one angle, while at other angles seen in different colors of the spectrum (from deep blue to red)".[23] Transmission holograms can be large or small, be one off's, or mass-reproduced using a technique known as embossing.[24]

B. Reflection Holograms

The other basic type of hologram is the Reflection Hologram. This is usually a single color - often yellow/gold looks the best and brightest - but can be two or even three colors.[25] Black and white holograms, although difficult to make, are possible. "Using the photographic analogy again, reflection holograms are like photographs in the sense that they are lit from the front and reflect the light back to the viewer".[26] The Reflection Hologram looks visually different to a Transmission Hologram. Its monochrome nature and high resolving power makes it look more like a three dimensional photograph.

C. Holographic Stereograms or "Moving Holograms"

A hologram may be produced from a series of two-dimensional pictures. These

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[23] Leseberg, Bryngdahl, Computer-generated rainbow holograms, APPLIED OPTICS/ Vol. 23, No. 14, 15 July 1984

[24] Roichman Y. , Cholis I. and Grier D.G. Volumetric imaging of holographic optical traps Opt. Express **14**, 10907-10912 (2006).

[25] G.C. Righini Reflection Holographic Filters for Compacting Optical Processors. App Optics 13:1019-22 May (1974)

[26] D.J. Cooke and A.A. Ward. Reflection-Hologram Processing for High Efficiency in Silver-Halide Emulsions Appl Opt 23:934-41 1984

may come from video, computer graphics, artwork, and photography, or can even be hand drawn animations. The result is a hologram that presents a succession of two dimensional images. If the initial images are made in the correct way, the resulting holographic image can be three-dimensional.[27] Alternatively the images may be animated and appear to move as the view changes from side to side or from top to bottom.

A combination of 3D and movement is also possible. This effectively creates a "holographic movie."[28] "There is a technical limitation to the number of frames from which the hologram is made. The maximum is about 60 frames."[29] This creates a small piece of animation. An example would be a footballer scoring a goal. However this is not a route for making full length feature films. One of the advantages of this type of holography is that images can be appropriated from existing sources such as video and film archives.[30] If the right sequence is chosen, very effective holograms can be made, for example of people who are no longer alive.

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[27] Toda, Takahashi, Iwata, 3D video system using Grating Image Tsukuba Research Laboratory, Technical Research Institute Toppan Printing Co., Ltd. SPIE Vol. 2406, Practical Holography IX 1995

[28] Lucente, Hilaire, Benton, Watlington New Approaches to Holographic Video, SPIE Proceding #1732, "Holographics International '92", July 1992

[29] Sutter, John David Viewer-Plane Experiments with Computed Holography with the MIT Holographic Video system MIT, September 1994

[30] Schulze, Elmar Synthesis of moving holographic stereograms with high-resolution spatial light modulators Heinz-Hertz-Institut für Nachrichtentechnik, Berlin
SPIE Vol. 2406, Practical Holography IX 1995

D. Colour Holography

After 40 years since the appearance of the first laser-recorded monochromatic holograms the possibilities of recording full-colour high-quality holograms have now become a reality. In theory, "the first methods for recording colour holograms were established in the early 1960s. Already in 1964 Leith and Upatnieks proposed multicolour wave front reconstruction in one of their first papers on holography."[31] The early methods concerned mainly transmission holograms recorded with three different wavelengths from a laser or lasers, combined with different reference directions to avoid cross-talk. The colour hologram was then reconstructed by using the original laser wavelengths from the corresponding reference directions. However, the complicated and expensive reconstruction set-up prevented this technique from becoming popular.

A reflection hologram can be reconstructed and viewed in ordinary white light from a spotlight. Over the last few years many high-quality colour holograms have been recorded mainly due to the introduction of new and improved panchromatic recording materials. On the market are the Slavich[32] ultra fine-grain silver halide emulsions as

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[31] E. N. Leith and J. Upatnieks, 1964, "Wavefront reconstruction with diffused illumination and three-dimensional objects", pp. 1295-1301.

[32] S. J. Zacharovas, D. B. Ratcliffe, G. R. Skokov, S. P. Vorobiov, P. I. Kumonko, and Yu. A. Sazonov, 2000, "Recent advances in holographic materials from Slavich," in HOLOGRAPHY 2000, pp. 73-80.

well as photopolymer materials, manufactured by E.I. du Pont de Nemours & Co.[33] Choosing the correct recording and exact laser wavelengths is the key issue where accurate colour reproduction is concerned. Most colour holograms have been recorded using three primary laser wavelengths, resulting in good colour rendition.

6. 1. 4. Holography as Art

Since 1947 many artists have used holography for the imaging of three-dimensional space, and they do so still today.[34] The technical route of three-dimensional imaging systems in the history of art has been comprehensively traced by art historians, from the development of geometrical perspective in painting. Artists who use holography as an artistic tool show a huge difference in their character and expressions, compared with other artists as the development and use of holography is quite new.

Actively working holography artists include Margaret Benyon (U.K.), Dieter Jung (Germany), Paula Dawson (Australia), Douglas Tyler (U.S.), Shunsike Mitamura (Japan) etc. These artists did not use holography from the beginning of their career but

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[33] M. Watanabe, T. Matsuyama, D. Kidama, and T. Hotta, 1999, "Mass-produced color graphic arts hologram," in Practical Holography X II, S. A. Benton, ed. pp. 204-212.

[34] Pepper, A., Drawing In Space A Holographic System to Simultaneously Display Drawn Images on a Fat Surface and in Three Dimensional Space, A PhD Thesis, University of Reading, 1988.

started as painters, sculptures, designers or many more diverse backgrounds, but then incorporated holography technique in their work as another transformed tool for expression. This may be a result of holography having such a short history and being relatively new that many artists are naturally becoming attracted to experimenting with a curiosity. Furthermore the increasing use of holography may also be a consequence to the present contemporary art movement which attracts more inventive techniques, original expression and expansion of artistic territory in the field of unlimited imagination shown in reality. Technology has been the source of the greatest cultural thrust in the twentieth century and in the twenty first century artists using technology are continuing to share in its potential as the source of change. By using holography as a medium from the beginning of its development, artists have already influenced the direction of its use.

The uses of holography by artists are varied and individual. Holography artists have come from the diverse backgrounds of the visual and literary arts, communications and, as well as time-based and "live" art. The majority have little or no scientific background, but a strong sense of personal challenge and a willingness to invent, and solve problems. Holography has also made artists out of people without any background in either art or science. The impact of their first experience of holograms is such that they feel driven, compelled, to make them for themselves. From the many choices possible at the different stages of making a hologram it is possible for each holographer's work to be unique to themselves, to their world view and to the medium.

6. 1. 5. Practical Experiments using a Pulsed Laser

Although pulsed lasers capable of freezing live or moving subjects were developed during the early years of holography, they were relatively scarce and expensive; out of reach of most holographers. However, I was fortunate to have an opportunity to be connected with a pulsed hologram studio in Korea to experiment.[35]

Fig. 11: Pulsed holography camera GP-2J in pulsed hologram studio in Korea

In Pulse laser technology it only takes 25~35 nano seconds (10^{-9}sec) of laser triggering time (exposure time) therefore we can have a clear hologram output even

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[35] HOLO SPIRIT Co. Ltd - pulsed hologram studio in Korea, http://www.holospirit.com/ Tel/Fax: 0082-2-564-7217

under vibrating conditions which is slower than the exposure timescale.[36] Furthermore this is a revolutionary technology which even allows recording an image of flowing water and people in holograms.

One beam (the reference beam) comes directly from the laser, while the other (the object beam) comes from the same laser but impinges on the object, and is distorted by it, before striking the photographic film. What is recorded on the film is the interference pattern produced by the two beams. Likewise hologram uses laser beams on an object to record the image on a photographic film. In that case would it be possible to record an object's reflection in a mirror?

An object seen in a mirror is not an object by itself but just a mere reflection of a true object. From the technical point of view, this was the main focus of my experiment for the Pulse laser holographic technique. The meaning of my work can be explored by understanding what a hologram actually is. The general idea of a hologram is to record an object in its true appearance, size and form existing in three dimensional space into a two dimensional plane like a mirror image. The hologram or the mirror itself is a two dimensional planar object but within the hologram or mirror image a three dimensional space can be perceived. Therefore a hologram is made by a technique

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[36] Srinivasan V. et al. Pulse Width Modulated Computer Generated Holograms. V Sci Instr 14:1141-2 O 1981

which creates a reflection of an object in three dimensional space into a two dimensional plane. In reality the object does not exist even though it may appear very real as a hologram; the image creates a convincing illusion that such objects exist inside the two dimensional plane. If an object does not exist in reality but can exist in our imagination through the illusion of a hologram, can we conclude such an object can exist or not? By double exposure in two different angles I have recorded two images of myself, one as I normally am and another while wearing a mask. The image changes depending on the angle you view the hologram.

Through superimposing two changing images together, I wanted to express how people live with two images of themselves which is a natural instinct of mankind. Most people have an image of their life style being down to earth but at the same time people imagine having a different life as well. In order to make the master hologram the subject is positioned within the hologram camera and a single flash of laser light illuminates them for fractions of a second. The master hologram can only be distinguished through the laser beam. Therefore, checking whether the master hologram has been exposed correctly with a laser beam needs to be done before initiating the process for the copy of the hologram production. Diagrams how to produce a master hologram and a copy hologram are depicted below.

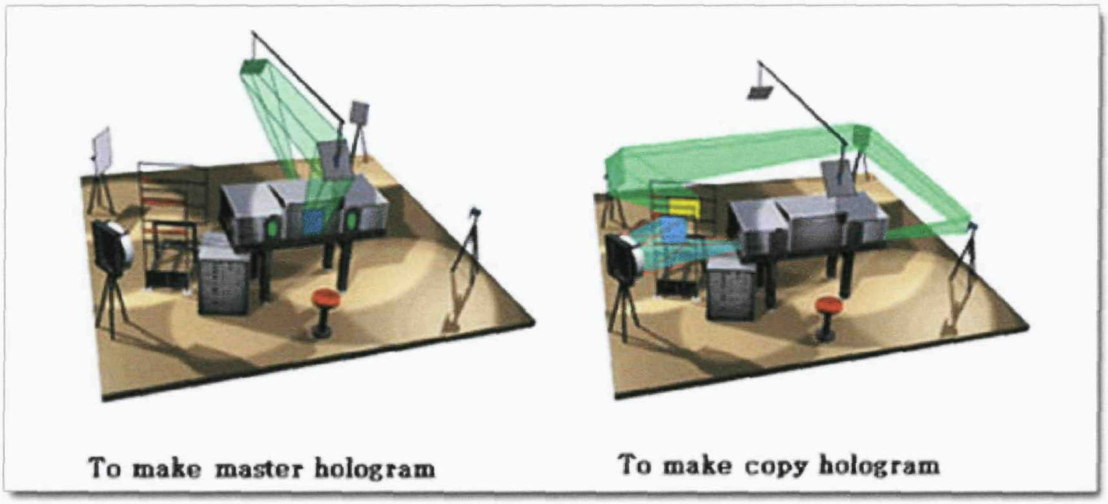

Fig. 12 Diagram showing holographic portraits production

Fig. 13 Experimental hologram work by Pulsed laser

The picture above is an example of experimental work with Pulse laser. This image produced by double exposure changes depending on the location and the angle of the viewer. The initial investigation in which whether a reflection of me in a mirror can also be recorded in a holographic plate was not so clear in the result but a faint reflection of an object was observed in the mirror.

Fig. 14 Edwina Orr's Self-Portrait, 1980[37]

A similar work is shown above by Edwina Orr's Self-Portrait - one of the prime developers of holography in the UK - holding a lens in which her reduced image can be observed. Pulsed lasers, although generally green in colour, have great clarity and detail.

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[37] Bjelkhagen Hans I. Holographic Portraits Made by Pulse Lasers Leonardo, Vol. 25, No. 5, Archives of Holography: A Partial View of a Three-Dimensional World: Special Issue. (1992), pp. 443-448.

6. 1. 6. Holography: Analysis & Summary of Experiments

Advantages:

- For this type of hologram I have experimented with is a 'true' hologram and as such it provides a solid, three-dimensional and realistic image with full parallax i.e. vertical and lateral viewing angles.
- The hologram can be easily wall mounted and illuminated from the front with a standard spot light.

Disadvantages:

- Animation is not currently available.
- The portrait image is monochromatic i.e. appears in a single colour, usually orange, yellow or green.
- Whilst deep images can be produced the parts of the image which are deeper than approximately 150 mm (6") are not usually in sharp focus.
- It is difficult for textile designers, without specific scientific knowledge in areas such as physics or optics, to understand the basic principles and processes of holograms
- Locating suitable hologram studios and the high costs of hologram films and emulsions are limiting factors in conducting experiments.

Summary

Holography has a number of properties in common with other media. In traditional terms it can be seen as an expanded form of both painting and sculpture, since it records three dimensions on a two dimensional surface. Almost fifty years on, holograms have indeed become part of everyday. As anti-forgery devices, they appear on credit cards, bank notes, concert tickets and bottles of wine.

Holography bridges the art and science fields. It provides useful new ways of comprehending images. The optical properties of holography and the fact that it is not lens-based, in addition to its three-dimensionality, also allows this technique to create effects that other media cannot. There are many visual potentialities that can be realised with the hologram that are not available through any other media. Therefore it is not surprising that before the application of holography became ubiquitous via credit cards and packaging, holograms were seen as technologically advanced. However, despite having many sophisticated advantages, holography has tended to remain within the sphere of novelty products (such as the portrait of the Queen Fig. 15) and anti-forgery products, rather than exploited as an alternative communication or decorative media in its own right.

Fig. 15 The hologram portrait of the Queen

Today, Benyon, "the mother of British holography", has all but given up on the medium to which she devoted her entire career. Tired of being ignored by the artistic establishment she also lacks the cash to finance what is a costly, and highly volatile, pursuit. Even Britain's leading collector of holographic art, Jonathan Ross has said "In the public mind, holograms have become kitsch and naff."[38]

Artists who use holography as an artistic tool show a huge difference in their character and expressions, compared with other artists. However, in pursuing the holographic research and experimentation, I have realised the technology itself has many aspects that still need to be developed further, in order to achieve the aim of my research project. The fact that holography can create three-dimensional representations of objects and space on a flat surface, is very interesting but its use is very limited when

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[38] Jonathan, D., 2004, Holograms: High art or just a gimmick?, BBC News, 23 Jun. news.bbc.co.uk/1/hi/magazine/3832361.stm

applied to representing nature. Although pulsed laser holography can record instant movements of animals and plants, the fact that holographic images can only be made life size, limits its use.

Currently the biggest problem facing holography is the difficulty in recording natural colour of an object and also recording background images. For example, recording a landscape in the distance is almost impossible because the recording studio would have to be big enough to contain the real size of the whole landscape and the film would have to be the same size as the landscape in order to record all the reflected laser beams. In the case of recording a natural environment an extensively huge Pulse laser with a strong output is required to act on a highly sensitive holographic recording material. Also in order to overcome the limitation of viewing angles, increasing the size of holographic recording material might be another difficulty. Other limitations include difficulty in recording objects in their true colour. At present only monochromatic colour (usually orange, yellow or green) is available as it was clearly evident from my experiments.

Other limitations include the necessity for having extensive knowledge in technology and materials in holography (such as holographic film, facility, emulsion, etc) to properly create images. Finally, the high costs of holography equipment are another major limiting factor for the research.

Although holography in art is still in its early developmental stage, we need to start to recognise its potential with technological advancements bridging the gaps between imagination and reality. Holography was first introduced as a new form of visual art among artists and has given us new experiences in three dimensional images.

Furthermore, holography has given us a new method and a fresh direction in expressing and experiencing visual images. The biggest challenge facing artists in this field is not only dependent on further development in laser technology and holographic emulsion but also depends on how artists themselves can express their ideas through holographic art world. At present, as contemporary art attracts more inventive techniques and as artistic practice expands into unlimited imaginative areas, holography has become an important tool for artistic expression.

6. 1. 7. Critical analysis of the result in Holography Experiment & Summary with particular reference to textile applications.

As previously mentioned in the Research Methods, my main objective of the practical experiment was to gain experience and understanding of 3D imaging technologies and to investigate potential applications for expressing three dimensional moving images in textiles. Firstly I have chosen an experiment with pulsed laser holography because I was concerned about the holographic film that is being used at present which uses polyethylene resin or holographic emulsion applied on glass. These materials require longer exposure time to capture an image in comparison with regular films. Therefore additional equipments to prevent vibration or movement during the longer exposure time is required for holography recording, such as a table that prevents any kind of external vibration.

Holograms created by initial continuous wave (CW) laser are advantageous over pulsed laser hologram because they have a better resolution. However the use of CW lasers for holography are very sensitive to vibration during recording and its use is limited in a sense that this method can only be used to record solid objects. Therefore people, animals, plants etc are impossible to record by this method. In contrast, as mentioned before, the pulse laser technology only takes 25~35 nano seconds (10^{-9}sec) of laser triggering time (exposure time) to record, resulting in a clear hologram output even under vibrating conditions which is slower than the exposure timescale. Therefore under this particular method people, animals, plants and even smoke or movement of water can be recorded for hologram. However enlargement or reduction of the image is very difficult and there is also a disadvantage of inability to express natural colour.

Then, is there any method available that can overcome the problems of CW laser and pulse laser face? Any possibility of going beyond the 1:1 life size images and being able to freely enlarge and reduce images while being able to record from a wide range of objects including people, animals and plants? Yes.

Stereo Hologram is a method that has overcome many problems of the previous methods. This sophisticated method uses a camera to take still shots of the image from many different angles and combines them together before recording them on a holographic film. However the downside is that it requires a lot of expensive equipments to run the recording and the resolution is pretty low. Furthermore the process of production through this particular method is difficult because combining still images ranging from few hundred to tens of thousands shots are time consuming and complicated. In addition there are very few places in the world that can deal with Stereo Hologram so within the scope of the research it was very difficult for me to gain any access to experiment with such technology. Therefore I have chosen pulsed laser hologram because there is still much freedom in the choice of objects to record and it is not affected much by vibration in recording environments.

The detail method for recording hologram with pulsed laser will be explained here. To make pulse laser portrait hologram requires two steps. The first step is to make a master hologram and the second step is to make a copy hologram. In order to make the master hologram the subject is positioned within the hologram camera and a single flash of laser light illuminates them for fractions of a second. The master hologram can only be distinguished through the laser beam. Therefore, checking whether the master hologram has been exposed correctly with a laser beam needs to be done before initiating the process for the copy of the hologram production.

As you might already expect holography can only take place in a complete dark room where only the laser beam can be exposed to the holographic film. Also the holographic film needs to be developed to produce a hologram. Although the methods for developing holographic film depends on the holographic emulsion, in this particular pulsed laser hologram experiment there were four stages; developing, fixing, bleaching and drying. After developing the film, brightness, 3D depths and contrast of the hologram depend on the chemical being used, the reaction time of the chemical and the temperature of water. Therefore depending on the holography artists there are several techniques for developing different types of films. Thus, there are many factors involved during recording and developing holographic images in the darkroom that we may need to take into consideration which influences the final piece. The main disadvantage may be when the final piece does not reach our expectations in terms of its brightness, depth or contrast it is very difficult to find the cause. Anything could have gone wrong during and between recording and/or developing stages and because so many factors are involved in the final piece we cannot even predict the outcome during any mid stages of holography production .

The advantage of the hologram is the ability to observe 3D images in a wide range of angles and it is particularly appropriate for the aim of my research project. However, due to many limiting factors it is expected to be difficult to apply this technique in textiles as there would be many problems to be solved. It is very rare in holography that an artist would build his/her own holography studio. The reasons behind this include the need for specialist knowledge in Physics and Optics in order to fully understand operating the equipments and a requirement for a particular space for preventing any vibration. Furthermore since such technology is not widely across a range of product areas, the cost of purchasing and maintaining the equipments for personal use are very high. Artists who enjoy much freedom in expression are forced to face technical problems that are difficult to understand which discourages them from experimenting with hologram in the first place. To summarize the difficulty in applying hologram to textile is that the image's brightness and contrast or clarity are poor under day light, the difficulty in expression of natural colour, landscape recording is impossible, lack of labs to experiment and the use of facility are very expensive, understanding basic principle and processes of holograms requires scientific knowledge (physics, optics, chemistry etc), personal experiments without financial support is impossible, also in order to overcome the limitation of viewing angles, increasing the size of holographic recording material might be another difficulty.

In conclusion through the experiments, theoretical understanding and analysis, I think holography has great potential but it is not suitable to achieve the aim of my research without making any further development in technology and chemicals to make the production process more simple and secondly the holographic image needs to be easy to view under day light while expressing natural colour.

6. 2 Lenticular Technique

Lenticular printing is one of the most exciting print technologies to emerge in recent years. The technology converts static, two-dimensional images into dynamic educational and promotional products that leave eye catching lasting impressions. Adding the perception of motion and depth, Lenticular printing creates excitement by stimulating the mind beyond the eye.

6. 2. 1. History of Lenticular

As far back as the late 1600's, artists have been experimenting with various techniques to create the optical illusion of 3D on a flat surface. In 1692, French painter Gois-Clair discovered he could achieve a multi-dimensional effect on canvas by interposing a grid of vertical laths between the viewer and the painting.[39]

The first images to be described as "Lenticular" were produced in the 1930s by Victor Anderson. By the late 1940s, Mr. Anderson's company was producing millions of simple lenticular images a year for everything from postcards of women winking at the viewer to Cracker Jack prizes, political campaign buttons and magazine inserts.[40]

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[39] Didik F.X., "A brief history of stereo images, printing and photography from 1692-2001", Tch. Rep., Didik.com/Vari-Vue.com, 2001.

[40] Roberts D.E., "History of Lemticular and Related Autostereoscopic Methods," http://www.microlens.com/HistoryofLenticular.pdf, 2003

The basic process used to produce these lenticular images was quite simple: the printer first printed the image on paper, and then laminated that paper to thick vinyl lens material. Unfortunately, these early methods and materials were incapable of delivering complex images in crisp detail.

In the late 1980's, personal computers became commonplace in the graphic arts industry with the advent of adequate speed, memory and software. This moved the lenticular creation process rapidly from the proprietary in-house photomechanical domain into the hands of many creative and proficient computer artists with a general understanding of the process. In 1994, National Graphics began work on a revolutionary new method to produce lithographic lenticular images.[41] Rather than printing on paper and then laminating the paper to the lens material, they pioneered the method of printing directly on the reverse side of the lens material, providing accurate registration of the printed image to the lens material and making it possible to deliver images with significantly greater detail and clarity. They also developed highly specialized interlacing software capable of generating more sophisticated imagery. In 2002, National Graphics was awarded a patent for a much thinner, higher-definition lens

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[41] Goggins T.P., "Method of producing multidimensional lithographic separations free of moire interference," U.S. Patent No. 5,488,451 assigned to National Graphics, Inc., 1996.

material specifically designed to meet the needs of publishers and packagers.[42] This new material, called Crystal lens is a 200-line material capable of delivering enough detail to accurately convey bar code information when scanned at the point of purchase. The Crystal lens is only .007 inches thick, making it practical for either books or magazines.

6. 2. 2. Understanding of the Technique

Lenticular print can easily be described as specially prepared graphics that are designed to work together with a lenticular lens to allow the viewer to see different images depending on the angle at which they view it. The use of both imagery and lens material are inseparable when it comes to making the desired effect come to life in a lenticular print. The image itself is a composite of two or more graphics that are interlaced together. The lens is a unique plastic that is made up of individual lenticules that must be perfectly aligned with the interlaced image underneath it in order for the effect to work. Based on the angle of the viewer, each lenticule acts as a magnifying glass to enlarge and display the portion of the image below. Many lenticules working in harmony form the entire lenticular image. In this way, lenticular print can appear to

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[42] Goggins T.P., "Method of producing multidimensional lithographic separations free of moire interference," U.S. Patent No. 5,617,178 assigned to National Graphics, Inc., 2002.

show motion or even three-dimensions because each eye is viewing the lenticular print from its own angle.

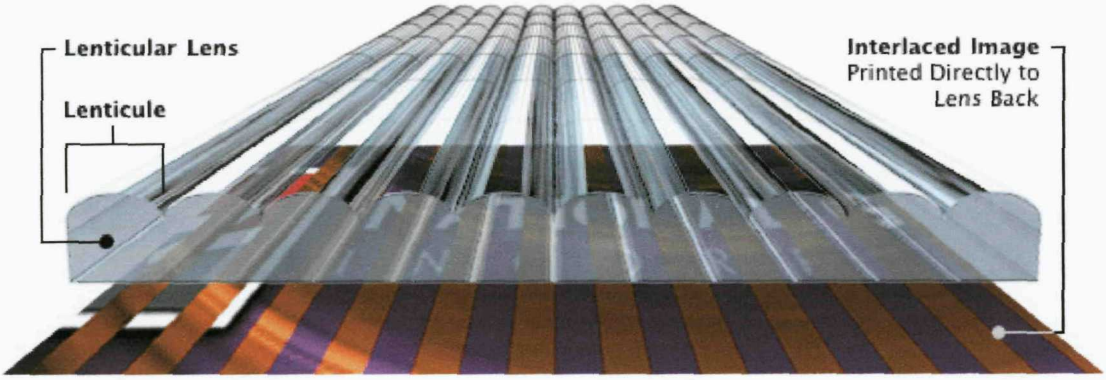

Fig. 16 A schematic representation of Interlaced Image

One side of an extruded plastic sheet is embossed with columns of tiny corrugations called lenticules,[43] hence the name "lenticular" in lenticular extruded lens. The lenticules are all the same size and are spaced equally across the sheet. The other side of the sheet remains smooth in order to be printed upon. The frequency of lenticules is called lines-per-inch or LPI,[44] and can vary from 10 to 200. Just as no one eyeglass prescription works for everyone, no single LPI works best for all project effects. The curvature or angle of the lenticule is important to keep in mind when selecting the proper lens. For an optimal 3D effect, a narrow-angle lenticular lens[45] with a viewing angle between 15 to 44 degrees works best. When working to achieve a

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[43] A single (or multiple) lens in a lenticular sheet

[44] Lines-per-Inch. In the lenticular process, this would also mean "Lenticules-per-Inch."

[45] A lenticular lens sheet with a viewing angle between 15-35 degrees. Narrow-angle lenses work best for 3D effects.

good animation effect, a wide-angle lenticular lens[46]with a viewing angle between 44 to 65 degrees works best.

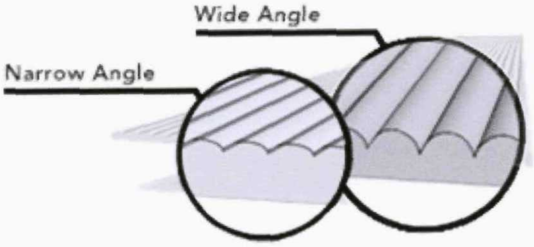

Fig. 17 Angle of Lenticules

Lenticular sheets range in thickness from 0.008 to 0.385 of an inch.[47] What you choose is determined by the desired effect you're looking to accomplish and how your project will ultimately be used. Sheets come in a number of sizes, with 20"x 28" and 28"x 40" being two of the most commonly used in offset printing.

6. 2. 3. Lenticular Lens Options

There are so many variables involved in putting together a great lenticular piece. Selecting the correct lens is ultimately one of the most important decisions to make. A simplified chart system to aid in finding the best lens options for your planned effect is summarised on the next page.

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[46] A lenticular lens sheet with a viewing angle between 40-65 degrees. Wide-angle lenses work best for "flip" and "animated" effects.

[47] Gabert S. and O'Brien K., "Made you look!" American Printer, 2005 http://americanprinter.com/mag/made_you_look_0805/

Planned effect

Print Process	**3D**	**Flip**	**Morph**	**Animation**	**Zoom**
Large Format Inkjet	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F
Offset	I,L	H,I,J,K	H,I,J,K	H,I,J,K	H,I,J,K
Flexography	K	K	K	K	K
Traditional Photographic	ALL	ALL	ALL	ALL	ALL
Screen	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F	A,B,C,E,F
Digital Photographic	ALL	ALL	ALL	ALL	ALL

Lens Types

	A	B	C	D	E	F	G	H	I	J	K	L
LPI	10	15	20	20	30	40	60	60	62	75	100	100
Viewing Angle	48°	47°	47°	29°	49°	49°	26°	54°	44°	49°	42°	30°
Gauge (mil)	150	98	85	150	52	33	48	20	27	18	14	23

Table 1. Lenticular materials[48]

A chart system to aide in finding the best lens options for your planned effect. The first step in lenticular design is to choose the effect that best suits your graphic or

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[48] http://www.lenstar.org/how/plastic.htm

the message you are trying to communicate. There are five different forms of lenticular effects to select from, 3D, flip, animation, morph, and zoom. Each focusing on a slightly different way to create a bold and captivating image that is sure to demand attention.

6. 2. 4. Lenticular Effects

3D effect - Objects within an image are layered to give the illusion of depth and perspective. Unlike 2-dimensional design, using this lenticular effect allows graphics to appear more realistic. Lenticular 3D can be incorporated into most images or design styles.

Flip effect - A dramatic swapping of two images-each vanishing and then reappearing from one to another. Utilizing this lenticular flip effect is most beneficial for demonstrating "cause-and-effect" or even "before-and-after" comparisons.

Animation effect - With a series of images coming together to create an animation much like a short movie clip, this is the most complex lenticular effect. The illusion of motion actually comes from either a selection of video frames or sequential still images. This lenticular animation effect is great for emphasizing body movement or mechanical action.

Morph effect - The conversion of one image into another is used to create the illusion of transformation. This lenticular morph effect can be used for showcasing a product or feature that may change or create change.

Zoom effect - The illusion of movement from background to foreground to create the effect of "leaping out" or "jumping back." A lenticular zoom animation can consist of one or more objects, or even a full image. This effect works best for highlighting elements such as products, logos, or important messages.

6. 2. 5. Interlacing for Lenticular Lens

In order to understand interlacing[49], having a good degree of working knowledge with graphic programs, resolution factors, output devices, proofing methods, image setters, and offset litho printing helps.

The printer's equipment and its capabilities will play a huge role in how you will need to interlace the art that they will proof and print. The printers proofing and plating devices have a defined output resolution, or target resolution[50] or a divisible factor of that resolution. (i.e.; 2400, 1200, or 600 dpi.) The target resolution divided by the pitch value of the lens is what will determine the number of frames (for animation effects) or views (for 3-D effects) that will be used to interlace the lenticular art file for

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[49] The process of striping and arranging printed information to a given pitch to match a lenticular lens

[50] The highest output resolution of the imaging device (inkjet printer, digital proofer, contract proofer, film setter, plate setter)

proofing and/or platting. By utilizing this formula, the interlaced file size will be closest to the targeted resolution.

Interlacing can be described as a linear process.

1. Choose a planned effect-Animation, flip, morph, zoom, or 3D.

2. Create or select art and/or images that are lenticular friendly.

3. Select the correct lenticular lens for the planned effect being used-keeping in mind how your piece will be used and the distance in which it will be viewed at.

4. Find the visual pitch[51] of your lens. Pitch-testing the lenticular lens to the proofing device will determine the proofing pitch.[52]

5. How to determine the visual pitch - When moving your head from right to left you should notice the lower LPI bars will move in the opposite direction and the higher numbered LPI bars are moving in the same direction as you.

6. Use a good color printer during the art-assembly stage.

7. Interlace your art to the planned effect

There are a number of lenticular and lenticular software packages available.

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[51] Visual Pitch: The working pitch of a lens at the planned viewing distance.

[52] Proofing pitch: The act of matching the proofing device's output to the lens' pitch by performing a pitch test. This test will help to find the pitch number (or LPI) that will be used to interlace the proofing file.

For now, let's assume that I am planning a 5-phase animation effect. I have five images. Image 1 will be the start of the sequence and image 5 is the end. Let's also assume that I am working with a 60 LPI lens that has a proofing pitch of 60.15 LPI. My goal, as well as the interlacing or lenticular software's, is to create a pattern of 1 to 5 in which each series of 5 will fit precisely under one lenticule. By doing so, I will have a factor of 5 images per lenticule—resulting in an interlaced file size of 300.75 PPI. How did I come to this figure? Here is the mathematical formula:

Number of Frames x **Proofing Pitch LPI of the Lens** = **PPI**

(My example would then be written to look like: 5 frames x 60.15 PPI= 300.75 PPI.)

This method is used when my target resolution is 300 dpi, because my proofing device—the inkjet printer—works in 300 dpi increments (300, 600, 1200, 2400, 4800.) The interlaced files megabyte size will vary due to the changes in physical size and target resolution. This is important to know because if the physical size is large and the target resolution is high I run the risk of creating an interlaced file too large for my computer, RIP[53], printer, and/or system to handle. A file size of 1-4 gigabytes is not uncommon for final interlaced art. The closer I am able to interlace to the proofing device's top resolution, the better quality action proof I will create; therefore, producing

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[53] Raster Image Processor: converts the interlaced image file to bitmap data for outputting since bitmapped data can be accommodated by the output device that ultimately outputs the final image

a higher quality lenticular piece.

Again, using the example above, let's assume 1200 dpi is my target resolution. To achieve this, I will have the same series-pattern of the interlaced images, but rather than having just one set of 5 under each lenticule, I will now have four sets of 5 images under each lenticule. This "x 4" factor will result in a higher interlaced file resolution of 1203 PPI (300.75 x 4.) To do this, I will simply duplicate each frame, or image, four times. Within the interlacing software, it would look like: 1,1,1,1,2,2,2,2,3,3,3,3,4,4,4,4,5,5,5,5 and so on. This is the higher resolution pattern that will fit under one lenticule. My lenticular software will take this information, slice the input images, and arrange accordingly.

6. 2. 6. Practical Experiments with Specific Lens using Magic Interlacer Pro

Firstly computer software that I am using for the experiment is described briefly as the following. Magic Interlacer Pro is a user friendly graphical intererlacing program designed and developed by two of the world's leading lenticular artists. [54] Interlace up to 100 images for 3D, Animation, Motion, Morphs, Flips and more. A FlashBand is basically a small black and white interlaced flip image. One image is

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[54] www.**promagic**.net/**pro**100.html

white, and the other image is black. FlashBand assists in determining the exact pitch of lenticular lens material to match printer calibration.[55]

As we go through each image we can find there is a common theme running through all of them. Most images represent something in nature such as human and flowers, these images were carefully chosen so that they do not contain any artificial identity. The common theme running through each image is that the one thing human civilization has to live in harmony is nature. I have chosen this theme because I believe this harmony should remain unchanged no matter how the world around us develops and changes.

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[55] http://www.shortcourses.com/how/lenticular/lenticular.htm

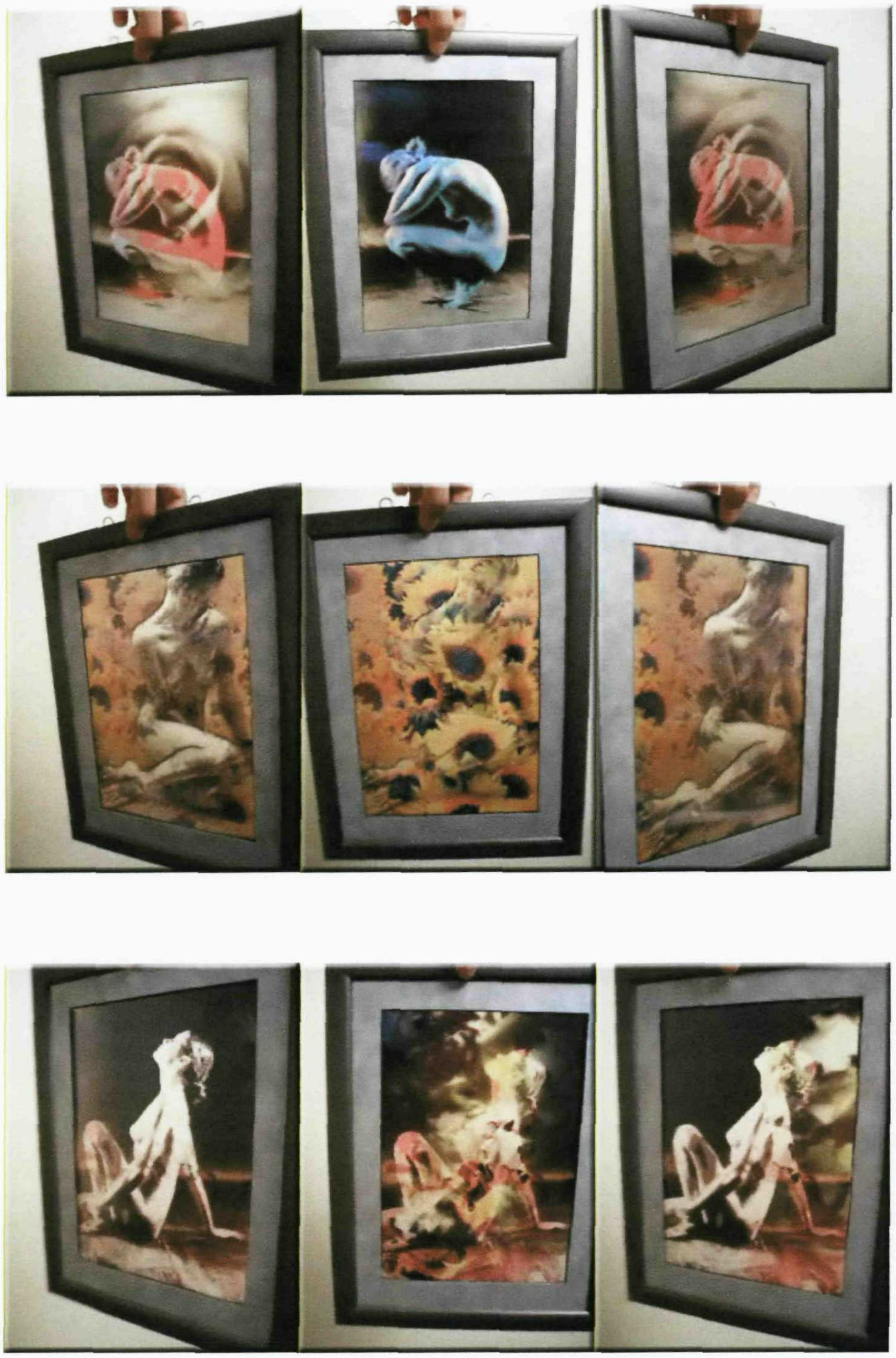

Fig. 18 Images from Experimental Lenticular work

Software : Magic.Interlacer.Pro.100.with.FlashBand.Generator.v2.3.0.

Lens : 30 LPI lens

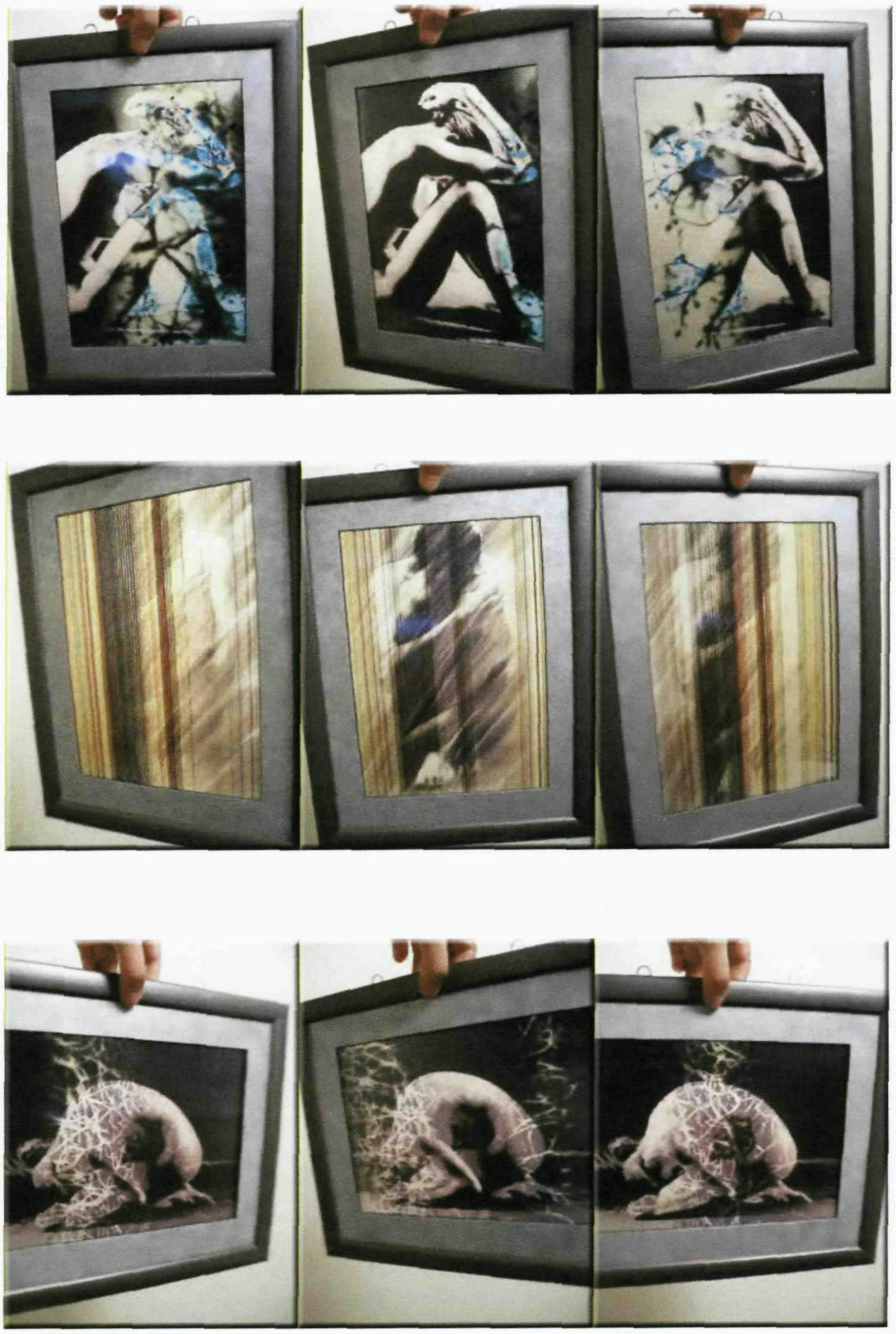

Fig. 19 Images from Experimental Lenticular work

Software : Magic.Interlacer.Pro.100.with.FlashBand.Generator.v2.3.0.

Lens : 30 LPI lens

6. 2. 7. Lenticular experimental Analysis & Summary

After working with 30LPI Lenticular lens film, I have realised there are a few problems in lenticular techniques. One of the biggest problems is the time consuming process of calibrating the output device. A black and white interlaced image is used to help to determine the exact pitch for the lens. Unfortunately, running the same file on various devices will often give different results. Therefore calibrating the output device is an essential procedure for lenticular technique.

Another problem of lenticular technique is the difficulty of correct alignment of final interlaced image with a lenticular sheet. The more LPI (Lines-per-inch) in a lenticular film the more detailed animation there can be as the image flips. Therefore with an increasing LPI lenticular film the alignment requires a much more accurate approach. A low LPI such as 30 LPI and below, alignment can be made easily with the naked eye and up to 60 LPI alignment can be made reasonably well. However LPI above 60 can be difficult to align accurately with the naked eye. You may require another device to assist in accurate alignment.

Summary

People often confuse lenticular images with holograms. While both techniques are capable of delivering the illusion of depth and motion, they are quite different in terms of their appearance, differing lighting needs, and being used for different purposes. Commercial holographic imagery generally requires the professionally-equipped holographic laboratory to create the original image before real production can begin. Lasers create a diffracting pattern that is recorded on holographic film. Unfortunately, special colour matches are not possible. Only the iridescent colours and tones inherent in the technique of holography are possible. Also, holograms must be viewed for best performance in halogen or laser lighting.

In lenticular, there are no real limitations to the range of possible colours, and they require no special lighting. Images are cleaner and brighter than holograms. Unlike holography, there is no need to create the image in a specialized laboratory environment. The image is generated directly from the art. File preparation is similar to conventional offset printing, giving the designers direct control of their image.

Lenticular technique is already being widely used in various kinds of products and advertising. In comparison with holograms, lenticular is highly attractive for its simple process of production, lower material costs, wider opportunity to apply in marketing field and positive response from people as a result of their natural curious interest for the lenticular animation. Lenticular technique has a high potential to expand its application in the near future.

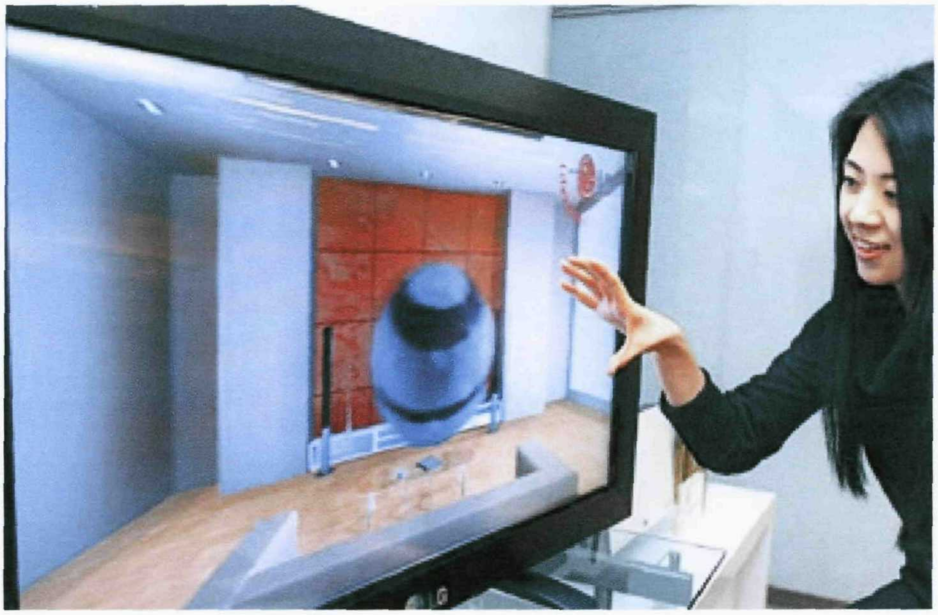

Fig. 20 A 42 inch 3D LCD monitor, which can display images in 2D and 3D, by LG Electronics [56]

We can already find use of such technology in HD television (fig. 20). In December 2006 in Korea a newly developed LCD monitor was exhibited by LG Electronics which used lenticular sheet for 3D display. A brief history in lenticular technology starts from 1980 in which 3D display was the focus of research. However the common television at the time was usually known as Braun TV which had a bulged

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[56] http://news.chosun.com/site/data/html_dir/2007/03/23/2007032300459.html

out screen. The bulging out TV screens in the 1980s, made it difficult to arrange the lenticular sheets accurately and lenticular applications on TV were put on hold. Therefore the recent 3D display technology can be acknowledged as a result of developments in flat screen monitors.

Fig. 21 Example of 1980s television with bulging out screens, Braun HF 1, Germany, 1959[57]

Imagine a lenticular sheet composed of clear plastic tube lens arranged vertically, is attached in front of a TV monitor. Displayed images entering from the left side of the lens will have light curving to the right eyes and vice-versa images from the right will enter the left eye. Likewise if images are being separated between right and left eyes it creates an illusion that a person is viewing an object with naked eyes known

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[57] http://www.braun.com/global/company/history.html

as binocular disparity. Therefore with two cameras one could record right side of the image and the left side of the image and then arrange it in an array on the monitor with right and left next to each other in an alternating pattern. Attaching a lenticular sheet on top of the monitor will then create a 3D display as the images are being projected in different directions.[58] However, there are disadvantages in this technology which includes image sharpness being low and only allowing one direction of 3D display (i.e. If 3D display can be viewed while sitting in an upright position, 3D display cannot be experienced when lying down).

6. 2. 8. Critical analysis of the result in Lenticular Experiment & Summary with particular reference to textile applications.

Lenticular technique is already widely being used in a range of products and advertisements and many people would have come across its effects. Experimental analysis has revealed that the most important part in this technique to experience the 3D effect and changing images depending on the viewing angles is the lenticular lens and the accurate alignment of the sliced background image. The experiment has shown that in order to accurately align the background image to above 60 LPI lenticular films an additional device is required to assist such procedure.

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[58] http://news.chosun.com/site/data/html_dir/2007/03/23/2007032300459.html

In lenticular, there are no real limitations to the range of possible colours, and they do not require any special lighting. Images are cleaner and brighter than holograms. Advantages of this technology include the ability to display the 3D qualities of nature and objects in close proximity, which increases its application for advertising, games and television etc. Lenticular technology is advantageous over the rather simplified production process, cost effectiveness, and freedom of colour expression. In the attempt to produce a facsimile of a mutable living fabric, this technique is relevant to achieve my research aim in that it allows animation and 3D effects by different viewing angle. However, it relies on non-flexible materials, image sharpness being low, and only allows one direction of display in vertical or horizontal.

As technology develops, thinner and more flexible and transparent materials will be available and they can be combined with textile application. Such combination can open lenticular technology for a wider use in the future.

6. 3 3D Integral Imaging using Fresnel Lens Arrays

This section focuses on the 3D Integral Imaging Technique using Fresnel Lens Arrays as this is the technique that provides the closest method of achieving the main objective of the research project.

6. 3. 1. History of Integral Imaging

On March 3rd, 1908, physicist Professor Gabriel M. Lippmann (1845-1921) proposed the use of a series of lenses placed at the picture surface to form a true three dimensional image. He announced this to the French Academy of Sciences under the title "La Photographie Integral."[59]

The first in depth study of lithographic printing of integral imagery was described in 1936 by Carl Percy and Ernest Draper of the Perser Corporation. The first integral animation printing effect was proposed in 1958 by Juan Luis Ossoinak of Argentina.[60]

A number of researchers continued to advance the process of Integral Photography over the last 40 years including, most prominently; Roger de Montebello, Lesley Dudley and Robert Collier of the US, Neil Davis and Malcolm McCormick of

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[59] Lippmann, M. G., 1908, Compt. Rend. Acad. Sci. Vol. 146, 446.

[60] Ossoinak A., (1958) Arrangement for the Exhibition of Dynamic Scenes to an Observer in Movement with Respect to a Screen, US Patent 2,833,176

the U.K. and Yu. A. Dudnikov and B. K. Rozhkov of the former Soviet Union.[61]

"Creating 3-D integral imagery, by digitally interlacing a set of computer generated two-dimensional views, was first demonstrated in 1978 at the Tokyo Institute of Technology in Japan."[62] They and others also developed experimental integral television methods. Digitally interlacing integral imagery for high-resolution colour pictures was first proposed in 1989 by Ivars Villums.[63] "Many thousands of experimental images have been produced throughout the last century by a wide variety of methods, exhibiting 3-D, animation and other impressive effects."[64] Research and commercialization of integral methods remains very active today including a wide body of work in integral television and other electronic displays. Although integral imaging has not yet achieved significant commercial success, its widespread use is inevitable.

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[61] Rozhkov B.K. (1987)The Transformation Properties of the Lens–Array System in Integral Photography Sov. J. Opt. Tech., Vol. 54 No. 2

[62] Higuchi H. and Hamasaki J., (1978) Real-time transmission of three-dimensional images formed by parallax panoramagrams, Appl. Opt., vol. 17 no. 24 3895-3902

[63] Villums I. (1989) Optical Imaging System Using Optical Tone-Plate Elements, US Patent 4,878,735

[64] Roberts D.E. and Smith Trebor 2003, The History of Integral Print Methods, An excerpt from: "Lens Array Print Techniques" http://www.integralresource.org/Integral_History.pdf

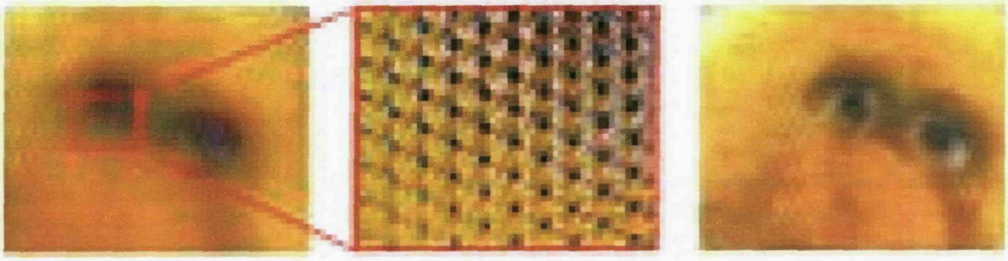

Fig. 22 Integral image (Left) without lens; Enlargement (Center), note that each lens records its own unique picture; Integral image (Right) resolved through a matching lens from a particular viewing position; Roberts & Villums.[65]

6. 3. 2. Understanding of the Integral Imaging Technique

Integral imaging is a true auto-stereo method.[66] An integral image consists of a tremendous number of closely-packed, distinct micro-images that are viewed by an observer through an array of spherical convex lenses, one lens for every micro-image. "The term "Integral" comes from the integration of all the micro images into a complete three dimensional image through the lens array."[67] This special type of lens array is known as a fly's-eye or integral lens array.[68]

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[65] Roberts D.E. and Smith Trebor 2003, The History of Integral Print Methods, An excerpt from: "Lens Array Print Techniques" http://www.integralresource.org/Integral_History.pdf

[66] Auto-stereo method: stereo imagery viewable without the requirement of special glasses.

[67] De Montebello R.L.,(1977)Wide-angle integral photography–The Integram System, Tech Digest 73-91

[68] Gottfried P., Brosh S.., (2002) Integral image, method and device US Patent 6483644 http://www.patentstorm.us/patents/6483644-fulltext.html

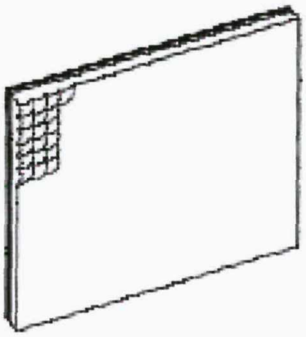

Fig. 23 Fly's eye lens sheet illustration; Okoshi, Academic Press 1976.

"Integral, which is also referred to as an integral photography, is one of the currently popular three-dimensional (3D) display techniques."[69] It can provide bare-eyed observers within a certain viewing angle with full colour and real-time 3D images that have both horizontal and vertical parallaxes.

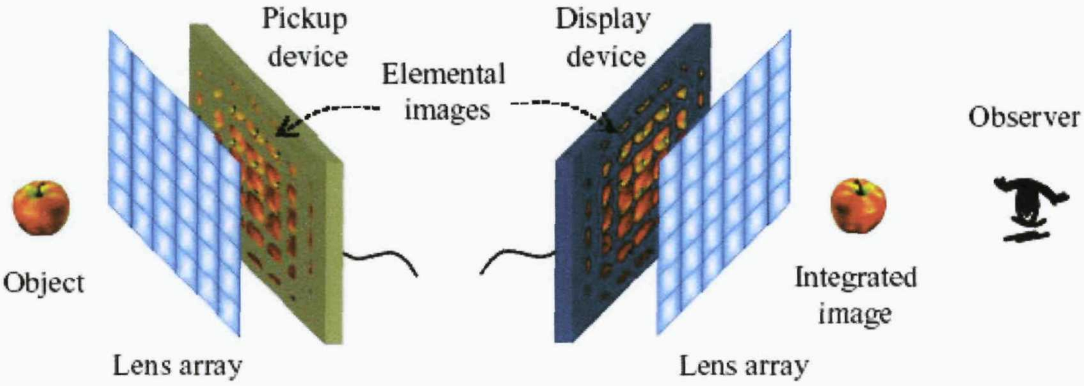

Fig. 24 Basic concept of integral imaging showing pick up and display process[70]

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[69] Ignat'ev N.K. et al, Two Modes of Operation of a Lens Array for Obtaining Integral Photography, Sov. J. Opt. Tech., Vol 50, No 1

[70] Park J., Kim Y. and Kim J. 3D/2D convertible display based on integral imaging and its extensions for viewing-angle and resolution enhancement., Article from School of Engineering and Computer Science, Seoul National University http://www.samsung.com/AboutSAMSUNG/ELECTRONICSGLOBAL/SocialCommitment/HumantechThesis/WinningPapers/downloads/11th/bronzeprize/ParkJaeHyeung.pdf

Figure 24 shows the basic concept of Integral Imaging. In the pickup process, each elemental lens constituting the lens array forms each corresponding elemental image based on its position relative to the object, and these elemental images are then stored. In the display process, the elemental images displayed on the display panel are integrated at the original position of the object forming a 3D image.

6. 3. 3. Fresnel Lens

A Fresnel lens is a type of lens invented by Augustin-Jean Fresnel.[71] Originally developed for lighthouses, the design enables the construction of lenses of large aperture and short focal length without the weight and volume of material which would be required in conventional lens design. Compared to earlier lenses, the Fresnel lens is much thinner, thus passing more light and allowing lighthouses to be visible over much longer distances.

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[71] Augustin-Jean Fresnel: (May 10, 1788 – July 14, 1827), was a French physicist who contributed significantly to the establishment of the theory of wave optics. Fresnel studied the behavior of light both theoretically and experimentally.

6. 3. 4. History of Fresnel Lens

"The first Fresnel lens was used in 1822 in a lighthouse on the Gironde River in France, Cardovan Tower; its light could be seen from more than 20 miles out."[72] Scottish physicist Sir David Brewster is credited with convincing the British to use these lenses in their lighthouses.[73][74]

The Fresnel lens is a thin, flat optical lens which consists of a series of small narrow concentric grooves on the surface of a lightweight plastic sheet in order to reduce the thickness, weight and cost. Each groove is at a slightly different angle than the next and with the same focal length in order to focus the light toward a central focal point. Every groove can be considered as an individual small lens to bend parallel Fresnel light waves and focus the light.

The Fresnel lens is a special optical lens. It can now be made from plastic such as acrylic (PMMA), polyvinyl chloride (PVC), polycarbonate (PC) and HDPE.[75]

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[72] Watson, Bruce. "Science Makes a Better Lighthouse Lens." Smithsonian. August 1999 v30 i5 p30. Reproduced in Biography Resource Center. Farmington Hills, Mich.: Thomson Gale. 2005. <http://libproxy.uncg.edu:2088/servlet/BioRC>.

[73] Brewster, Sir David., 2005, Encyclopedia Britannica Online. 11 November 2005 <http://search.eb.com/eb/article-9016395>.

[74] David Brewster., 2005, World of Invention, 2nd ed. Gale Group, 1999. Reproduced in Biography Resource Center. Farmington Hills, Mich.: Thomson Gale. <http://libproxy.uncg.edu:2088/servlet/BioRC>.

[75] Andersen G. and Knize R.J. 1998, A high resolution, holographically corrected microscope with a Fresnel lens objective at large working distances Optics Express Vol. 2 No.13 546-551

A traditional glass convex lens would be thick, heavy and very expensive, but a plastic Fresnel lens is a thin, flat, lightweight and low cost alternative.

Fig. 25 Fresnel Lens displayed in the Musée national de la marine in Paris, France

6. 3. 5. Practical Experiments with Fresnel Lens Array

In this section the continued experiment with Fresnel lens of 15,22mm focal length is discussed. Although 3D Integral Imaging has already been mentioned earlier in this chapter, this section further discusses the findings from my experimental investigations into the factors that provide full parallax and continuous perspective within the viewing zone.

Before discussing the Fresnel lens experiments, broadly speaking, there are two types of arrays that can be used to create 3D Integral Imaging, firstly the array of spherical Micro-Convex lenses and secondly the Fresnel Lens Array. However, I could only experiment with the Fresnel Lens Array because the spherical micro-convex lens array, which is usually used for professional high-tech display devices are very expensive. For example, for a high quality Micro-Convex Lens array, 51mm x 51mm (Fig. 24 spherical micro-convex lens array) costs around 8,000 Euros[76], whereas Fresnel Lens Arrays with a considerably larger size, 130mm x 130mm, are cheaper, around 75 Euros.[77] Therefore I have chosen the Fresnel Lens for the experiment.

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[76] advanced microoptic systems gmbh, Lebacher Str. 6a, D-66113, Germany, http://www.amus.de/www/pages/home.html

[77] Fresnel technologies inc.(Texas, US, WWW.fresneltech.com)

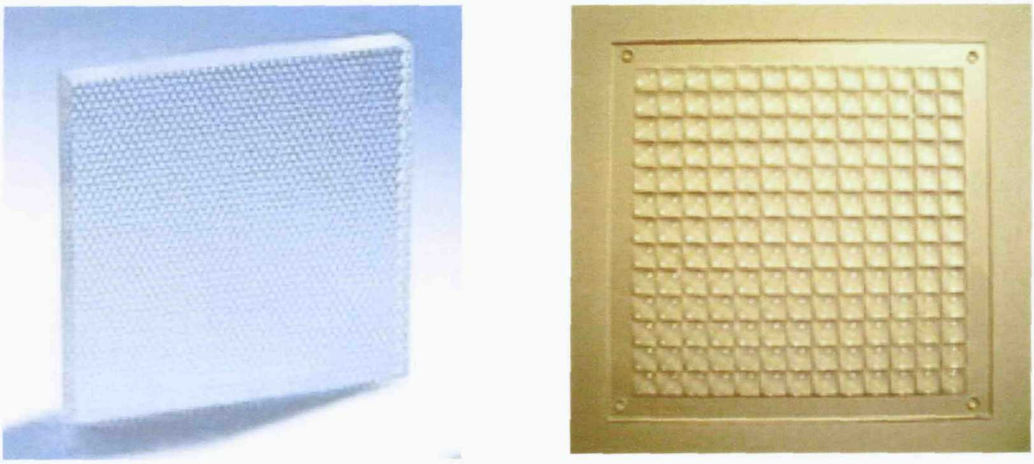

Fig. 26 Two types of lens arrays, Spherical Micro-Convex Lens array (left) and Fresnel Lens Array (right)

Specialist information and technical support, including Fresnel Lens specifications, was kindly provided by Prof. Byoungho Lee (School of Electrical Engineering, Seoul National University) and Dr. Jeong (Reader, Optoelectronics Research Centre, University of Southampton). Fresnel Lenses were purchased from Fresnel technologies inc.(Texas, US, WWW.fresneltech.com) with focal length 15mm, 22mm(13x13), quantity was 5 each so 10 in total.

Since this technique was proposed first by Lippmann as integral photography in 1908,[78] it has been modified and developed. Continuous efforts have focused on the enhancement of the viewing resolution or image depth in integral imaging. In addition, with rapid development of high resolution CCD (charge coupled device) or display

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[78] M. Lippmann, 1908, "Epreuves reversible donnant la sensation du relief," J. Phys. 7, 821-825.

devices, Integral Imaging has attracted much attention for its real-time application.[79] For example it is applicable to a 3D TV system or a 3D animation display.

However, in spite of many advantages, the limitation of the viewing angle is one of the main problems. Software called Imageman2 was provided and demonstrated by Dr. Jeong.

6. 3. 6. Method of Experiments

In order to use this Software my computer was firstly calibrated with its pixel size to the Fresnel Lens to be used. Thereby an image which is sliced according to the Fresnel Lens and is aligned by checking focal length above the image as the resolution is set. In addition, by checking that the image information is being transferred correctly, the image can then be printed. Finally an image product is made by overlaying the printout with the Fresnel Lens. Please refer to Equipment Specifications in the table.

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[79] F. Okano, H. Hoshino, J. Arai, and I. Yuyama, 1997, "Real-time pickup method for a three-dimensional image based on integral photography," Appl. Opt. 36, 1598-1603.

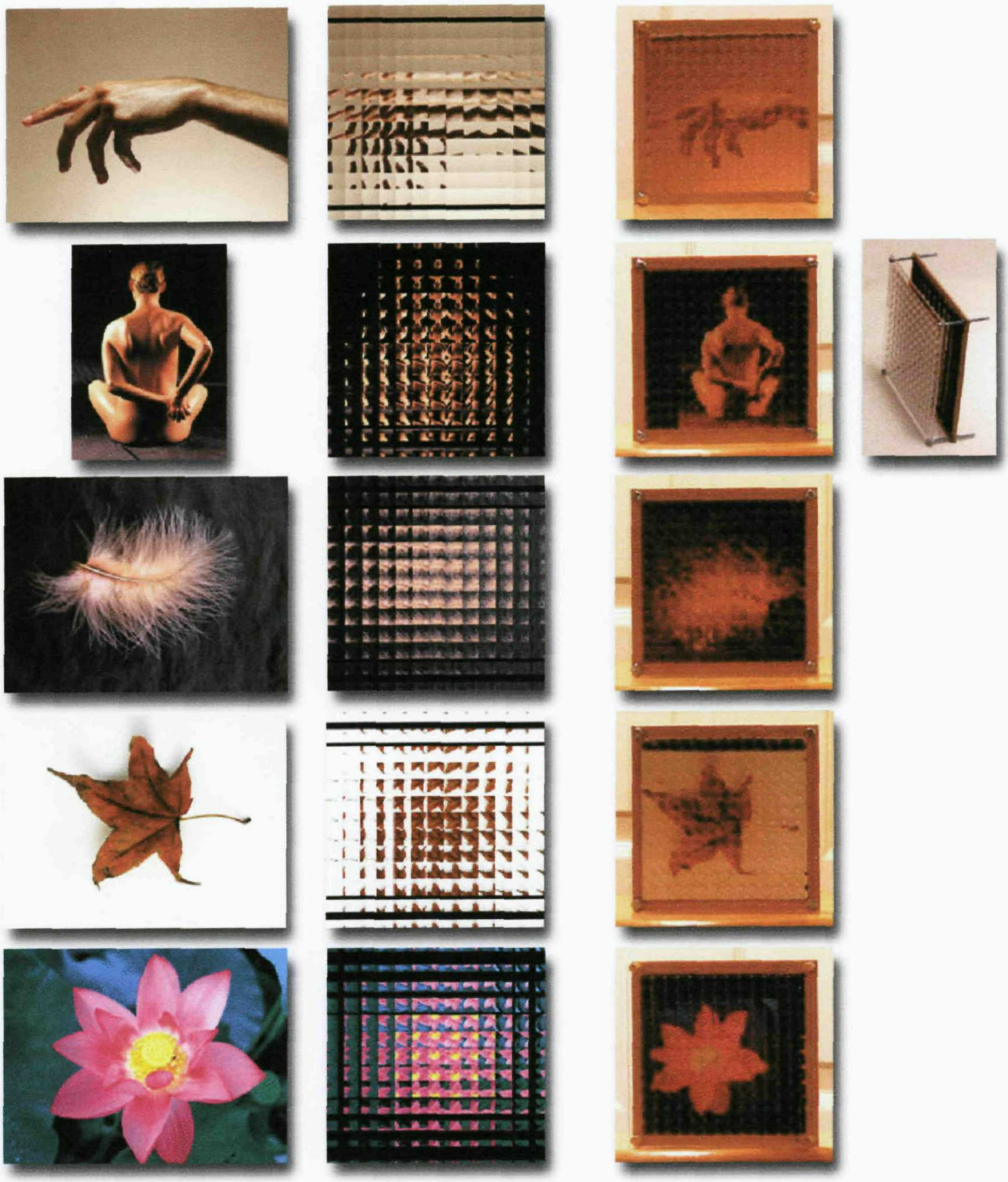
Setup	Specification	Characteristics
Flat panel CRT display	Number of pixels	1280(H) / 1024(V)
	Pixel size	0.24mm
Fresnel lens array	Number of elemental lenses	13(H) / 13(V)
	Pitch of the elemental lens	10mm
	Focal length	15mm, 22mm
Polarization shutter screen	Type of polarization	Circular

Table 2: Equipment Specifications for Fresnel Lens Array

This technology will be used as a base for my future research and technological assistance would be required to support my understanding of a number of technical aspects. The work below shows images produced by the Fresnel Lens. (Focal Length 15 and 22mm)

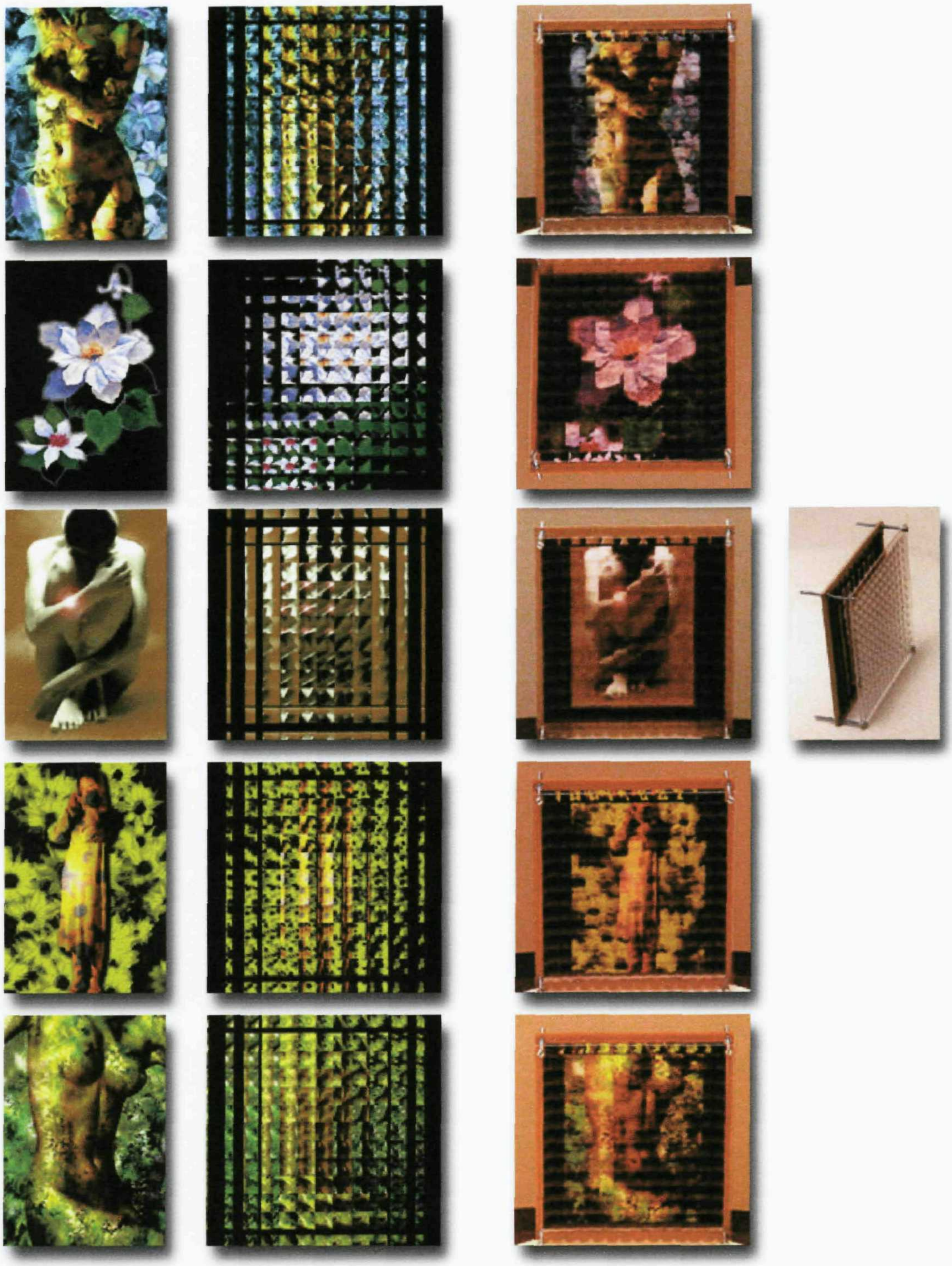
The images used for 3D Integral Imaging experiments were selected for their natural rather than artificial character, for example, the human figure and flowers. We are constantly surrounded by man-made environments as a direct consequence of technological developments. However we continue to live in harmony with natural environments as we are also part of nature. I have chosen these particular images of nature to express this message.

I started by using a simple, clear photographic images, progressing to more complex images using Fresnel Lens Integral Imaging technology. The main objective of this experiment was to explore the limitation of viewing angles, colour and 3D depth in different focal lengths (15mm and 22mm) of Fresnel Lens.



a) Original Image b) Elemental Image c) Result

Fig. 27 Practical experiment with 15mm focal length Fresnel Lens



a) Original Image **b) Elemental Image** **c) Result**

Fig. 28 Practical experiment with 22mm focal length Fresnel Lens

6. 3. 7. Experimental Analysis & Summary of 3D Integral Imaging Technique using Fresnel Lens Array

The Integral Imaging Technique is currently the most intensely investigated and developed technique as mentioned earlier in the History of Integral Imaging section. This technique offers technological advancements in broad areas including advertisement, computer games, medical techniques and the media and will bring unimaginable changes to 3D display in the near future.

In 3D Integral Imaging Technique using diffractive Fresnel Lens Arrays, my most important interest was in finding how much shorter the distance could be made between an image and the Fresnel Lens, while the image is expressed in mid-air in the space between the viewer and the lens. This distance is a crucial factor for determining size and number of grooves on each rectangular Fresnel Lens, and the limitation of the viewing angle. A good understanding of physics and optical science behind the theory of such imaging technique is necessary to calculate the distance and therefore mathematical ability is required as well. Furthermore, in order to express an image in mid-air, a special computer programme is needed to perform complex calculations and to distort the original image according to specific distances.

Secondly, a thin and flexible material that can be engraved on and also adhered to fabric is desired to be developed. In order to explore the potential of the methods above for creating 'living' textile, I have bought short focal length Fresnel Lens from a Japanese lens company (each lens size 10x10mm, focal length 3mm, quantity 500pieces, and cost 2000pounds) and attached it to fabric. However due to high refraction the images being produced were unclear. Additionally, for creating focal length of 3mm a 3mm acrylic sheet was used for the gap which caused negative effects on 3D image display as a direct consequence of unwanted refraction. Furthermore the number of grooves in the 3mm focal length Fresnel Lens were increased by 2 or 3 times more than the number of grooves in 15 and 22mm focal length Fresnel Lens which caused significant decrease in transparency. Therefore there are still some improvements and developments to be made to get closer to achieve 3D mutable 'living' textile. Although this technique has limitations of viewing angles and other minor problems, the fact that it can produce illusionary effects while expressing both the image and the colour at the same time, is the closest technique that I have found capable of accomplishing the original idea of my project. Lastly specialist support would be required for an improved resolution and quality product when increasing the range of viewing angles.

6. 3. 8. Critical analysis of the result in 3D Integral Imaging Experiment & Summary with particular reference to textile applications.

Important factors to consider in applying 3D Integral Imaging Technique using Fresnel lens array to textiles are firstly the Fresnel lens itself and secondly the flexibility and transparency of the spherical Micro-Convex Lens array. For textile application, A Fresnel lens that has a short focal length is required. The lens itself does not need to be a Fresnel lens. Any lens that contains the similar characteristics of the Fresnel lens could be used. A short focal length simply means the distance between the Fresnel lens and the sliced elemental background image is small. The distance depends on the focal length of a specific Fresnel lens. If such short focal lengths can be achieved there would be only a small gap between the image and the lens and we could then simply use a material that consists of the characteristics of Fresnel lens and attach it straight to a textile or laminate it to experience the 3D illusionary effects as a textile material.

Shorter focal lengths also mean individual Fresnel lens sizes need to be smaller. The smaller sizes of Fresnel lenses means individual elemental background images, working with the Fresnel lens, should also reduce further in size. Spherical Micro-Convex Lens array illustrated in Fig.26 could be an example of a very good example of a potential material. Although it was a material that I could not experiment with because of its high cost, if I could come across a similar but cheaper material with the same characteristics of short focal length I would be able to apply to textile for its advantages. Please refer to video clips of simulations in the Appendix VII.

In order to apply the spherical Micro-Convex Lens arrays to flexible textiles, the characteristics of the material must be flexible and transparent to experience the 3D illusionary image effect. Although holograms are advanced in 3D effects, they can be difficult to view under natural day light conditions, and this means natural colour cannot be expressed. Furthermore the production process is rather complicated and there are other technical problems that follow. In the lenticular technique, the effect can only be viewed from one direction, the use of non-flexible material and image sharpness being low are other problems that need to be tackled further. On the other hand 3D Integral Imaging technique has no restriction in viewing angle for experiencing 3D illusionary effect by the use of lens arrays. 3D effects are expressed in the space between the viewer and the lens and therefore the image resolution is far superior than other techniques. By applying such technique to textile and solving the problems mentioned above, the aim of my research project would be achieved.

6. 4. Further Experiment using 3D Integral Imaging Technique

3D Integral Imaging Technique uses Lens Arrays to form true three dimensional images. This became evident from the findings of the Fresnel Lens Array investigation described in Chapter 6. There are differences between Fresnel Lens and traditional glass convex lenses, particularly in their thickness, weight and price. Fresnel Lenses are thinner and lighter compared with traditional glass convex lenses and they are cheaper. Therefore I have chosen Fresnel Lenses for 3D Integral Technique experiments. Of course, the 3D Integral Imaging Technique with traditional glass convex lenses can also produce 3D effects, but because of financial reasons I could not experiment with this particular material. Therefore, in this chapter I would like to discuss experimental findings from materials that closely resemble the main characteristic of traditional glass convex lenses.

6. 4. 1. Detail of the Material

I have experimented with a product called Bumperstops, made from polyurethane material. They are being used as versatile protection stops to prevent noise and vibration and to provide non-slip protection to free standing desk and countertop items used in hospitals, workplaces, stores, and hotels or simply around the home.

Fig. 29 Bumperstops made from polyurethane material, which are being used as versatile protection stops to prevent noise and vibration and to provide non-slip protection

Among the many different types of Bumperstops, I have chosen a clear hemispherical shaped product that closely resembles traditional glass convex lenses, for 3D Integral Imaging Technology experiments.

6. 4. 2. Method of Experiments

The principle behind Bumperstops creating 3D effects is similar to the Fresnel Lens technique except that Bumperstops require accurate manual arrangements of each Bumperstop individually, which at prototype stage is a time consuming manual process. In order to arrange the Bumperstops accurately I first ran a graphics programme to print array patterns of the same size as the Bumperstops. Then I used this printout to accurately arrange Bumperstops individually with a tweezer on an overlaid transparent material (plastic acrylic sheet or transparent film).

Since Bumperstops are produced for versatile protection to prevent noise and vibration and to provide non-slip protection its use for other purposes, such as replicating traditional glass convex lens character, was expected to be quite limited. In particular, it was difficult to get the exact focal length, so the focal length had to be calculated by using light to focus images. Furthermore, individual Bumperstops had small differences in size and shape between them, which further affected the lens array, size and focal length.

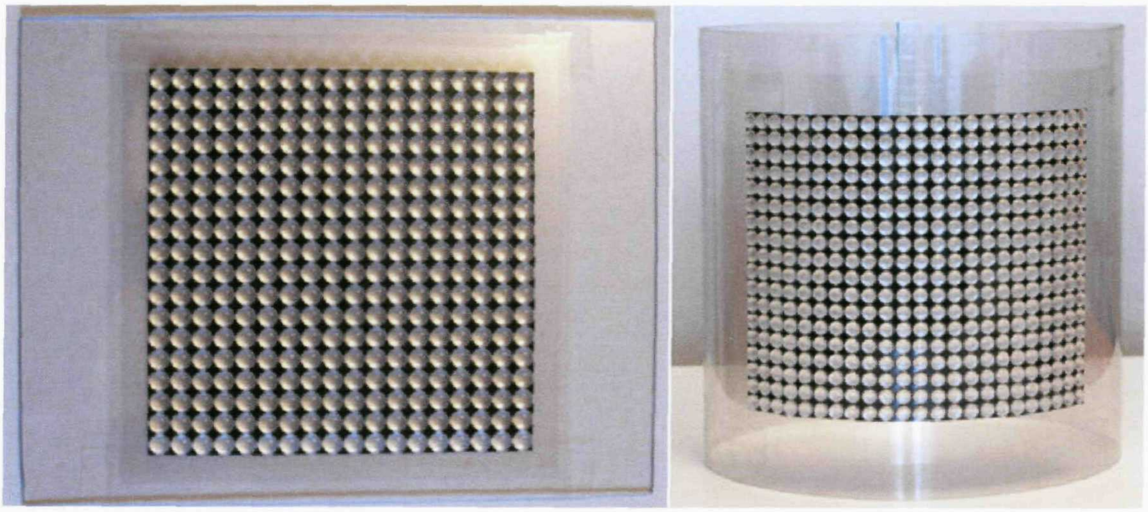


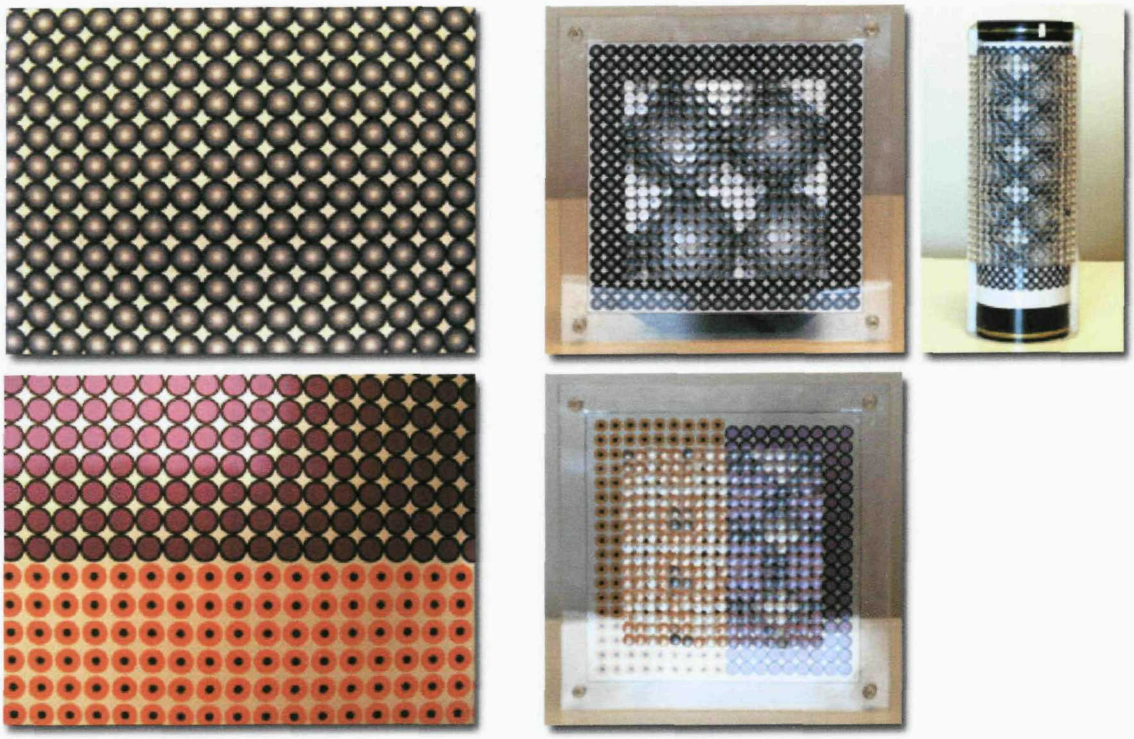
Fig. 30 Bumperstops lens array on acrylic sheet (left)
and transparent film cylindrical structure (right)

Table 3: Equipment Specifications for Bumperstops Array

Setup	Specification	Characteristics
Flat panel CRT display	Number of pixels	1280(H) / 1024(V)
	Pixel size	0.24mm
Bumperstops	Diameter	6.4mm, 8.0mm
	Height	1.9mm, 2.2mm
Bumperstops array	Number of elemental lenses	18(H) / 18(V)
	Pitch of the elemental lens	6.7mm, 8.3mm
	Focal length	7mm, 9mm

6. 4. 3 Practical Experiment

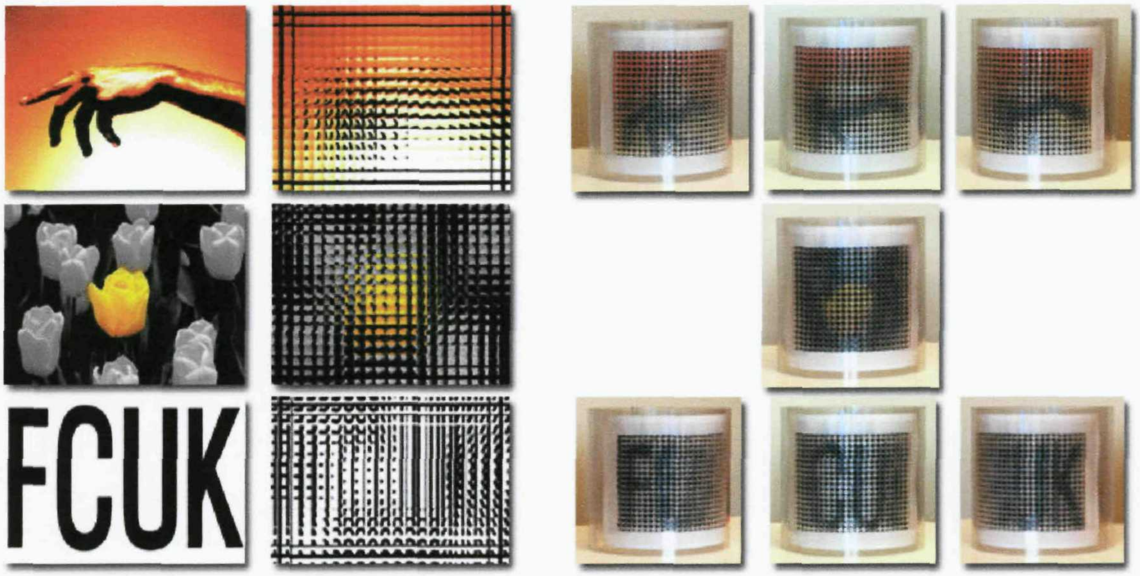
The experiment was focused on revealing the effects of the Bumperstops array using simple geometrics, text. And photographic images previously used in the Fresnel Lens experiments. These images were selected so that I could compare the effect of Bumperstops array easily with previous experiments and to overcome the accuracy limitations of Bumperstops array i.e. individual Bumperstops had small difference in sizes and shapes between them which further affected lens array, size, focal length etc. I also attempted to experiment with the effect of having a cylindrical structure rather than a flat surface to explore flexibility in 3D effects. The Imageman2 programme was also used to transfer original image into elemental images to fit the Bumperstops array.



a) Elemental image

b) 6.4mm Bumperstops array

Fig. 31 Practical experiment with 6.4mm Bumperstops lens array (focal length: 7mm)



a) Original image

b) Elemental image

c) Left, Front, Right

Fig. 32 Practical experiment with 8mm Bumperstops lens array (focal length: 9mm)

6. 4. 4. Critical analysis of Experiments

Bumperstops array was used in 3D Integral Technology experiments to replicate the effects produced by much more expensive traditional glass convex lenses. The experimental findings have demonstrated that 3D Integral Technology using Bumperstops array, which has similar characteristics of the convex lens material, can create 3D effects through its array. Also since Bumperstops allows flexibility in its arrangements, I have experimented with a cylindrical structure and explored its effect in creating 3D images. The cylindrical structure revealed that flexibility can express the illusion of 3D depth, appearance and disappearance of images.

However such findings from 3D Integral Image technology in Bumperstops lens array still have many limitations to accomplishing the original idea of my project. Firstly, each of the Bumperstops has irregularities in size and shape which affects the viewing of the final 3D image. Secondly, the hemispherical shape of Bumperstops array has empty spaces in between which creates overlapping of elemental image with the 3D image, giving a blurred appearance in the final 3D effect. In order to prevent the raw appearance of elemental image through the empty spaces in between hemispherical Bumperstops I coloured the gap in black (Fig. 30) but the fact that the whole space cannot be used affects the final 3D effect of the image. Thirdly, focal length cannot be calculated accurately which can also be related to irregularity in individual Bumperstops.

However if the Bumperstops array was replaced by traditional glass convex lenses the focal length issue could easily be solved as glass convex lenses are all made in the same shape and size with no irregularity whatsoever. Lastly, although transparent Bumperstops were used for this experiment, it was not totally transparent and this also may have affected the final results of the 3D image effect.

In conclusion, it was difficult to achieve satisfying 3D effects from Bumperstops lens array but the fact that it can produce illusionary effects to some extent demonstrated a way forward and provided a useful insight into this possibility. As mentioned before in 3D Integral Imaging Technology using Fresnel Lens, this 3D integral imaging technology is being actively experimented with widely and would be expected to transform 3D displaying technology in the near future. This kind of transformation can naturally transfer into 3D textiles and bring new aesthetic directions into environment. This new artificial or illusory environment, a space with endlessly emerging and re-emerging 3D images world, can soon be realised in the real world; making it difficult to distinguish the real from the artificial and also making it possible for both environments to co-exist harmoniously.

6. 5. Combining Lenticular & 3D Integral Imaging Technique using Fresnel Lens array

I have investigated various 3D technologies for textiles, which can be both real and illusive, interacting with light and different viewing angles, shifting and moving in time. Through case studies, comparative analysis and testing process I have found that Lenticular technique has the advantage of showing different images with different angles even though it has a few drawbacks, and also I have concluded that 3D Integral Imaging Technology holds a potential to direct a new textile development to have an impact on how we view the environment. In particular, 3D Integral Imaging Technology can create 3D images in a 3D space due to the lens array and the 3D display appearing much more natural than any other display techniques.

In this chapter, the following diagram and experimental work shows how I have combined Lenticular and 3D Integral Imaging Technology. This is the first time this combination has been applied to produce 3 dimensional illusory effects using Fresnel Lens array.

6. 5. 1. Method of Experiments

Through experiments I found that there are advantages in combining the Lenticular technique with the 3D Integral Imaging Technique using Fresnel Lens. The diagram shows the simple model used for this technique.

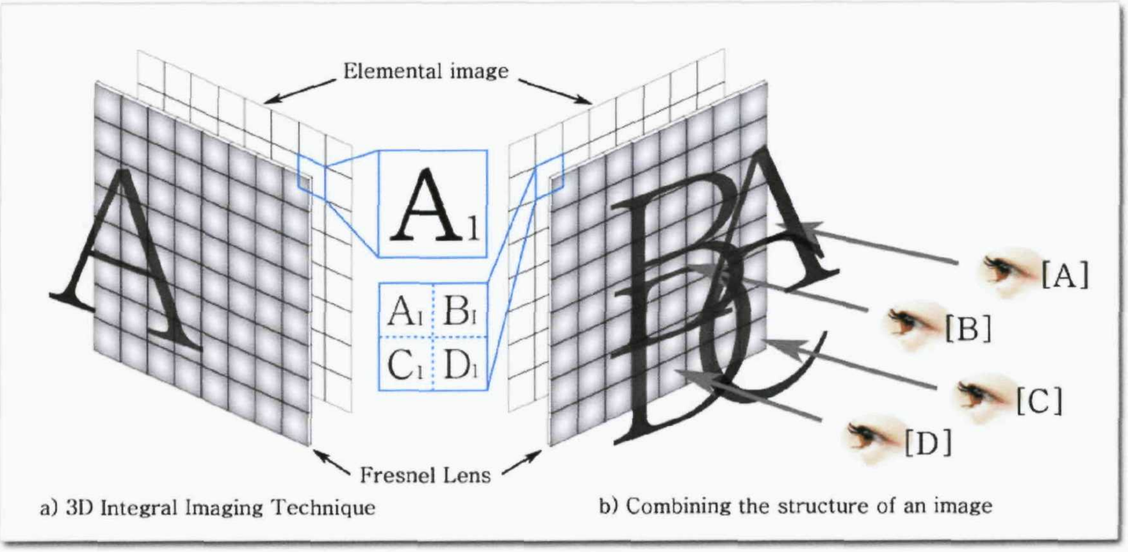
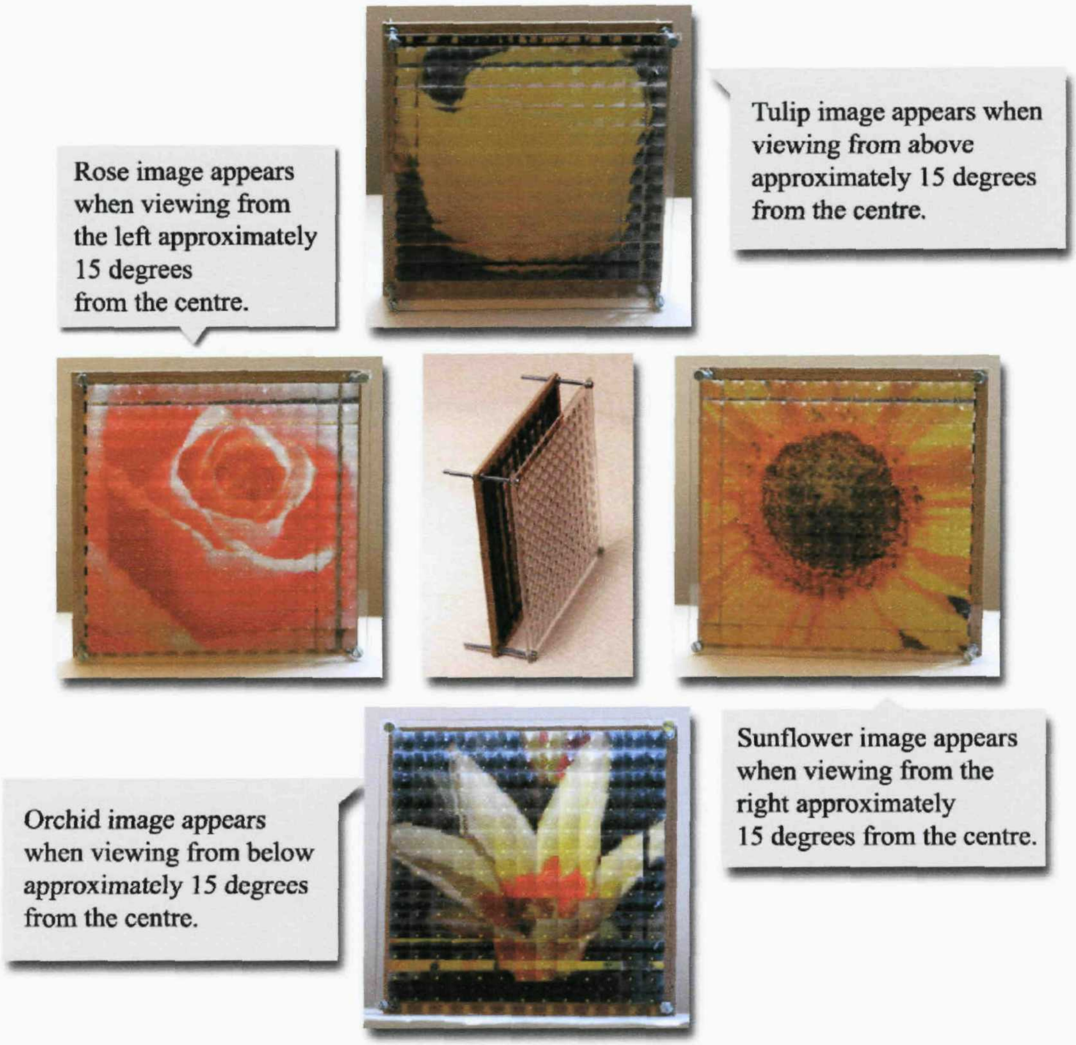


Fig. 33 Diagram showing the combining structure of

Lenticular & 3D Integral Imaging Technique

The advantages of the combination shown in the diagram above are that the elemental image can be divided according to the Lenticular technique. This allows different images to be seen through the interaction between the composition of the divided image and the Fresnal lens placed in front of the image. Normally the elemental image is composed of just one image, but in the case of the model developed through the research, the elemental image is composed of different images and this creates the possibility of seeing a number of different floating 3D images, depending on the viewing angle. In this way the new effect is created by combining the structure of an image normally associated with the Lenticular technique with 3D Integral Imaging Technique using Fresnel Lens array.

6. 5. 2. Practical Experiment



Tulip image appears when viewing from above approximately 15 degrees from the centre.

Rose image appears when viewing from the left approximately 15 degrees from the centre.

Sunflower image appears when viewing from the right approximately 15 degrees from the centre.

Orchid image appears when viewing from below approximately 15 degrees from the centre.

Fig. 34 Experimental work of Combining Lenticular & 3D Integral Imaging Technique using 22mm focal length Fresnel Lens

Dr. Yoonchan Jeong, a Reader from Optoelectronics Research Centre, University of Southampton University, has worked as a researcher in 3D Integral Imaging Technology and stated that he has never come across 3D Integral Imaging Technology combined with Lenticular Technique. He showed his interest in this newly created combined imaging technique. Figure 34 shows an example of the effect of combining the advantages of two technologies, Lenticular & 3D Integral Imaging technique using Fresnel Lens array. This combination of techniques allows the viewing of many different 3D images as the viewpoint changes.

6. 5. 3. Critical analysis of combining Lenticular & 3D Integral Imaging Technique using Fresnel Lens array

The advantages of combining Lenticular and 3D Integral Imaging Technique using Fresnel Lens array are that the Lenticular technique has an advantage of showing different images with different angles and 3D Integral Imaging Technique using Fresnel lens array has the ability to separate and rearrange elemental image through its lens which effectively creates 3D images appearing to float in mid air. In other words, the advantages of combing two techniques are firstly, the ability to overcome the initial limitation of one direction of 3D display in vertical or horizontal expression in Lenticular technique. The experimental works of combined two techniques allow the viewer to experience the floating 3D image in unlimited directions of viewing angles. Therefore there is the advantage of viewing angle covering a wider range than the Lenticular technique on its own. The second advantage of combining the techniques would be the ability to create floating 3D images while simultaneously allowing the viewer to see different images depending on their viewing angle.

I propose a technique that combines the advantages of Lenticular and 3D Integral Imaging technique that could express 3D mutable 'living' textile even closer than 3D Integral Imaging Technique alone. The experimental work of these combined techniques (Fig34) demonstrates a potential to achieve the original aim of my research project. Furthermore, as the focal length is short, the development of a flexible material for the Fresnel Lens that could be attached to fabric can be seen as the best method for achieving the textile research aim. In this respect, my research methods have answered the main research question by combining techniques of Lenticular and 3D Integral Imaging in which 3D illusory pattern and colour changes can be accomplished by changes in viewing angle with naked eyes. Also, as the focal length is short, the development of a flexible material for the Fresnel lens that could be bonded or laminated to fabric is possible. My conclusion is that this is the best method for achieving 3D mutable 'living' textile.

Finally as mentioned in the summary of the 3D Integral Imaging Technology there are still aspects of the technology and materials that need to be further developed in order to apply the technique industrially and commercially to flexible fabrics. To fulfil the original research aim, firstly, there needs to be further development in miniaturizing printing technology as this would allow for the combining technique to be applied to printed fabric with the level of accuracy of adjustments required for the technique to succeed. This is important because very precise adjustments to the printed image need to be made for the image to interact with the lens in such a way that the effect of a floating 3D photographic image is achieved. As described earlier, the proposed technique depends on technical factors being combined using high levels of resolution and for the best results the elemental image would need to be microsized. Hence, to advance the work with the microlens, miniaturizing printing qualities has to be improved, because the size of each elemental image is almost a pixel size.

Secondly, to achieve 3D illusory photographic effects onto fabric, high refractive thin transparent film materials which do not disturb their transparency need to be developed. When I experimented with 3mm short focal length Fresnel lens, each lens has 2 or 3 times more grooves than the number of grooves of 15 and 22 mm focal length Fresnel lens, which result in decreasing the transparency significantly.

This combining technique can be applied within the fields of interior and fashion textiles and architecture with imaginative 3D visual sensations, also advertisements for the marketing field and applications to 3D TV systems or 3D animation for display device are possible.

7. Other Case Studies

7. 1. Anaglyph

Anaglyph was one of the first historical methods used for 3D stereoscopic visualization and it is still popular, because it is easy to make an anaglyph visualization setup. The main character of this technology is the complete loss of colour information. Anaglyph is a technical name for the familiar red/blue or green pictures viewed with red/blue or green glasses. The brain combines the different shades of coloured images for eyes to see completely different colour interpretations of the scene in three dimension.

7. 1. 1. History of Anaglyph Technique

Anaglyph was implemented after the invention of stereography and it has long been a highly recognizable tool for 3-dimensional imaging techniques. When stereoscopic views became tremendously popular in the 1850s, different investigators sought alternative means of displaying the stereo image.[80] Helmholtz, in his Treatise on Physiological Optics, cites the work of Rollman, who in 1853 illustrated the principle of the anaglyph using blue and red lines on a black field with red and blue glasses to perceive the effect. By 1858, Joseph D'Almeida began projecting three-dimensional

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[80] http://en.wikipedia.org/wiki/Anaglyph_image

magic lantern slide shows using red and blue filters with the audience wearing red and blue goggles.[81]

7. 1. 2. Imaging Technique of Anaglyph

Fig. 35 Colour anaglyph taken using two cameras
about 40cm (16in) apart for enhanced depth effect.

Anaglyph stereoscopic system is disclosed wherein left and right images are encoded as complementary colour fringes in the defocus regions such that the image, when viewed through appropriately filtered glasses, is perceived as a three-dimensional coloured image but, when viewed without glasses, appears essentially as a normal two-dimensional coloured image. In order to enhance the three-dimensional effect and the compatibility of the two-dimensional image, a special iris is employed for controlling the amount of light passing through the taking lenses of the imaging system. Essentially,

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[81] http://www.3dwebsite.de/en/html/tanaglyphen.html

the iris restricts the amount of light in the vertical direction only, thereby retaining full left-right separation as the amount of light passing through the filter is restricted by the iris. The taking filters of the imaging system are selected so that after normal processing, the image colorimetric is not disturbed.[82] This requires that the spectral characteristics of the photoreceptors maintain the same ratios with the filters as without. The glasses through which the three-dimensional image is viewed, includes complementary colour filtering means for the left and right lenses of approximately balanced luminosity characteristics. Viewer comfort is materially enhanced without substantial degradation of the stereoscopic image by providing for a limited amount of cross-talk between the respective lenses.

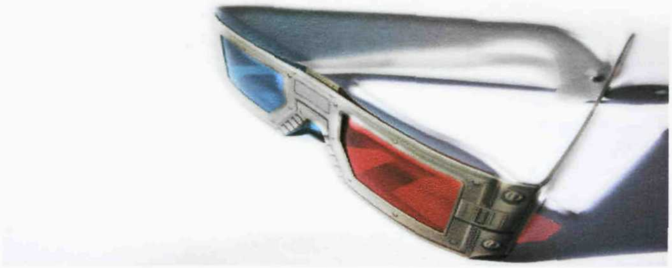

Fig. 36 Anaglyph Glasses used for viewing 3-D images

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[82] Calculating Stereo Pairs
http://local.wasp.uwa.edu.au/~pbourke/projection/stereorender/index.html

7. 1. 3. Viewing Anaglyph

"A pair of eyeglasses with two filters of the same colours used on the camera (or simulated by image processing software manipulations) is worn by the viewer. In the case above the red lens over the left eye allows only the cyan part of the anaglyph image through to that eye, while the cyan (blue/green) lens over the right eye allows only the red part of the image through to that eye."[83] Portions of the image that are red will appear dark through the cyan filter, while cyan portions will appear dark through the red filter. Each eye therefore sees only the perspective it is supposed to see.

7. 1. 4. Future of Anaglyph

Anaglyph is an inherently monochromatic, or black-and-white system, however stereographic artists are increasingly using a fuller palette of colour in the creation of this unique form of 3-D image. The polychromatic or full colour anaglyph has had a relatively limited use up to the present day, but one may now typically use an image processing computer programme to simulate the effect of using colour filters, using as a source image a pair of either colour or monochrome images. In recent years popular professional programmes such as Adobe Photoshop provide the basic digital tools for processing of anaglyphs and this computer technology with professional skills has made

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[83] http://en.wikipedia.org/wiki/Anaglyph_image

it practical to convert still images, movies and videos to 3D, which promises to increase its application in a variety of media.

7. 1. 5. Summary of Anaglyph Technique

In the past, anaglyph was a purely photographic process, but now, computer image processing techniques are used to compose the images. Two discreet views are combined in two layers in the digital image. These views incorporate parallax of the slightly different viewpoints into an integrated stereo image.[84] The composited stereo image must then be viewed with "anaglyph glasses", which use colour filters to create a discreet luminance separation of the views, providing a slightly different perspective to each eye. The visual cortex of the brain fuses this into stereo perception of a three dimensional scene or composition

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[84] www.anaglyph.co.uk

7. 2. Optical Camouflage with a "Transparent" Coat

Optical Camouflage, as the name implies is an example of active camouflage using techniques of "Retro-reflective Projection Technology (RPT)/X'tal vision"[85] The principle of Optical Camouflage is to create a virtually transparent illusion by projecting a background image of the scene on to the masked subject, thus forcing the viewer to feel as if he or she can "see through" the subject. The idea of optical camouflage is not completely new as it has appeared in many fictional works from the classical "Invisible Man" by HG. Wells to recent Harry Potter series where an invisibility cloak is described. Outside of fiction, such concepts existed only as a theory but in recent years it has been demonstrated to be technically feasible to a certain extent by professors at University of Tokyo in 2003.[86] Masahiko Inami created a prototypical camouflage system in which a video camera records the real-life background scenery behind the subject, transmits that image to a front-mounted projector, which then displays the scene on the reflective

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[85] N. Kawakami, M. Inami, D. Sekiguchi, Y. Yanagida, T. Maeda and S. Tachi, "Object-Orientated Displays; A New Type of Display Systems – From immersive display to Object-Oriented Displays-", IEEE International Conference on Systems, Man, and Cybernetics '99 Abstracts, p.493, 1999

[86] Susumu Tachi, Masahiko Inami and Naoki Kawakami, Optical Camouflage Using Retro-reflective Projection Technology, IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR' 03), IEEE Computer Society 2003

material.[87]

7. 2. 1 Principles of Retro-Reflective Projection Technology

Optical Camouflage uses Retro-reflective Projection Technology. When using a See Through Head Mounted Display (STHMD) to merge virtual and real environments, the operator may see the image of a virtual object that is actually located behind a real object. This contradicts the intuition of depth as the projected image of an object in one's field of view will be obstructed at least partially. This depth cue which is known as occlusion is critical for the effectiveness of the presentation of virtual objects in three dimensions.[88] The development of Retro-reflective Projection Technology has solved the occlusion contradiction problem. There are three key techniques of Retro-reflective Projection Technology as follows:

1. To use an object covered by retro-reflective material as a screen
2. To place a projector into a position optically conjugated with the observer's eye by using a half mirror
3. To make the projector's iris as small as possible by using a pinhole.

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[87] "Scientist show off 'invisible coat'", The Sydney Morning Herald, March 30, 2003

[88] Susumu Tachi, Masahiko Inami and Naoki Kawakami, Optical Camouflage Using Retro-reflective Projection Technology, IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR' 03), IEEE Computer Society 2003

7. 2. 2. Optical Camouflage

Optical Camouflage is developed simply by a projector projecting background image onto the masked object. The object that is transformed into being transparent needs to be painted or covered with retro-reflective material. The principle behind this technique is quite simple. A background image is taken by a camera behind the masked object. The image to be projected is composed by computer using an image-based rendering method to create the image that should be seen from the viewpoint of the user.

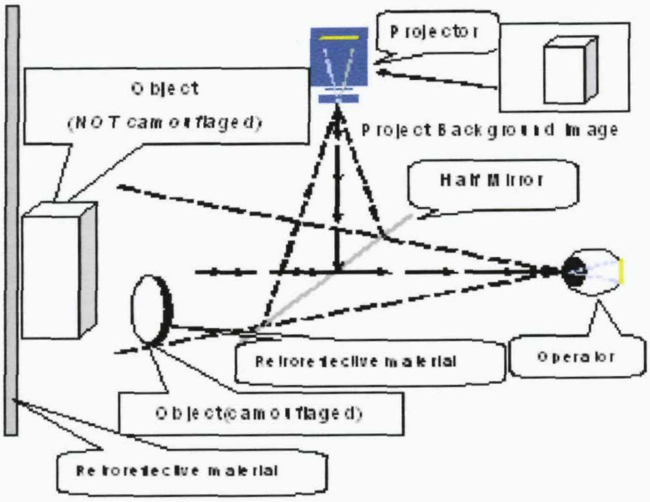

Fig.37 Optical Camouflage Configuration

7. 2. 3. Summary of Optical Camouflage

An optical Camouflage system has now been developed and is technically feasible to a certain extent. The potential use of Optical Camouflage technique includes use on surgical gloves or equipment so that they don't block surgeon's view during major delicate operations. Furthermore with flexible electronics available such as a flexible liquid crystal display, display of background image by the material itself may become possible in the near future and this form of optical camouflage which closely resembles its fictional counterparts. It may seem optimistic, but the use of optical camouflage, such as transparent cloak introduced in the Harry Potter series and the Predator film or the transparent car from the recent James Bond movie may not be so far away with further development in Optical Camouflage technique.

8. Final Conclusion and Plans for Future Research

The new technologies in textiles are making it possible to create specific materials for a variety of technical, decorative and contemporary art solutions. In this context, my particular interest is in emerging imaging technologies because of the ways in which interactions between natural and artificial worlds can be explored and redefined as a homogeneous world. The rapid development extending from the period since digital technologies became more accessible allows designers to transform traditional textile materials into fluid forms that merge with media normally associated with film and animation.

In order to look into the future of textiles in the context of the research, it has been important to consider how technologies might continue to evolve. The development of technical textiles is already bringing greater sophistication to this field and this is likely to result in future textiles being more suited to resolving some of the technical issues I have found in my research. In particular the possibility of increasing the lightness and fineness or miniaturisation of complex materials will make a significant difference to the practical application of the outcomes of my research. In this technical context, I have found it necessary to collaborate with scientists who have been able to show me what is possible and what the limitations of the project currently are.

As technology continues to develop it is clear that this collaboration and sharing of specialist know-how will be increasingly important in the design and science fields.

In this study, the key question I have explored is how close textiles can express imaginative visual sensations demonstrated by the examples of the science fiction films I have referred to. The research has questioned how we can generate environments capable of fusing nature with built environments through textiles, and how this be proven theoretically and technically within the scope of contemporary textile technologies. Specifically the aim of the project was to explore the potential application of the illusions created by various 3D imaging techniques and to develop textiles to create new environments where reality and fiction are fused. As described earlier, my objective was to produce intriguing textile patterns and images in which the objects and colours change as viewpoints change like 3D mutable 'living' textile. Therefore current techniques in Holography, Lenticular and 3D Integral Imaging have been thoroughly investigated through literature searches and practical experiments as these techniques have an advantage of displaying 3D images with naked eyes. Out of three techniques I have found that the 3D Integral Imaging technique using Fresnel lens was the closest technique that I have found capable of accomplishing the aim of my project. The technique can produce illusionary effects while expressing both the image and the colour at the same time. In contrast, Holography and Lenticular technologies have many aspects that still need to be developed further, in order to achieve the aim of my research project. Holographic images can only be made life size with monochromatic effect which appears only in a single colour and therefore its use is very limited. Currently the biggest problem facing holography is the difficulty in recording natural colour of an object and also recording landscape images. In Lenticular technique the disadvantage was the fact that this technique only allows one direction of 3D display in vertical or horizontal direction. Although this particular technique allows animation and 3D effect it relies on non-flexible materials. I have investigated various 3D technologies for textiles, which can be both real and illusive, interacting with light and different viewing angles, shifting and moving in time. Through the investigation and experiments concerned with 3D expression and technologies, I have concluded that 3D Integral Imaging Technology holds a potential to direct a new textile development to have an impact on how we view the environment. 3D Integral Imaging is promising as it is not restricted to only one direction of 3D display which is the disadvantage of the Lenticular display technique, but has unlimited directions of viewing angles by the use of lens arrays. In particular, 3D Integral Imaging can create 3D images in a 3D space due to the lens array and the 3D display appearing much more natural than any other display techniques. This is because it also displays natural colour unlike holography. Also since the viewing angle covers a wide range, a number of people can experience the 3D display at the same time. Additionally I propose a technique that combines the advantages of Lenticular and 3D Integral Imaging technique that could express 3D mutable 'living' textile even closer than Integral Imaging Technique alone.

The advantages of the combination shown in the diagram (Fig.33) are that the elemental image can be divided according to the Lenticular technique. This allows different 3D illusory images to be seen depending on the viewing angle through the interaction between the composition of the divided image and the Fresnel lens placed in front of the image. In this way the new effect is created by combining the structure of an image normally associated with the Lenticular technique with 3D Integral Imaging Technique using Fresnel Lens array.

The experimental work of these combined techniques (Fig34) demonstrates a potential to achieve the original aim of my research project. Furthermore as the focal length is short, the development of a flexible material for the Fresnel lens that could be attached to fabric can be seen as the best method for achieving 3D mutable 'living' textile. As mentioned in the summary of the 3D Integral Imaging Technology there are still aspects of the technology and materials that need to be further developed in order to apply the technique industrially and commercially to flexible fabric.

Fig.38 Experimental fabric samples from JAKOB SCHLAEPFER[89]

Video clip 2 from AppendixⅦ shows an experiment with a material that resembles the characteristics of Spherical Micro-Convex Lens array in fig. 26.

The particular configuration of the image in video clip 2 uses matte paper to print the experiment, but sample fabrics (Milva, Lardo, Hayden, Ixo) in fig. 38 were printed by JAKOB SCHLAEPFER (Switzerland, Textile manufacturer) using different lightweight

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[89] http://www.jakob-schlaepfer.ch/2007/index.html, Switzerland. Producer of innovative textiles.

textile substrates which are suitable for fashion applications.

The experiment (video clip 2) on spherical Microlens array material applied to each fabric sample has revealed that the print sample on fabric Lardo (100% polyester) was the most effective way of creating 3D effects. Fabric Milva (100% polyester) was also a good material for 3D effect but less effective than Lardo. On the other hand the fabric sample Hayden (100% polyester) which has transparent features, showed limited 3D effects. How precisely the elemental background image is printed on the fabric is very important in determining its 3D effect. The 3D effect is created by the pixels of the image interacting with individual Microlens. Therefore in order to create a 3D effect on textiles using Spherical Microlens array, the fabric structure and the quality of print are important factors to consider and determine.

Fabric sample Ixo (90% polyester, 10% metal) has a characteristic of maintaining creases. When Spherical Microlens array is applied to the fabric, the creased parts which create a relief surface, give the optical effect where the Microlens array comes into contact with the fabric. The inner regions of the fabric which do not come into contact with the Microlens array do not create the optical effect. This demonstrates how fabric manipulation can be used as another method of creating optical effects.

The interaction between the fabric samples and Spherical Microlens array shows how fabrics could be developed through the combination of these fabrics and the lens array technique. Also, the sample suggests the development of attaching sequins, composed as a lens, to the materials. This could allow for different distances to be created between the lens and the fabric and therefore the optical effects described above. Based on the methods developed through the research it is possible to recognize the potential for variety of different optical and three dimensional pattern techniques to be achieved as textiles. Commercial applications are clearly demonstrated by the initial prototype fabric examples. At the same time, it is recognized that there would be a need for further development in terms of practical solutions for controlling the focal lengths and the aspects of touch that could add variety to the optical effects possible.

In this respect, placing Microlens array on a fabric composed of an image with a particular configuration shows how different pressures applied by touch can create different optical effects. Fabric sample Ixo is a good example of this. This optical effect is dependant on the different pressures, quality of different print fabrics, scale of each Microlens and the elemental image. To apply those different effects, it would be necessary to collaborate with company such as JAKOB SCHLAEPFER to develop techniques which are suitable to achieving the combination of technical factors that would enable the prototypes to be realised as commercial products.

However my research methods have answered the main research question by combining techniques of Lenticular and 3D Integral Imaging in which 3D illusory pattern and colour changes can be accomplished by changes in viewing angle with naked eyes. 3D Integral Imaging technique has a high potential to expand its application for areas such as advertising, games, television in the near future. As technology develops, thinner and more flexible materials will be available and they can be combined with fabric. Such combinations can open 3D Integral Imaging Technology for a wider use in the future.

Lastly, I would like to return to talk about my work and how it has been inspired by those sophisticated 3D technologies that I have experimented with before. The most interesting aspect of the images produced by 3D technology is that images can be distorted, blurred or clearly seen depending on the audience's viewing angle. This can be a reflection of how our memories are sometimes clear or blurred depending on the subject we try to remember. These distorted, blurred or clear images can express how memories that we cherish are repeatedly being made and forgotten or lost. But the main point of my expression is that even the memories that seem so blurred can be recreated to appear so clearly as if you can see them with your own eyes.

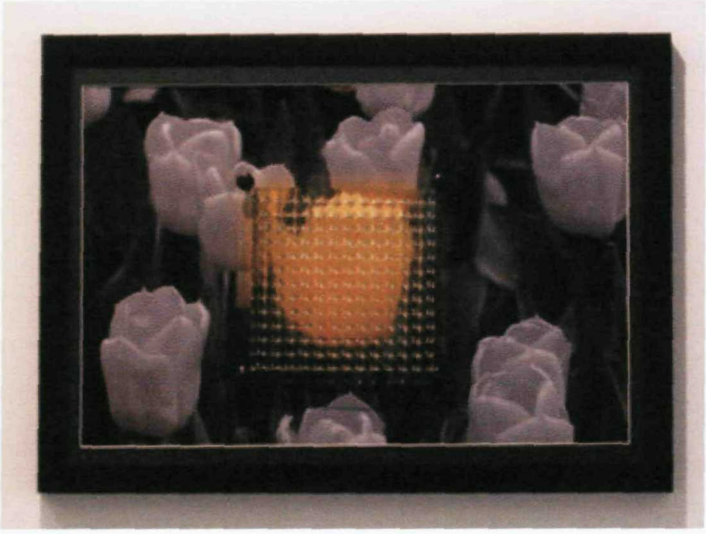

Fig. 39 Artwork using 3D integral imaging technique with
15mm focal length Fresnel Lens

As you walk through my images, you will be able to see that they all have something in common. Most illusionary images are of something in nature such as human and flowers, these images were carefully chosen so that they do not contain any artificial identity. Each image implies a message that humans need to live in harmony with nature because I believe this harmony is one thing that should remain unchanged no matter how the world around us develops and changes. What did I want to achieve through the application of 3D techniques into textile? Honestly speaking, if all of the techniques including the ones only existing in science fiction movies are possible the areas there can be applied are endless, far beyond our imagination. What I really want to express through the 3D technologies is how to fill my work with the fantasies I can only dream of. This includes the things I love and the moment I want to remember and cherish. Some people might say you can do all the same things with existing widely used photography and video recordings techniques. However, the advantage of 3D technologies is the ability to create a sense of existence of something that is nonexistent.

A precious memory, that can no longer exist in reality but cannot be forgotten, is something we all like to hold onto as a human nature and desire so we can experience the emotion we had before. Every moment of space and time in memories that we treasure can become existent like the floating memory display image as shown in Minority Report movie when Tom Cruise remembers his wife and child. I believe the experience of 3D technologies which brings a new sense of space and reality will become a new form of expression for the people living in reality. The investigation into 3D technologies in my work will continue to express the moments I want to remember, the flowers that I love, the beautiful scenery, and the people.

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Appendices

Appendix Ⅰ: Glossary of Terms

HOLOGRAM

Channels- These are images in a hologram which change abruptly from one to another as the viewer passes by. They can also fade or overlap as they change. Animated holograms are essentially made up of hundreds of image channels.

Computer generated hologram- A hologram made from a 3-D computer model.

Cylindrical- Transmission holograms produced with the film curved into the form of a cylinder, so that the image is seen in the center from a full 360° field of view.

Depth of image- The distance from the front to the back of the hologram image, which is focused in space by the hologram film. There are several ways to measure image depth precisely, using various types of rangefinders. Image depth is not limited by the lateral dimensions of the hologram film.

Diffraction- This is the process that makes holograms work, and refers to the bending of light as it passes through very small openings. Diffraction "patterns" use light wave interference to intricately control the intensity distribution of the light transmitted, so that 3-D, animated images can be formed. This is different from refraction, which is the bending of light when it passes from one medium to another, like air to glass.

Efficiency- In holography, this refers to the brightness of an image. It is the ratio of diffracted to incident light intensity.

Embossed holograms- Holograms stamped on foil in large numbers, from a transmission hologram original, and often used for credit cards and packaging.

Emulsion- This term is used for the light sensitive surface of photographic and holographic films, although an actual chemical emulsion is sometimes not used.

Flash images- Images that appear and disappear suddenly as the viewer walks past a hologram.

Full color- Coloring of an image to represent the natural subject colors as closely as possible, as in color photography.

Grating- A pattern of light and dark lines which will diffract light. A simple linear grating will disperse white light into a spectrum of colors. Holographic gratings can produce many spectra, focused to different distances. An image hologram is essentially an extremely complex grating.

Halogen lamps- The mr-16 type halogen lamp is usually the preferred light source for holograms. This small bulb is common and inexpensive, but requires the standard 12 volt dc housing. An excellent alternative is the PAR 16 lamp, which operates on ordinary line voltage.

HOE's- Holographic Optical Elements are holograms produced to perform the function of traditional optics, such as mirrors and lenses.

Hologram- 3-D image recorded on film, and recreated by the process of diffraction.

Holograph- From Webster's "A manuscript in the handwriting of the author."

Holographic- Pertaining to a hologram (not a holograph), such as "holographic art".

Lamination- In holography, this is the permanent application of the hologram film to a rigid substrate like glass or acrylic sheet. This is usually done to keep the film flat during display, and also to protect the emulsion

Laser- Source of coherent light, produced by the quantum process of stimulated emission. Coherent light has the purity and organization required to record diffraction patterns, and therefore holograms.

Laser transmission holograms- The original type of hologram, viewable only with laser light. These images are startlingly realistic, but not practical for public display, due to the need for a laser.

Lenticular photograph- A series of photographs, cut into strips, combined into a single print and viewed through a plastic overlay lens sheet to produce a 3-D effect. These non-holograms offer good color and replication, but the 3-D and resolution are very limited.

Lighting angle- The vertical angle, usually around 45°, at which light must strike the hologram to produce the brightest image. Approximately equal to the reference beam angle when the hologram is made.

Master hologram- The first hologram in a 2-step process, usually viewable only by laser light, and often combined with other masters for the final hologram transfer.

Mercury vapor lamp- Short arc mercury vapor lamps make a good light source for laser illuminated holograms. Images are brighter and more evenly lit than with a laser. But cost and maintenance still often make this type of hologram impractical for public display.

Mirror mounted hologram- A transmission hologram placed directly in front of an ordinary mirror, so that it can be lit from the front instead of the rear. This is often convenient where there is limited space. The image appears the same, although there is usually a slight loss in contrast.

Multiplex- The simultaneous recording or transmission of multiple data. Cylindrical holograms are often called "multiplex," although this is not always technically the case.

Object beam- One of the two parts of a laser beam used to produce the wave interference pattern to be recorded into a hologram. This part carries the information about the subject, and is equivalent to the signal wave in radio communications. The pattern is formed by mixing this beam with the reference beam.

Parallax- The difference in appearance in an object when seen from different perspectives. The parallax between left and right eye views produces 3-D perception. Holograms are unique in providing a wide, continuous range of parallax on the image.

Photopolymer holograms- Replicated in large numbers on photopolymer emulsions from a reflection hologram original, and often used for gift items, tickets and packaging.

Polarization- The orientation of the electric and magnetic vectors in a light wave. Many lasers produced linearly polarized light, which is important to their suitability for holography.

Projection holograms- There are much confusion over this term. Any imagery focused in front of the hologram film is usually referred to as "projected". Cylindrical holograms can also produce images behind the film which can be seen from a full 360 degrees of view. But complicated and cumbersome holographic "projectors", as imagined in science fiction movies, do not exist.

Pseudoscopic perspective- The appearance of a scene with the depth relationship of objects reversed. This can be accomplished by viewing a hologram from the reverse side or by certain mechanisms that can switch the left and right eye perspectives.

Rainbow hologram- Nickname for white light transmission type hologram, deriving from the spectral image colors.

Real images- As opposed to virtual images, these are made up of actual, focused light. These can be seen on a projection screen placed at the image location, or exposed onto film. In holography, this is the imagery in front of the film plane.

Reference beam- One of the two parts of a laser beam used to produce the wave interference pattern to be recorded into a hologram. It is the equivalent of the carrier wave in radio communications. The pattern is formed by mixing this beam with the object beam.

Reference angle- The angle at which the reference beam strikes the hologram film. It is usually close to 45 degrees, and equates roughly to the illumination angle when the hologram is displayed.

Reflection hologram (white light) - Designed to be lit from the front, these holograms have fixed color, parallax in both vertical and horizontal directions, but limited size and brightness.

Silver halide holograms- Any hologram made on a silver halide based emulsion, similar to standard photographic film. Emulsions can be coated onto film or glass, but must be extremely fine grain.

Stereogram- Hologram produced from movie footage of a rotating subject. Images can be computer generated, animated, reduced or enlarged, or photographed on site. This is an alternative to the original hologram process, in which the subject is imaged directly onto the film with a laser exposure.

Stereogram printer- Hologram camera specifically designed to produce a hologram master from a series of photographic images, showing the subject rotating from one to the next. Every printer is designed and built for the particular needs of the lab, and is usually computer automated to perform several hundred step-and-repeat exposures, "building" the master hologram from left to right.

Stereo pair- The perspectives required for the left and right eye in order to see an image in 3-D. Stereoscopic cameras provide one pair, for 3-D viewing from one angle only. Lenticular photographs provide several, so the image can appear to rotate slightly. Holograms provide a wide continuum of stereo pairs, for truly 3-D imagery.

Transmission hologram (white light) - Also called rainbow holograms, these are designed to be lit from the rear, but can also be mirror-mounted and lit from the front. Images are spectral colored, very bright, and in sizes up to 1.1x1.8 meter.

Transfer hologram- The final hologram, viewable with ordinary "white" light, and made from the images focused by one or more masters. Many transfers can be made from the same set of masters, and masters can be archived for later use.

Vibration isolation- This refers to the stability of the optical system that is required when a hologram is recorded. No vibration isolation is needed when the hologram is displayed.

Viewing angle- This is the area from which a holographic image can be seen. Anyone standing too far from center may not see the image.

Viewing distance- The ideal distance for viewing a transmission hologram. Although the hologram can seen from any distance, here the colors will be constant from top to bottom. Viewing distance can be tuned to suit the display situation.

Virtual images- As opposed to real images, these are not made up of actual, focused light. Light paths coming from an optical element, such as a hologram, trace back to these positions, so that an image appears to be at that location. These images will not show up on a screen placed at the image position. In holograms, these are all images focused behind the film.

Wavelength- The length of one cycle of a wave. In visible light, the wavelength determines the color. On a broader scale, it defines the different types of radiation, such as gamma and x-rays, ultraviolet, microwave and radio waves.

LENTICULAR

Action Proof- A proof created on an imaging device (inkjet printer) during the concept stage of the lenticular project. This proof may not be color accurate or created to the target resolution of the printers proofer or platter, but is a cost effective way of fine-tuning the interlacing and planned effect prior to creating costly hi-res printer proofs. (These proofs should be viewed only for effect or action and not for color accuracy.)

Alignment- The adjustment of a print so that the image stripes are parallel to the lenticule

Alignment Bar / Image- A tool used on the press form that helps the press operator square the sheet to the print. The lines in the image run in the same direction as the lens. (This tool works much like a carpenters level.) The image should be CMYK and will also aid with obtaining color registration. This alignment bar / image / tool is NOT interlaced at the same pitch as the lens.

Animation- The use of multiple frames of sequential images put together to give the illusion of fluid *movement—much like a short video clip.*

Animation- Lenticular effects with a series of images coming together to create an animation much like a short movie clip, this is the most complex lenticular effect. The illusion of motion actually comes from either a selection of video frames or sequential still images. This lenticular animation effect is great for emphasizing body movement or mechanical action.

Banding / Linear Banding- An unwanted pattern in the planned effect that runs in the direction of the lens. Depending on the effect, this pattern is static while the effect is taking place. This is primarily due to to a resolution mismatch between the interlaced image and the imaging device.

Binocular / Binocular Disparity- Seeing with two eyes. This allows humans to see the world in 3D depth.

Checkerboard Banding- An unwanted visible pattern that runs both vertically and horizontally. It is similar to linear banding but is caused by a resolution mismatch and the imaging device itself.

Color Leakage- An unwanted or poor registration between colors. When colors are not in correct registration alignment, one or more colors can appear to be out of time or become visible before the other(s) as the effect takes place.

Direct-to-lens- The use of any printing process that prints directly onto the flat surface of the lenticular lens material. This is most common in offset printing.

DPI- Dots-per-Inch.

Filler Space- In an interlaced print, a technique that utilizes a neutral stripe of printed information to separate multiple frames of images from each other in order to minimize "ghosting."

Flip- A lenticular effect that, in its simplest form, contains two images and shows them one at a time to the viewer as his viewing angle to the lens sheets changes. Images can have more than one flip effect.

Gauge- The thickness of a sheet of lens.

Ghosting- Seeing two or more images at the same time from a single viewpoint in a lenticular image. This is caused by several problems including poor registration or a pitch mismatch, images with too much contrast, the use of too many images/frames, and/or exceeding the resolution capabilities of your output device in conjunction with a particular lens sheet.

Interlacing- The process of striping and arranging printed information to a given pitch to match a lenticular lens.

Keyplane- In a 3D image, the plane that appears to be most in focus with other planes appearing to be in front and/or behind it.

Kissprint- The use of just enough impression to allow ink to transfer from the blanket to the substrate. Too little impression will cause the image to appear to be cloudy or have breaks. Too much impression will cause dot gain and/or the lenticular sheet to stretch or be squeezed and augment.

Lamination- The process of adhering a preprinted media to the lens sheet. It is commonly used to apply both photographically imaged and digitally outputted images to the lens sheets.

Lens Count- The number of lenticules-per-inch (LPI.)

Lens Sheet- A sheet of transparent plastic material that has been extruded, cast, or embossed with an array of identical parallel lenses.

Lenticular- Lenticular is a specialized printing process that allows depth, motion, or a little of each to be shown in a flat sheet of plastic. The effect is created using lenticules in the plastic sheet that serves as a decoder for the image that is printed behind it.

Lenticule(s)- A single (or multiple) lens in a lenticular sheet.

LPI- Lines-per-Inch. In the lenticular process, this would also mean "Lenticules-per-Inch."

Mechanical Pitch- The exact, and true, physical pitch of a lens. (Although a lens manufacturer may label their lens to be a 75 lpi, the true mechanical pitch will not be exactly 75 lpi. This is due largely to the fact that there are slight variances that take place during the extrusion or manufacturing of a lens.)

Morph - A lenticular effect that begins with one image which is then transformed in stages to a second, perhaps unrelated, image.

Motion- A lenticular effect that utilizes selected highlights of frames from animated illustrations, video, or film originals. The frames are displayed to the viewer one sequence at a time. The viewer is given an impression of movement from one frame to the next.

Narrow-angle Lens- A lenticular lens sheet with a viewing angle between 15-35 degrees. Narrow-angle lenses work best for 3D effects.

Parallax / Parallax Shift - In a 3D image, the phenomenon where objects in a scene seem to shift relative to one another as the angle of view is changed. Objects closer, or in front of the keyplane, will be opposite objects behind the keyplane.

Phasing Registration- The placement of the interlaced image to the lens. Phasing registration affects the angle by which the first frame of the interlaced image may be viewed. Due to many variables in the printing process, phasing registration may vary from piece to piece.

Pitchtest / Pitchtest Form- A series of graduated bars with an ascending LPI value that is used to determine the visual pitch of a lenticular lens sheet. This is generally used during proofing, platting, and on press. It is not uncommon for a lens to have a different visual pitch between the proofing device and the printing press.

PPI- Pixels-per-Inch.

Press Registration- The alignment of colors to perfect fit.

Press Pitch-The act of matching the printing press' output (or fingerprint) to the lens' pitch by performing a pitchtest on the same press that will run the actual product. This test will help determine the visual pitch number (or LPI) that will be used when interlacing the file that will go to press.

Printer's Proof- The proof that is generated by the printing company. These proofs are color calibrated to the printers system and presses.

Proofing Registration- The alignment of the interlaced proof to the lens.

Proofing Pitch- The act of matching the proofing device's output to the lens' pitch by performing a pitchtest. This test will help to find the pitch number (or LPI) that will be used to interlace the proofing file

Radius- The degree of curvature of the lens.

Refractive Index - The extent to which a lens focuses incoming light.

Registration- Alignment and/or placement.

Resolution- The sharpness of an image on film, paper, computer screen, disc, tape, or other medium. In regards to DPI and Printing: The higher the resolution of your printer or image setter, the greater detail you can print and the better appearance of your output

Screen Angle- The angle(s) at which the halftone screens are placed with relation to one another in order to avoid an undesirable moiré pattern.

Stripe- A computer "slice" of artwork represented by a row or column of pixels.

Sweeping- The unwanted "meshing" or "merging" of two images rather than a clean flip (which is the intended action.)

Target Resolution- The highest output resolution of the imaging device (inkjet printer, digital proofer, contract proofer, film setter, plate setter) or a divisible factor of that resolution. (i.e.; 2400, 1200, or 600 dpi.) The target resolution divided by the pitch value of the lens is what will determine the number of frames (for animation effects) or views (for 3-D effects) that will be used to interlace the lenticular art file for proofing and/or platting. By utilizing this formula, the interlaced file size will be closest to the targeted resolution.

3D Lenticular effects- Objects within an image are layered to give the illusion of depth and perspective. Unlike 2-dimensional design, using this lenticular effect allows graphics to appear more realistic. Lenticular 3D can be incorporated into most images or design styles.

2D to 3D Conversion/ 3D Layer Depth - A process whereby multiple layers of different elements are interlaced together to create the illusion of three dimension.

Viewing Angle- A calculated angle of refraction inherent on a lenticular lens design that determines how fast or slow it is viewed.

Viewing Distance- The distance from which the final lenticular piece will be viewed. (For example, a lenticular postcard that is a hand-held piece will typically be viewed at 5-12 inches, where as a lenticular poster may be viewed at 2-20 feet.) Determining the precise viewing distance is critical to achieving a successful effect.

View Frames- A sequence of images, where each image represents a slightly different perspective view of a single 3D scene. When interlaced and viewed through a vertically oriented lenticular lens this sequence of images creates a 3D illusion.

Visual Pitch- The working pitch of a lens at the planned viewing distance.

Wide-angle Lens- A lenticular lens sheet with a viewing angle between 40-65 degrees. Wide-angle lenses work best for "flip" and "animated" effects.

Zoom- A lenticular effect that gives the observer the impression that the object is either moving from foreground to background, from background to foreground, or getting larger or smaller.

Appendix Ⅱ: Industrial Contacts

HOLOGRAM

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3D INTEGRAL IMAGING USING FRESNEL LENS ARRAYS

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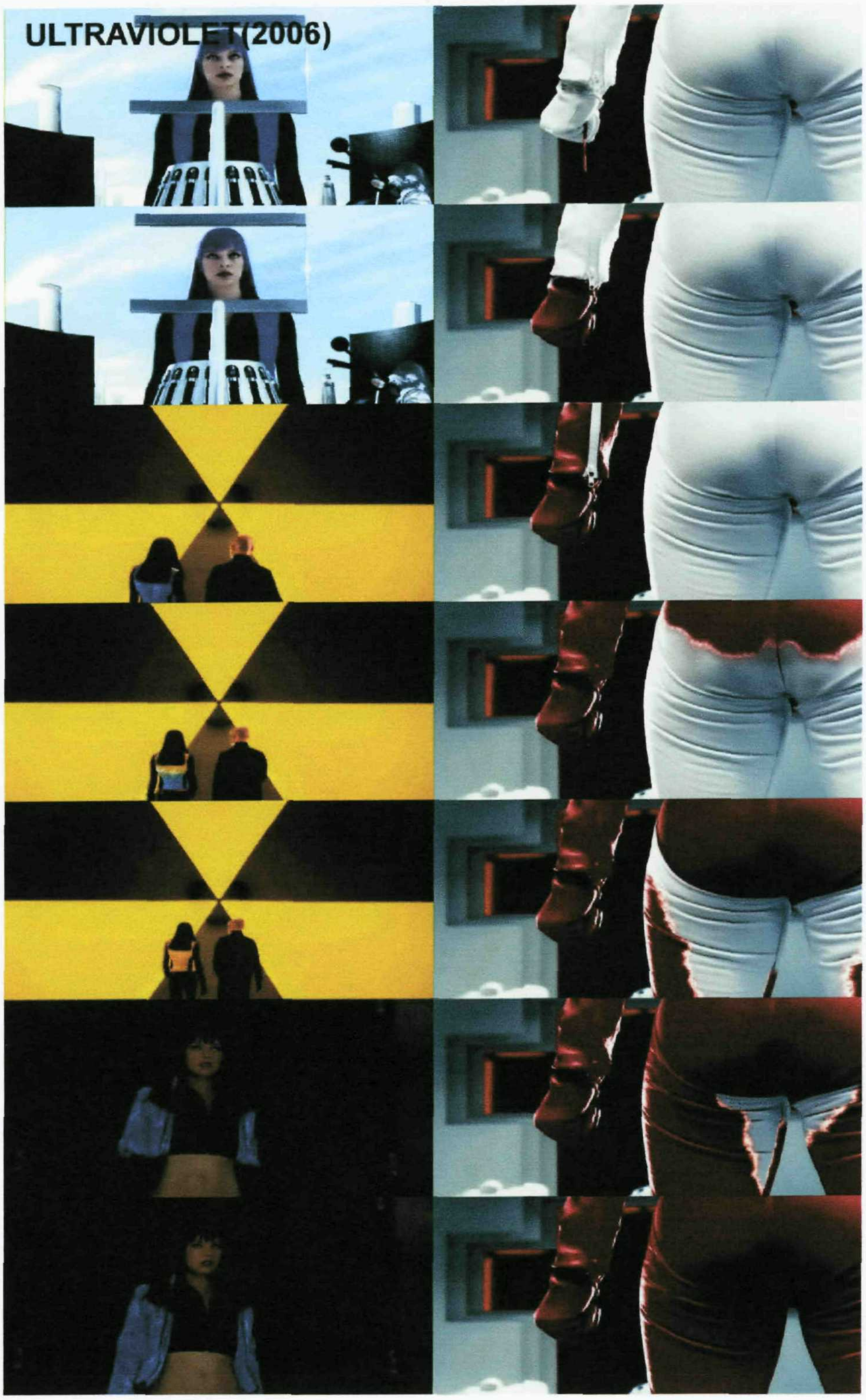
Appendix III: Images / Illustrations (captioned)


MINORITY REPORT(2002)
PRECRIME
PRECRIME
BLV
press
Precrime
Hunts its Own!
Capt. John Anderton, DCPD prime target in citywide precrime manhunt.
Molecular nano-
Mechanical
Precrime
Hunts its Own!
Capt. John Anderton, DCPD prime target in citywide precrime manhunt.
Molecular nano-
Mechanical


BEE SEASON


ULTRAVIOLET(2006)

Appendix IV: Jonathan Ross Hologram Collection

INTRODUCTION

The Jonathan Ross Hologram Collection, established in 1978, has evolved over the years to incorporate most aspects of display holography.

It includes representative holdings of many artists who have used the medium, ranging from the British and American pioneers to many of the graduates of the Royal College of Art's Holography Unit in the period 1985-1995.

The collection also holds examples of commercial holography from dozens of companies from around the world, demonstrating the versatility of the medium in many applications such as security printing, packaging, illustration and point-of-sale.

As an alternative to the website, which presents the collection through selections of work by individual artists and manufacturing companies, this CD explores some of the different visual styles of holography through the familiar classifications of Still Life, Portraiture/Figure and Abstraction.

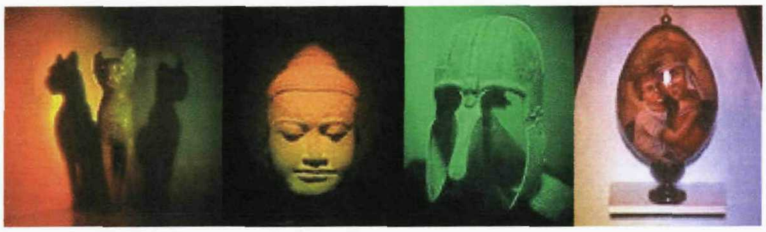
Holography has started to develop a unique vocabulary but is nevertheless just another medium with its own place in the history of visual art and, as such, references can often be made to other disciplines.

STILL LIFE

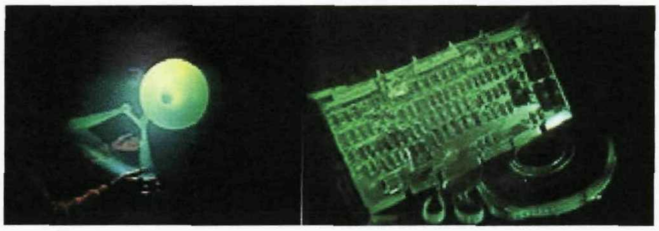
Much early holography was limited by the fact that, when using continuous wave lasers, the subject of the hologram had to remain completely motionless during the exposure period and an uninspired choice of object was responsible for the medium being dismissed by many as trite.

However when the object to be recorded was a thing of beauty in itself, its immobility was not necessarily a shortcoming. This is certainly the case with what might be called Museum Holography, where holography is called upon to create a record of a museum object. Russian holographers excelled at this from the beginning and, indeed, the Russian notion of Art Holography was the holographic recording of 'art objects' whereby the original could remain in its display case at the Hermitage, for example, and its holographic doppelganger could be sent on tour around the provinces.

The Ross Collection contains some fine examples of Museum Holography. For example, Caroline Palmer's Ancient Art Series, Richmond Holographic Studios' museum commissions and Hans Bjelkhagen's superb full colour experiments.



As a display medium, holography has frequently been employed to create an attraction on exhibition stands at trade fairs and Nick Phillips's classic reflection hologram 'Digital' is a fine example of this as every detail of the circuit board being illustrated is clearly reproduced in the *hologram with the added feature of a magnifying glass in the foreground to highlight the manufacturer's name. 'Trombone' by AP Holographie* is another, more blatant, example with the slide of the instrument projecting way out into the viewer's personal space.

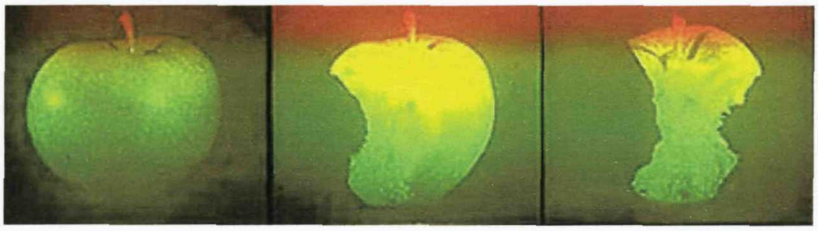


Display Holography, where the holographer makes creative use of the medium without aspiring to the realms of Fine Art, is represented in the collection with examples from a variety of sources. Mike Medora's 'Ragtime' is a brilliant multiple-exposure piece, showing several musical instruments in one 30x40cm hologram. His 'Nova' is a superb example of pseudo-colour work.

'Crystal Dreams' and 'Shells' from Larry Lieberman's Holographic Images are two good examples of holograms from a company that produced reasonably priced editions of high quality images for the giftshop and hologram gallery market. Kevin Baumber's 'Shocktail' illustrates how pulsed lasers can be used to freeze moments in time in a similar way to stroboscopic flash photography: a cocktail glass is recorded at the moment an airgun pellet explodes it.

Several holographers have chosen household objects or tools as their subject matter, transforming them with the alchemy of holography into objects of wonder or just simply encouraging us to observe the quotidian with a new fascination. John Kaufman's 'Hoses', 'Toolworks', 'Rake' and '2-Color Moiré Screen' are cases in point and his studies of rocks found in the landscape around Point Reyes in California, where he lives, exemplify the ability of holography to create things of beauty from the everyday.

Another Californian, Randy James, worked a similar magic with his 'Newton's Apples' and 'Egg & Jewel'.



Bostonian Harriet Casdin-Silver transforms a banal kitchen implement using the unique potential of holography to flip an object inside out : her pseudoscopic 'Grater' becomes a glittering light sculpture in the process. This latter work enters the territory where two classifications overlap as Still Life starts to become Abstraction.

Dominic Welby's 'Ebb and Flow' and Ruben Nunez's 'Homage to Louis Comfort Tiffany' occupy similar ground with their studies of glass objects. Nunez originally worked as a glass sculptor and adopted holography as a medium with which to record his pieces, at once becoming one of the foremost alchemists of the medium as his glassworks become universes, the macrocosm in the microcosm. Welby's piece began as 'an experiment to analyse and compare the lensing effects of glass and perspex' and resulted in a seriously gorgeous piece of optical art. With his 'Orgone Accelerator', Jon Mitton performs comparable optical wizardry with the simple ingredients of glass and wire mesh.

Examples of a wide selection of holographic techniques are provided by Walter Spierings didactic 'Shells' series, in which the same objects are shown as Laser Transmission, Reflection, Rainbow and Achromate holograms, Pseudoscopic, Real and Virtual Images.

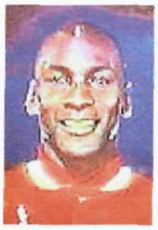
PORTRAITURE/FIGURE

Although the pulsed lasers capable of freezing live or moving subjects were developed during the early years of holography, they were exceedingly rare and expensive beasts - out of reach of most holographers - with the result that holograms of living creatures were fairly rare to begin with. This, perhaps more than any other factor, accounts for the slow growth of holography as a medium compared with photography, which from the 1840s made portraiture an affordable reality for a far wider audience than had ever been the case with painting or sculpture.

As an alternative to the pulsed hologram, a hybrid form of holography and cinematography was developed in California by Lloyd Cross and others, the product becoming initially known by its trademark name of Multiplex Holography. These images, in which sequences of film footage became synthesised into animated holograms, were generally displayed in revolving 360° cylinders or behind 120° screens and showed a rainbow coloured image, usually smaller than lifesize, composed of a number of vertical slit holograms.

The immediate use for this type of hologram was advertising though it was soon, like early photography, pressed into service as a novelty form of pornography. Peter Claudius, chief cinematographer at Multiplex Corp., had a blue-movie background and produced a number of classic images with titles such as 'Pam and Helen', 'Celeste Undressed' and 'Banana Lady'.

Eventually *'holographic stereograms', as they are now more commonly known, became more sophisticated, and full colour techniques have* been developed permitting the first really lifelike holographic portraits. A few companies have produced large format stereograms for museum and advertising displays, but the medium has reached its widest audience as an embossed hologram such as the Shakespeare bank card image or Michael Jordan on the cover of Sports Illustrated.



Some artists have experimented with holographic stereograms, notably Harriet Casdin-Silver whose 'Venus of Willendorf '91', presented as an achromatic nickel shim (or embossing plate), is a miniature masterpiece, reminiscent of a Daguerreotype in appearance but timeless in content. Patrick Boyd's 'Virtual Dialogues' is another example - commissioned as a cover image for a publication on virtual reality, its full-colour animated image of a father and new-born child clad in VR headset never fails to stir some emotion in the viewer.

Jeffrey Robb's 'My Great Aunt' presents a vision of what family snapshots might look like one day, in the simple but delightful animation of his elderly relative toasting him with a cup of tea - the hologram resulting from a short sequence of photographs.

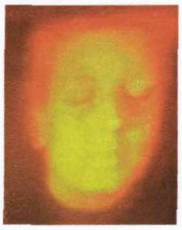
Pulsed lasers eventually fell into the hands of a number of individuals not primarily employed in scientific pursuits and the resulting portraits, although generally green in colour, have far greater clarity and detail than can be achieved with stereogram techniques. A nice example in the Ross Collection dates from the early 1980s. Edwina Orr's Self-Portrait depicts the subject - one of the prime movers of British holography - holding a lens in which her reduced image can be observed.

Margaret Benyon's 'Cosmetic Series' of holographic portraits, superimposed on painted images of the sitter, allows the viewer to move at will from a 'true' version of the subject - presenting themselves in an ideal light - to a handpainted likeness. In addition to providing a frisson as a 2D images transforms into a 3D one, this technique has the advantage of extending the visibility of the image and allowing the owner of the work to see something from any vantage point rather than just the limited viewing zone of the hologram.

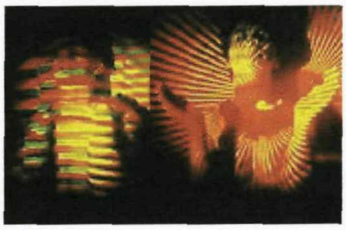
The starting point for this technique was Benyon's celebrated self-portrait 'Tigirl', in which a hologram of the artist, exhibiting the fringe patterns of a double exposure pulsed hologram, is juxtaposed with a photographic reproduction of a tiger's face, aligned so that the woman's and the cat's eyes are in the same place.

A collaboration with the 'Pop'artist, Richard Hamilton, provided Benyon with an opportunity to produce a distinguished set of portraits: reworking a lenticular self-portrait of Hamilton's from the 1970s in which the artist is glimpsed behind a screen of his own brushstrokes, Benyon used pseudocolour techniques to create some of the most lifelike yet mysterious holographic portraits in the canon.

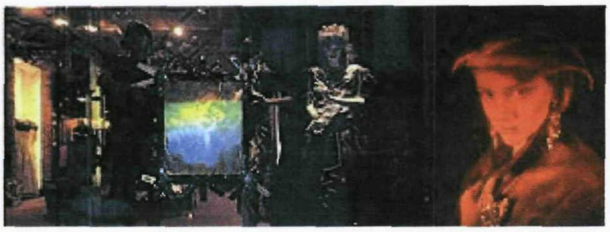
Pearl John's work at the RCA focused largely on personal history and issues relating to self-image, creating in the process some beautiful and evocative images, distinctly female yet obscured through the simple intervention of some rippled glass, that have the quality of faces glimpsed in a flickering fire.



Jonathan Cope, also at the RCA, introduced a graphic element, projecting patterns onto his subjects' bodies and creating a drama that is absent in most straight portrait holograms.



Patrick Boyd's pulsed laser holograms, which predated his stereogram work, are artfully posed in a sort of surrealist/fashion illustration style. (Zandra Rhodes once commissioned him to make a hologram for her Bond Street shop window.) His 'Lucy in a Tin Hat' is a most appealing work in which the wide eyed beauty fixes the viewer with a soulful gaze that can be partly obscured by the projecting brim of her hat as the viewer changes position.

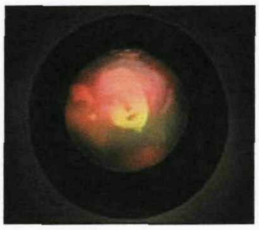


His 'Breakfast' and 'Temporary Measure', set pieces on the subjects of a good fry-up and a secretary's lot, respectively, have both charm and optical fascination as the scene is observed through a projected fresnel lens.

Martin Richardson has repeatedly used himself as a subject and his 'Inner Vison' and 'Analytical Male' are both thoughtful and provocative views of a man contemplating his own psyche. His sensitive eye is just as effective when focused on other people and he has produced a considerable body of work in which the subjects may well be chosen for their beauty or celebrity but equally for their role in conveying an idea. It is always portraiture plus...

David Pizzanelli is probably best known for his Muybridge Series, in which he appropriated the well known sequential images of the Victorian photographer and converted these studies in Human and Animal Locomotion into delightful holographic animations.

His PhD explored Temporal Parallax in a wide range of other found imagery, but perhaps his most personal work is 'Dorothea, Blue Moon, Eclipse', in which a relationship with a beautiful German woman is charted in a multi-channel image full of surprises.



ABSTRACT

The initial attraction of holography as a medium must have been, for many, its capacity to make an exact 3D facsimile of an object or person. For others, however, the intangible nature of the object reproduced and the fact of the essential element of light in the recording and reconstruction of holograms has led to a different assessment of the medium's potential.

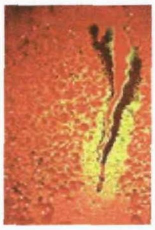
The scientist Steve Benton, inventor of the Rainbow (white light transmission) hologram, has made collaborations with various artists, notably Harriet Casdin-Silver and Margaret Benyon, and has also created several memorable holograms himself. Perhaps his most famous image, 'Crystal Beginnings', is constructed from points of light, apparently receding into the distance, like an infinity mirror contained in a single pane of glass.

Another celebrated hologram, 'Rind II' occupies a territory between figuration and abstraction - inspired by Escher, as many holographers have been, a human head emerges from a spiral form like an orange rind.

Bill Molteni, another scientist who has served time at Polaroid, and produced a body of work exploring the creative potential of holography, has employed holographic diffraction gratings to build his 'Cathedral of Light'. Bill Reber also harnesses the beauty of holographic diffraction to mesmeric effect in his 'Mandala'.

Alexander, who has striven to extend the boundaries of holography with his large format figurative stereograms, holographic 'movies' and pulse images has, in a recent series of work, explored the interaction of painted abstractions with holographic elements to create what he calls Extra-Dimensional Paintings. (Duet for Painting and Light No.2)

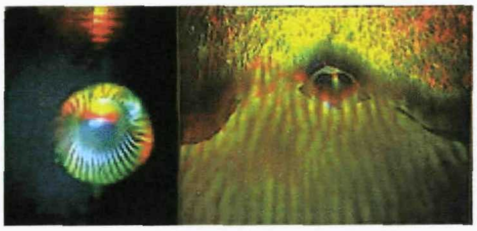
Matthew Andrews, with his Water Pieces, focuses his attention on the surface of the holographic emulsion and entirely ignores the 3D potential of the medium in favour of its ability to generate intense colours. These works require the interaction of the viewer who is encouraged to spray the hologram with water and effectively paint with light by making patterns on the wet surface. As the water evaporates the colours change until eventually the 'canvas' becomes blank again.



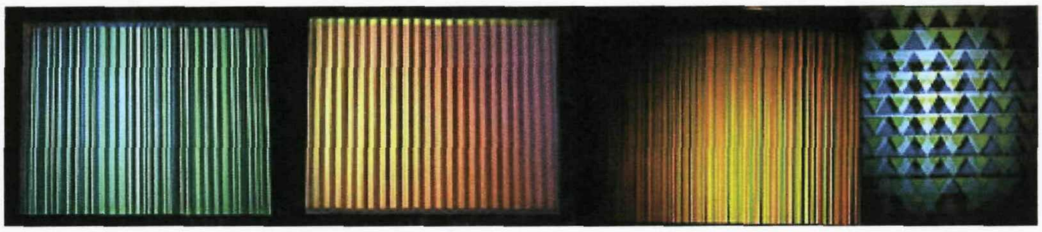
Jo Fairfax also pays attention to the surface of the hologram in his piece 'Limbic System', marking it with a regular pattern of bars. Behind these, however, lurks another, three dimensional, pattern of light, by contrast amorphous and mysterious.

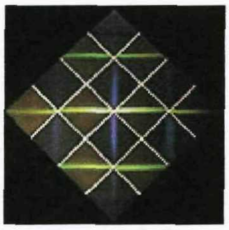
Of Doris Vila's series of the four elements Earth, Air, Fire and Water, her interpretation of Fire is the most literal and at the same time the most fascinating - a flickering pattern of flames and sparks ingeniously recreated holographically.

By viewing a holographic plate through the reverse side, an inverted or pseudoscopic image may be observed which is often unrecognisable as the object recorded. This is a popular weapon in the holographic artist's armoury and may be put to good effect in the creation of abstract images. All we can tell from Dan Schweitzer's 'Vortex II' and Ken Harris's 'Horizon' is that the former probably derives from a shiny metal object and the latter from some patterned glass - not that it matters, as they can be appreciated as optically fascinating works that could not be achieved by any other medium.

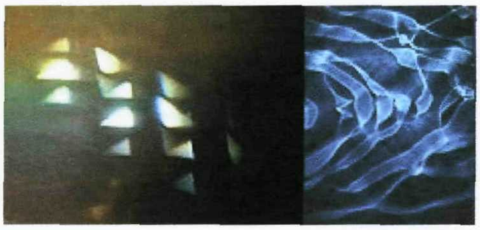


Some artists have used holography to create graphic works in 3-dimensions. Caroline Palmer began her career in holography making 3D facsimiles of ancient artifacts but, while at the Royal College of Art, produced an entirely different body of work using vertical or horizontal lines reminiscent of Bridget Riley ('Bar Code', Candy Canes' 'Elevator', 'Easter') or patterns derived from Islamic and Tantric Art (Sakti Cluster).



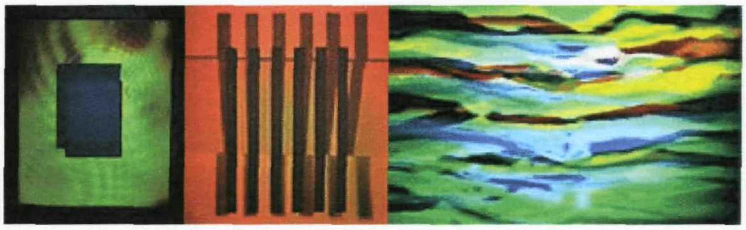


Rudie Berkhout has worked through a wide repertoire of abstract designs in space from his early geometric transmission works (Pinchin' Mother Nature's Nipple') to his more lyrical recent reflection pieces (Study in Light #6).



Anthony Hopkins, a holographer working in splendid isolation in the Channel Islands, produced a diverse body of work in varied graphic styles including some attractive abstract pieces (Erik's Artwork', 'Saturn I').

Andrew Pepper, a model of sublety and restraint in a medium not especially noted for those qualities, has steadily explored the holographic language of light and shadow and three dimensional mark-making, usually restricting himself to a monochromatic palette. ('Square Eclipse',' Six Lines Folded'). His collaboration with Eric Krantz, which resulted in a new technique for colour imaging, produced some beautiful and uncharacteristically exuberant works (Colour Study 1993).



EXHIBITION POTENTIAL

It is many years since Britain has seen any major exhibitions of holography and whole generations have grown up whose only experience of holography has been in the form of novelty items and security printing on credit cards and the like, unaware that artists have ever used the medium.

When holography was first exposed to a wide audience through exhibitions at the Royal Academy and Science Museum in London, for example, these were amongst the most successful exhibitions those institutions have ever staged and a similar phenomenon was observed in Europe, America and the Far East.

The various exhibitions in the UK and abroad to which the Jonathan Ross Hologram Collection has contributed in the past few years, have demonstrated that the public are still fascinated by the medium and have a desire to see more of it.

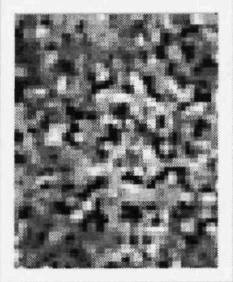
The Ross Collection has been created to illustrate the versatility of holography and to demonstrate that it is more than just a gimmick or a useful anti-counterfeiting device. Exhibitions of holography can be stimulating, entertaining and educational, they can generate an enthusiasm for further knowledge and inspire a new creative vision in artists unfamiliar with the techniques available. Some works will provoke a smile, the best will inspire a sense of wonder and a memory that will last a lifetime.

Portfolios of work by individual artists and manufacturing companies and documentation of various exhibitions staged at Ross's private gallery can be seen on the Jonathan Ross Hologram Collection website at www.holonet.khm.de/jross.

For further information please contact Jonathan Ross at
286 Earl's Court Road, London SW5 9AS, UK.

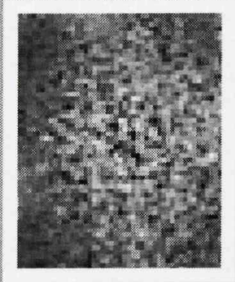
Appendix V: Emulsions for Holography

Emulsions For Holography

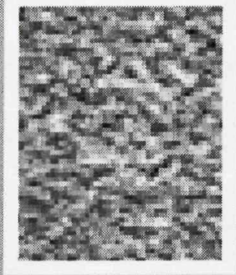


Fine Grain

GEOLA



Ultra-Fine Grain



DCG

TECHNICAL PRODUCT SPECIFICATIONS AND SALES INFORMATION BROCHURE JANUARY 2001

GEOLA

Geola is the international coordination office for the distribution of Holography films and plates.

Geola actively participates in the origination of new products and in primary product testing.

Geola certifies holography materials through its own in-house quality control programme.

Geola's network for the sale, wholesale and distribution of holography materials is currently the largest such distribution network worldwide.

PRODUCTS

Geola currently supplies both Silver Halide and Dichromated Gelatine emulsions for holography applications. Table 1 summarises all materials presently available from Geola.

The fine grain, green-sensitive VRP-M emulsions are very close analogues to the old Agfa 8E56 products and can be used for both Pulsed and CW laser recording of holograms.

The fine grain, red sensitive PFG-01 material gives equivalent performance to Agfa 8E75 for CW recording.

The PFG-03M (red sensitive) and PFG-03C (panchromatic) materials are super-fine grain emulsions.

Finally PFG-04 is a long-life Dichromated Gelatine emulsion for recording in the blue and green sprectral ranges.

All of the Silver Halide materials are available coated onto glass or TAC film substrate and cover a wide range of sizes.

Name of Material	Description
VRP-M	Fine-grained green sensitive holographic plates and film designed for reflection or transmission hologram recording. Average grain size is 35-40nm, resolving power is more than 3000 lines/mm, spectral sensitivity range includes 488nm, 514nm, 526nm, 532nm.
PFG-01	Fine-grained red sensitive holographic plates and film designed for reflection or transmission hologram recording. Average grain size is 40nm, resolving power more than 3000 lines/mm, spectral sensitivity range 600-680nm (including 633nm, 647nm).
PFG-03M	Ultra fine-grained red sensitive plates and film designed for reflection hologram recording. Average grain size is 8-12nm, resolving power more than 5000 lines/mm, spectral sensitivity range includes 633nm, 647nm.
PFG-03C	Ultra fine-grained panchromatic (full colour) holographic plates and film designed for colour reflection hologram recording. Average grain size is 8nm, resolving power more than 5000 lines/mm, spectral sensitivity range up to 700nm (457nm, 514nm, 633nm).
PFG-04	Dichromated Gelatine holographic plates designed for phase reflection hologram recording. Resolving power greater than 5000 lines/mm, spectral sensitivity range up to 514nm (457nm, 488nm, 514nm).

Table 1: List of Available Holographic Materials

Acknowledgements

Geola is grateful to Sergey Vorobyov for the technique of latensification. We would also like to acknowledge the work of Hans Bjelkhagen and Nicholas Phillips, on which much of the chemistry listed in this brochure is based, as well as that of Bernadette and Ron Olson for the technique of colour-shifting by D-Sorbitol.

FINE GRAIN SILVER HALIDE MATERIALS

VRP-M
(GREEN SENSITIVE)
AND PFG-01
(RED SENSITIVE)

Characteristic curves of fine-grain red (PFG-01) and green (VRP-M) emulsions, showing spectral sensitivity versus wavelength, are shown in Fig.1. The VRP-M optical sensitivity (to CW radiation) is seen to peak at aproximately 75 $\mu J/cm^2$ and that of the improved PFG-01 (to CW radiation) at approximately 80 $\mu J/cm^2$. (This improved batch will be comercially available in the second quarter of 2001). Fig.2 shows the optical density after exposure by CW radiation and after development versus energy. Grain size characteristics for the VRP-M and PFG-01 emulsions are shown in Fig.3.The diffraction efficiency versus exposure for reflection holograms recorded on PFG-01 (using a CW laser) and on VRP-M (using a pulsed laser) is presented in Fig.4. The maximum diffraction efficiency is seen to be >45% for both emulsions. Material lifetime is more than two years.

The VRP-M and PFG-01 emulsions may be used equally well with pulsed lasers and with CW radiation. In the pulsed laser radiation case the emulsion should be post-sensitized with the technique of latensification. The

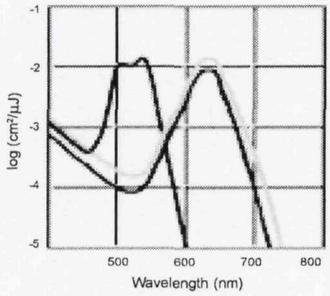


Figure1: Spectral Sensitivity curves for VRP-M (left) and PFG-01 (right). In grey we show a new PFG-01 sensitivity curve (commercially available in the second quarter of 2001).

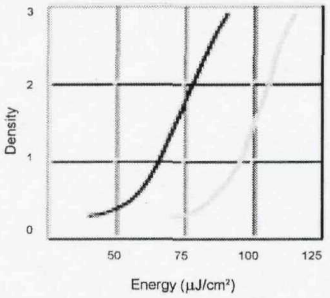


Figure 2: Characteristic Curves for VRP-M (left) and PFG-01 (right).

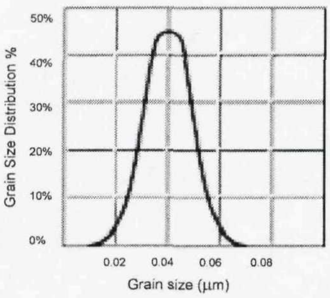


Figure 3: Grain Size Distribution Curve for VRP-M and PFG-01.

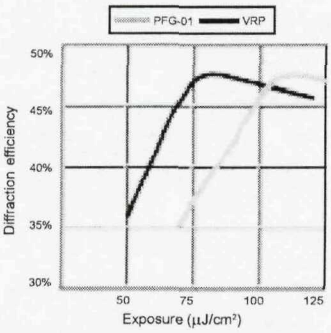


Figure 4: Diffraction Efficiency Curves for VRP-M and PFG-01.

VRP-M PFG-01	Mastering and Copying with Pulsed Radiation	Mastering and Copying with CW Radiation.
Exposure:		
MASTERING	20-40 μJ/cm^2	60-80 μJ/cm^2
COPYING	30-60 μJ/cm^2	70-90 μJ/cm^2
Latensification	**Yes**	**If needed**
Development	**SM-6,** 2min	**CW-C2,** 2min
Wash	Water, 1-2min	Water, 1-2min
Bleach	**PBU-Amidol** until clear (~2-3 min)	**PBU-Amidol** until clear (~2-3 min)
Wash	Water 5 mins	Water 5 mins
Final Wash	Water with wetting agent (Agepon) 1min	Water with wetting agent (Agepon) 1min
Drying	Slow Air	Slow Air

Table 2: Recommended Processing for VRP-M and PFG-01

RECOMMENDED CHEMISTRY FOR VRP-M and PFG-01

latensification technique is described below.

Table 2 shows a summary of recommended processing schemes for use with VRP-M when exposed by pulsed Neodymium lasers (526.5nm, 532nm) and for use with VRP-M and PFG-01 when exposed by CW Argon or by HeNe lasers. In the case of exposure by CW radiation latensification is usually not necessary.

White-light holograms made on VRP-M have a natural green reconstruction colour that can be easily changed by the technique of colour -shifting using D-Sorbitol (described below). White-light holograms made on PFG-01 have a natural yellow/orange reconstruction colour when using a HeHe laser and the recommended chemistry.

All chemicals necessary for the preparation of the recomended solutions can be obtained from the following companies -

(i) Photographer's Formulary Inc. (www.photoformulary.com),

(ii) Sigma-Aldrich www.sigma-aldrich.com),

(iii) Prolabo (www.Prolabo.fr).

For pulsed work one may also use the standard D-19 Kodak developer if 6-8g of Methyl Phenidone is added into the final solution.

SM-6 Developer	
Sodium Hydroxide	12.0g
Methyl Phenidone	6.0g
Ascorbic Acid	18g
SodiumPhosphate (dibasic)	28.4g
if 12 H_2O	71.6g
Water	to 1.0L
CW-C2 Developer	
1 part A + 1 part B	
Part A	
Catechol	20.0g
Ascorbic Acid	10.0g
Sodium Sulphite (anhydrous)	10.0g
Urea	100.0g
Water	to 1.0L
Part B	
Sodium Carbonate	60.0g
Water	to 1.0L
PBU-Amidol Bleach	
Potassium Persulphate	10.0g
Citric Acid	50.0g
Cupric Bromide	1.0g
Potassium Bromide	20.0g
Amidol	1.0g
Water	to 1.0L
Potassium Iodide Bath	
Potassium Iodide	18.0g
Water	to 1.0L

Table 3:VRP-M and PFG-01 Developers, Bleach and Colour-shift bath.

LATENSIFICATION

The temperature of all solutions described in this brochure is 20 ^{0}C.
PFG-01 and VRP-M emulsions have peak sensitivities to exposures in the millisecond regime. In order to obtain optimal sensitivity to exposures different from this regime the technique of latensification must be used.

Latensification is usually done directly after the holographic exposure. Before applying the process a latensification time appropriate for your system must be worked out. This procedure is as follows: Place a 25W white lamp at a distance of 1m from a test holoplate or film such that its light uniformly illuminates the emulsion. You will need to try several exposure times.

First of all you will need to develop the unexposed emulsion under normal safelight conditions. The plate will darken a little. This is called the "fog" level. After development wash this control plate, dry and keep it handy. Now a series of exposures with small test plates must be made. Start at about 2 secs and go up to around 10 secs. After each exposure develop your plate and match the darkening of this plate to your control plate. If it is the same, more exposure is needed so go back and repeat the process. Stop when a result that is just marginally darker than the fog level is obtained. This is then the correct latensification exposure for your geometry.

Now that the proper latensification time has been discovered, after every proper holoplate exposure you must take your plate and illuminate it exactly as described above for the time that you have worked out. Then all processing is as normal.

Latensification stabilizes and enhances the latent image formed by the holographic exposure. If required, chemical processing may be done with significant delay after latensification (~8 hours). For the VRP-M emulsion we recomend two colour shifting techniques. One produces a fixed colour-shift towards the red of approximately 50 nm. The other produces an adjustable colour shift.

COLOUR CONTROL

The fixed colour shifting is accomplished by soaking the final hologram for 1 minute in a bath of Potassium Iodide solution (Table 3). Adjustable colour shifting is accomplished by soaking the hologram for 1 minute in an aqueous solution of D-Sorbitol (sugar substitute - $C_6H_{14}O_6$) with added wetting agent. The colour of the final hologram depends on the solution concentration (Fig.5). After soaking, the film must be taken out and put onto a flat surface. Water drops must be removed using a rubber wiper such as a windscreen wiper. Here one must be delicate - if too much force is employed you may obtain a somewhat different colour than that predicted by Fig. 5. If, after drying of the hologram, the replay colour achieved is not satisfactory, the fi warr a ne solut

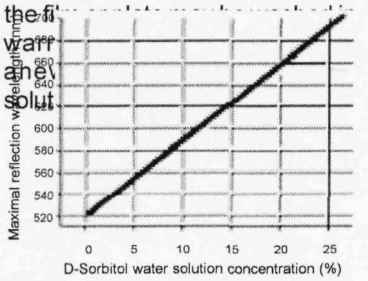


Figure 5: Hologram Colour versus D-Sorbitol Solution Concentration for exposure @ 526 nm.

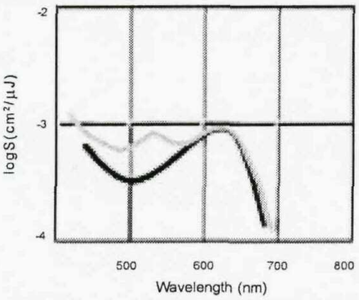


Figure 6: Spectral Sensitivity curves for PFG-03C (grey) and PFG-03M (black).

ULTRA-FINE GRAIN SILVER-HALIDE MATERIALS

PFG-03M

RED SENSITIVE EMULSION

This material is designed for reflection hologram recording using CW radiation in the red spectral range (633nm - HeNe laser and 647nm - Krypton laser). The spectral sensitivity curve of the material is shown in Fig.6.

Peak emulsion sensitivity is around 1.5-2$\mathrm{mJ/cm^2}$. The grain size distribution curves for both PFG-03M and PFG-03C are shown in Fig.7. Recommended processing is given in table 4.

PFG-03C

PANCHROMATIC EMULSION

This material is designed for the production of full-colour reflection holograms using CW laser radiation in the blue (457nm - Argon laser), green (514nm - Argon laser) and red (633nm -HeNe laser).

A spectral sensitivity curve of the PFG-03C material is shown in Fig.6. Diffraction efficiency versus exposure is shown in Fig.8. The maximum diffraction efficiency in the blue region is >25% and in the green and red regions >45%.

Typical sensitivity values for PFG-03C are 2$\mathrm{mJ/cm^2}$ and 3$\mathrm{mJ/cm^2}$ for the blue and red/green regions respectively.

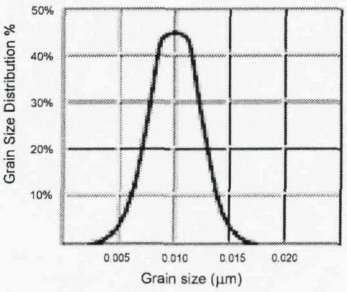


Figure 7: Grain Size distribution curve for PFG-03C and PFG-03M.

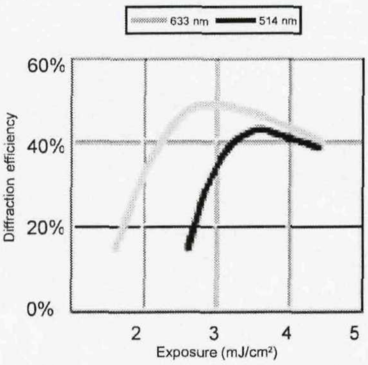


Figure 8: Diffraction Efficiency Curve for PFG03C.

Hardener	
Formalin 37%	10ml
Potassium Bromide	2g
Sodium Carbonate	5g
Water	to 1L
GP-2 Developer	
Concentrated solution:	
Methyl Phenidone	0.2g
Hydroquinone	5g
Sodium Sulphite(Anhyd.)	100g
Potassium Hydroxide	5g
Ammonium Thiocyanate	12g
or Potassium Thiocyanate	24g
Water	to 1L
Working solution:	
40ml GP-2+1L H_2O	
VRP Developer	
Concentrated solution:	
Sodium Sulphite (Andydrous)	194g
Hydoquinone	25g
Potassium Hydroxide	22g
Methyl Phenidone	1.5g
Potassium Bromide	20g
Potassium Metaborate	140g
1,2,3-Benzotriazole	0.1g
Distilled Water	to 1L
Working solution:	
1 part of developer + 6 parts water.	
Fixer	
Sodium Thiosulphate (cryst.)	160 g
Potassium Metabisulphite	40 g
Water	to 1L
Stop Bath	
Acetic Acid	20g
Water	to 1L

Table 5: Recommended Chemistry for PFG-03C and PFG-03M.

Reflection holograms	PFG-03M	PFG-03C
Exposure	**1500 - 2000 $\mu J/cm^2$**	**2500 - 3000 $\mu J/cm^2$**
Hardening	**Hardener, 2-3 min**	**Hardener, 6 min**
Wash	Water, 1-2 min	Water, 1-2 min
Development	**GP-2,** 10 - 15min	**VRP,** 4 - 5min
Wash	Water, 1-2 min	Water, 1-2 min
Fixing	**Fixer**, 2 min	**No**
Bleach	**No**	**PBU-Amidol**, 5-8 min
Wash	Water, 1-2 min	Water, 1-2 min
Stop bath	**No**	**Stop bath**, 2 min
Wash	No	Water, 1-2 min
Bathing	**No**	**Water with wetting agent,** 1min
Drying	**50%,75% and 96% Ethyl Alcohol**, 2mins each bath	**Slow Air Drying**

Table 4: Recommended Processing for PFG-03M and PFG-03C

DICHROMATED GELATINE PFG-04

This material is designed for the recording of reflection Denisyuk type holograms using CW laser radiation (e.g. 488nm, 514nm - Argon laser). The material spectral sensitivity curve is shown in Fig.9. The sensitivity reaches $100mJ/cm^2$ in the blue spectral region and $250mJ/cm^2$ in the green. Due to its grainless structure, this material has a very high resolving power and a diffraction efficiency of >75%.

The recommended processing technique for PFG-04 is as follows:

1).Thermal Hardening after exposure (100°C) - Depending on the layer freshness. See Fig.10.

2).Cooling to room temperature.

3).Bathing in running filtered water - 3mins.

4).Bathing in 50% Isopropyl Alcohol solution for 2 - 3 mins.

5).Bathing in 75% Isopropyl Alcohol solution for 2 - 3 mins.

6).Bathing in 100% Isopropyl Alcohol solution for 2 - 3 mins.

7).Drying in a desiccator. (100°C) for 60 mins.

8).Emulsion layer preservation using optical anhydrous adhesive and protective glass.

Note that the processing solution temperatures must not exceed 20°C for fresh layers. If holograms appear "milky" in colour then the processing solution temperature should be decreased or the thermal hardening period should be prolonged. The material shelf life is 18 months (average observed period).

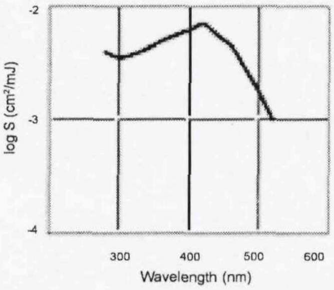


Figure 9: Spectral Sensitivity Curve for PFG-04.

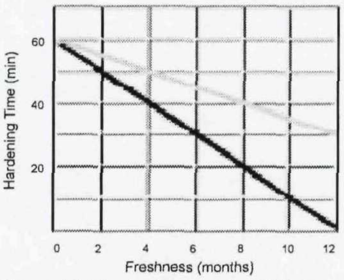


Figure 10. Hardening time for PFG-04 vs Storage Time. The black curve corresponds to a storage temperature of 18 °C and the grey curve to 4 °C.

TEMPORARY LAMINATION

Holography materials certified and distributed by Geola are manufactured on glass and TAC film substrates that are ostensibly identical to those used by Agfa.

The temporary film lamination technique described below is an alternative to the well-known index matching technique and is easier and less time-consuming. The technique is appropriate for film sheets of 20x30cm or larger.

We recomend using an electrostatic transparent film similar to the 5105CL "Penstic" Transparent film from Molco GmbH (www.molco.com), Germany. The procedure is as follows.

1. Clean a glass plate and place it horizontally. The plate should be slightly bigger than the actual film.

2. With a soft brush create an electrostatic charge on the glass plate.

3. Apply the electrostatic film to the glass plate with a (photographic) rubber roller making sure that you eliminate all the air bubbles.

4. Again take a soft brush and create an electrostatic charge on the electrostatic film.

5. Apply the holographic film to the electrostatic film with the rubber roller making sure, once again, that you eliminate all the bubbles.

6. Now use the glass plate as you would a normal holographic plate.

7. After making an exposure (and latensification) simply peel off your photosensitive film and process it as described above.

Another technique useful to achieve the necessary flatness for the recording of film holograms smaller than 20x30cm is to put the film between two glass plates.

FINAL LAMINATION

The emulsion of holograms made on film and glass plates should be protected from humidity and UV light.The diffusion of water into the emulsion leads to the colour of the hologram changing. UV radiation causes hologram brightness degradation (the "print out" effect). In order to protect the hologram from these unwanted effects one may cover and seal the hologram on one or both faces. In the case of glass holograms sealing from the back side is sufficient whereas film holograms should be sealed both from the front and the back.

The best way to protect the back side (the emulsion) of reflection holograms is by lamination of a black self-adhesive film. We recomend "Black Oracal" 641-070M from Orafol GmbH, Germany (www.orafol.de), or a similar product. It is straightforward to apply this black film to the emulsion side of the hologram using a photographic rubber roller. Alternatively a cold lamination machine may be used. The result is a sandwich consisting of the holographic substrate, the emulsion and the protective film.

For emulsion protection of transmission film holograms we recomend the use of a transparent double-sided self-adhesive film (e.g. Optimount 60238 from Hunt Graphics Europe Ltd.) and a plexiglass sheet (e.g. Plexiglas XT, from Rohm GmbH, Germany, www.roem.de).

One side of the double-sided film is applied to the emulsion side of the hologram and the other side is stuck to the plexiglass. This can be done either by hand (rubber roller) or by using a cold lamination machine. The result is a sandwich consisting of holofilm substrate, emulsion, adhesive and plexiglass.

In order to insure flatness of film reflection holograms the same technique of mounting to a plexiglass sheet using a doublesided film may be used. The result is a sandwich consisting of the film substrate, the emulsion, a black self-adhesive film, the double-sided self-adhesive film and finally the plexiglass sheet.

Front-side protection of the hologram from UV radiation can be effected by use of the standard UV reflecting films available from Edmond Scientific(www.edsci.com).

Material Sizes

PLATES Emulsion*	Plate Size (mm)	Q-ty per Box	Box Size (mm)	Box Weight (kg)
VRP-M, PFG-01, -03C,-03M, -04	63x63	30	180x80x90	0.95
VRP-M, PFG-01, -03C,-03M, -04	102x127	25	240x165x215	3.30
VRP-M, PFG-01, -03C,-03M, -04	300x406	6	426x325x40	5.45
FILMS Emulsion**	Sizes mmxm (Roll)	Q-ty of Rolls per Box	Box Size (mm)	Box Weight (kg)
VRP-M,PFG-01,-03C,-03M	35x20	1	ϕ100x50	0.3
VRP-M,PFG-01,-03C,-03M	102x20	1	ϕ100x265	0.9
VRP-M,PFG-01,-03C,-03M	203x20	1	260x97x88	1.8
VRP-M,PFG-01,-03C,-03M	304x10	1	370x97x88	1.3
VRP-M,PFG-01,-03C,-03M	350x10	1	410x97x88	1.5
VRP-M,PFG-01(on request)	1150x10	1	1350x105x95	8.9

*bigger sizes on request **cut sheets on request

Table 6: Material sizes available as standard products.

SUMMARY OF TECHNICAL SPECIFICATIONS

Parameters	PFG-01	VRP-M	PFG-03M	PFG-03C	PFG-04
Holographic Sensitivity					
@ 457nm CW µJ/cm^2	.	.	.	2000	80000
@ 488nm CW µJ/cm^2	.	.	.	.	100000
@ 514.5nm CW µJ/cm^2	.	75	.	3000	250000
@ 526.5nm 30ns pulse with latensification - µJ/cm^2	.	75	.	.	.
@ 633nm µJ/cm^2	80	.	1500-2000	3000	.
Maximum Density on Characteristic Curve (D_{max})	<4.0	<4.0	<4.0	<4.0	x
Resolving Power (R), mm^{-1}	3000	3000	>5000	>5000	Grainless
Max. of Spectral Sensitization, nm	633	530	633	457/514/633	415
Swollen Emulsion Layer Strength after Chemical Processing, H (gm force)	900	900	>50	>50	x
Deformation Temperature of Emulsion Layer in Water (T_{def}),°C	>90°C	>90°C	>35°C	>35°C	x
Emulsion Layer Thickness (microns)	7 to 8	6 to 7	6 to 7	9 to 10	16 to 17
Normal Diffraction Efficiency for Reflection					
@ 457nm, %	.	.	.	>25%	>75%
@ 488nm, %	.	.	.	.	>75%
@ 514.5nm, %	.	45%	.	>45%	>75%
@ 526.5nm, %	.	45%	.	.	.
@ 633nm, %	>45%	.	>45%	>45%	.
Observed Storage Period for the holographic materials certified by Geola: At 4° Celsius, 30% Humidity.					
Film Roll (months)	18	18	18	x	x
Cut Sheets (months)	12	12	6	x	x
Plates (months)	18	18	12	12	12

Sales & Purchasing Information

International Sales Centre

UAB Geola is the International Sales Coordination office and International Stockhouse for all Holographic consumable products.

Distribution Network

In order to increase customer service, product quality and the processing speed of commercial orders, Geola has created a large International network of distributors and sales offices for holography materials. Please see below in order to find out which is *your nearest and most convenient* Holographic materials distributor.

Service

The Geola International Sales Coordination Office was formed in order to ensure that end-users obtain the highest quality materials available. All batches of holographic materials are tested in our modern laboratories and certified. The best processing techniques for each material are continuously reviewed by our highly skilled team of experienced photonic engineers and chemists.

Guarantee

In the unlikely event that any certified holographic product is found to be defective due to manufacture and this product has been sold through the Geola *Distribution Network*, this product will be replaced free of charge in the shortest possible time.

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Your Local Representative

Appendix VI: The History of Integral Print Methods

The History of Integral Print Methods

An excerpt from:
"Lens Array Print Techniques"

David E. Roberts
19264 Seeley Ridge Road
Hillsboro, WI 53634-3494

Trebor Smith
14395 Terrapin Station
Painter, VA 23420-0386

Integral imaging is a true *auto-stereo* method (stereo imagery viewable without the requirement of special glasses). An integral image consists of a tremendous number closely packed distinct micro-images, that are viewed by an observer through an array of spherical convex lenses, one lens for every micro-image. This special type of lens array is known as a *fly's-eye* or *integral* lens array; Fig. 1.

When properly practiced, the result is stunning three dimensional imagery that coveys a realism matched only by museum-quality holograms. Indeed, it has been demonstrated that an integral image can very accurately reproduce the wavefront that emanated from the original photographed or computer generated subject, much like a hologram, but without the need for lasers to create the image. This allows the eyes to accommodate (focus) on foreground and background elements, something not possible with lenticular or barrier strip methods. The term "Integral" comes from the *integration* of all the micro images into a complete three dimensional image through the lens array. In addition to three dimensional effects, elaborate animation effects can also be achieved in integral images, or even a combination of these effects.

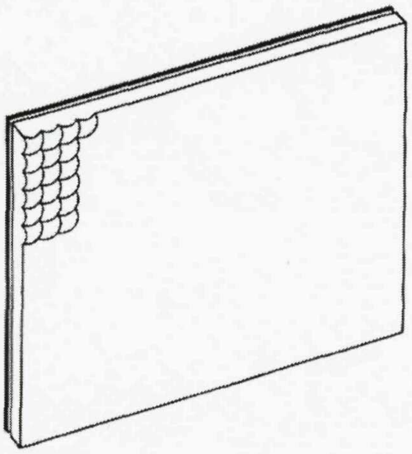

Figure 1: Fly's eye lens sheet illustration.

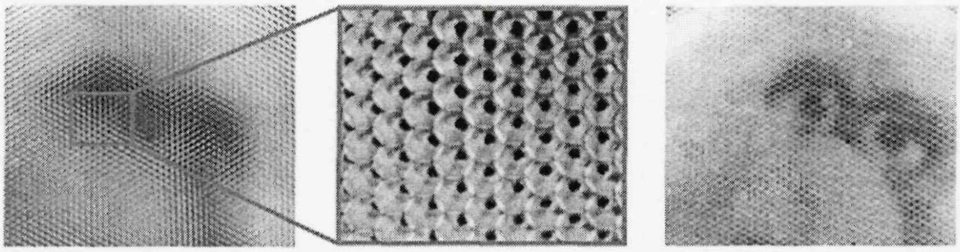

Figure 2: Integral image (Left) without lens; Enlargement (Center), note that each lens records its own unique picture; Integral image (Right) resolved through a matching lens from a particular viewing position; Roberts & Villums, 1989.

Integral imaging is based on a principle known as the lens "sampling effect". To achieve this effect, the thickness of the lens array sheet is chosen so that parallel incoming light rays generally focus on the opposing side of the array, which is typically flat; see Fig. 3 (far right image). This flat side is known as the focal plane. It is at this plane that the micro images are placed, one for every lens, side by side. Since each lenslet focuses to a point onto a micro image below, an observer can never view two spots within a micro image simultaneously; just one spot at a time, depending at what angle the observer looks though the lens. For example, if you have an array of small white dots, on an otherwise black background, behind each lens at the focal plane, any given lens will appear either completely black or white, depending on whether or not the lens is focused on a white dot, or the black background; Fig. 3 (left). The state of each lens will vary depending on the point of observation. If all the dots are precisely ordered in a pre-calculated way, a completely different composite image can be directed to each eye of an observer, simultaneously, since each eye looks through the lens array at a different angle. The resolution of an integral image is therefore directly determined by the density of lenses in the array, since each lens effectively becomes a "dot", or pixel (picture element), in the picture, with the visual state of each dot being a function of the viewing angle.

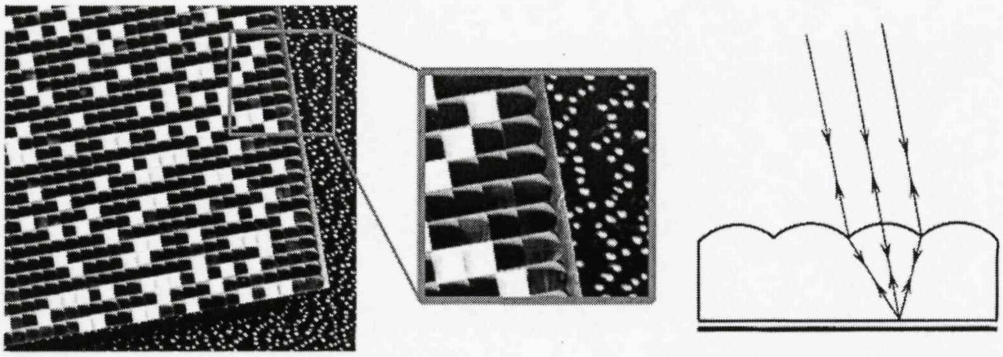

Figure 3: Sampling effect using a fly's eye lens array placed on a printed image of white dots on a black background; Left, Roberts. Sampling effect illustration; Okoshi, Academic Press, 1976 (64).

Unfortunately, in the early days of integral imaging, lens arrays were nearly non-existent. It wasn't until World War II that inexpensive and formable thermal plastics became widely available and methods evolved to form the new materials into arrays. Before then, most of the research utilized arrays of the optically analogous *pin-hole* aperture. In fact, a pin-hole aperture is a lens, but a lens based on diffraction rather than refraction. It is essentially a clear aperture, or hole, in an otherwise opaque plate. In photography, the radius of the pin-hole is selected to focus upon the film a concentrated and well distributed image of an object, where the focal length is approximately the wavelength of light divided into the square of the radius of the pin-hole. To use a pin-hole array as a viewing screen, the radius is typically much larger to allow more light to pass through the array. However, to properly to view an integral image, the aperture must generally be ten percent or less open, which results in a very dark image, even when a bright light is used for back lighting.

The first integral imaging method was "Integral Photography". In this method the lens array is used to both record and play back a composite three-dimensional image. When an integral lens array sheet is brought into contact with a photographic emulsion at its focal plane, and an exposure is made of an illuminated object that is placed close to the lens side of the sheet, each individual lens (or pin-hole) will record its own unique micro image of the object. The content of each micro image changes slightly based on the position, or vantage point, of the lenslet on the array. In other words, the integral method produces a huge number of tiny, juxtaposed pictures behind the lens array onto the film. After development, the film is realigned with the lens sheet and a composite spatial reconstruction of the object is re-created in front of the lens array, that can be viewed from arbitrary directions within a limited viewing angle.

Integral was the first lens-based auto-stereo method, followed by lenticular in the 1930's. It was first proposed on March 3rd, 1908 by physicist Professor Gabriel Lippmann[1] to the French Academy of Sciences, under the title "La Photographie Integral"(56). He proposed a method to record a complete spatial image on a photographic plate, with parallax in all directions, utilizing an array of small spherical convex lenses, all in a single exposure. In his approach, later known as the direct method, an object or scene is recorded directly in front of the lens array. Lippmann proposed this technique without actually ever having proven the concept in experiment. In a second paper in 1908 (55) he described a crude test where he used a screen composed of glass rods with spherical ends where he reported limited success. In a later paper in 1911 (57), he describes a test where he used an array of 12 small lenses mounted in a rectangular frame. He stated that "in illuminating the plate one no longer sees individual microscopic images; they are replaced by a single (integral) image, which is seen under the same angle as the original subject". He went on to report that the resulting image changes form, just like the original object itself, depending on the position of the viewer, and also changes its angular dimensions with distance. He also proposed a 360 degree panorama that could be fixed on a integral cylindrical plate, and even a spherical one that could accommodate all surrounding space.

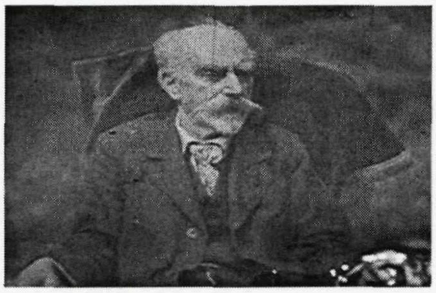

Figure 4: Professor Gabriel M. Lippmann. A self-portrait using his color photographic process.

The first experiment to verify Lippmann's method was preformed by Professor P..P. Sokolov of the Moscow State University in 1911 (76), using a pin-hole aperture sheet. Although this resulted in a relatively dark image, the experiment was successful in imaging a light bulb filament, that appeared to float off the screen. Sokolov provided a detailed mathematical and experimental description of Lippmann's method and was the first to compute the ideal shape of the back surface of the lens array. He established that integral photographs, "being taken without an objective lens, give, upon direct examination, an impression of relief characteristic of stereoscopic photography, the photographs exhibiting not only a complete relief, but a perspective varying depending on the angle at which one views the plate, that is, an approximation of reality which, until now, has been unattainable in any other instrument."

---

[1] Professor Gabriel Lippmann was perhaps best known for his invention of the first photographic reproduction of true color in 1886; Fig. 4. The colors were reproduced by recording standing waves formed within an emulsion layer by the interference of direct and reflected light (the photographic plate was floated in a mercury bath). He was awarded the Nobel Prize for the invention in 1908. The invention was ironically, in essence, the first holographic method.

Estanave of France repeated the experiment in 1930, again creating an image of a bright light filament. He worked with units of 56 and 95 *stanhope* glasses (a type of magnifying glass), and then later used an array of 1250 apertures, which he called *stenopic* cameras (29).

Lippmann's direct method had its limitations. First, it only allowed for objects to be recreated in front of the lens array, in other words, objects appeared to float only in front of the lens array, not within or behind it. Further, because of the limitations in the depth of field of the individual lenslets, the distance an object could be placed in front of the array was limited, and indeed only objects located several centimeters from the array where properly re-imaged.

Herbert E. Ives later improved the technique in 1930, by incorporating a large aperture camera lens (a lens with a diameter wider than the interocular distance between the eyes) to optically suspend a "real" aerial image of an object in front of, within, or behind the lens array. Later known as the indirect method, this allowed for a substantial increase in the depth of field, and for the first time, objects that appeared to float behind the lens array as well as in front. Ives also proposed the use of a large concave mirror as an alternative to the objective lens.

The biggest drawback, however, to the Lippmann method was that the recorded images were pseudoscopic, or depth reversed, where the foreground becomes the background and vice versa. Interestingly, Lippmann himself was apparently not aware of this problem, as he never wrote about it. Herbert E. Ives was the first to recognize the problem in 1931 (50), and proposed a secondary exposure solution to invert the depth. Known as a "two step" method, where a secondary exposure of the original photographic plate through another lens sheet was made. He demonstrated this solution by using a secondary array of pin-hole apertures.

Clarence W. Kanolt also experimented with arrays of pin-hole apertures and large objective camera lenses; Fig. 5. His aperture arrays varied between 40 and 200 per square inch, including hexagonal-packed, square-packed and random arrays. He also proposed using lenses instead of apertures, although it is not clear that any reasonable arrays were available to him at the time.

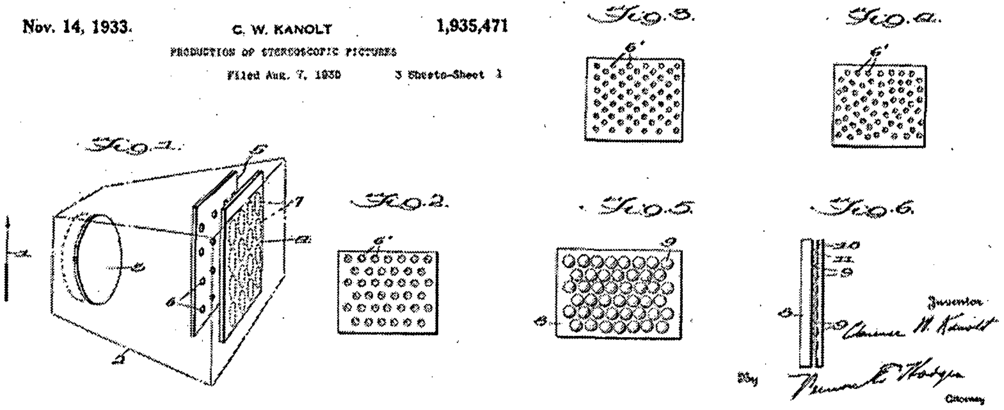

Figure 5: Integral array, U.S. Patent 1,935,471; Kanolt, 1933 (51).

Important refinements were also made to the indirect camera designs and pseudoscopic reversal schemes by the prolific inventor Douglas Winnek of New York in 1936, including establishing a direct relationship between the objective lens design and the design of the lenslets. Winnek constructed elaborate cameras and expanded on the use of objective lens apertures, using a variety of integral screens; Fig. 6.

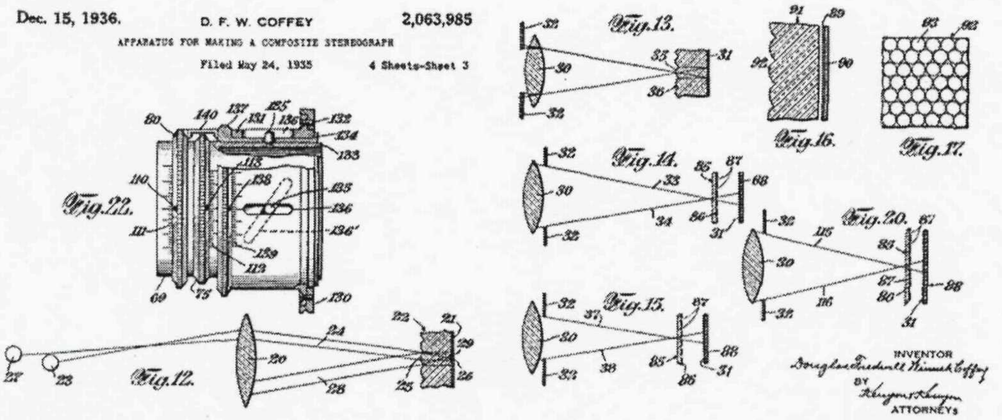

Figure 6: Integral screens and cameras, U.S. Patent 2,063,985; Winnek, 1933 (82).

Investigators Granont and Planovern of France experimented with an integral method that used an array of flat mirrors instead of a lens or pin-hole array (29). The mirrors were precisely placed in such a way that each provided an image of a subject from a slightly different point of view to the film. By projecting the resulting exposure through the same system of a camera and mirrors, a three dimensional image of the original subject was produced.

The first experiments using a proper lens array were apparently performed in 1948 by S.P. Ivanov and L.V. Akimakina of the Soviet Union (80). The lens array reportedly had two million lenses with a diameter of .3 mm (85 lenses per linear inch) and a focal length of .5 mm (.020 inches). This would suggest that the array size was nearly 42 cm (17 inches) square.

Maurice Bonnet of Paris France proposed the first camera method that was capable of recording both dimension and/or motion; Fig. 7. His camera utilized a scanning "selector" mask to record a scene over a short period of time, a method he later mastered using lenticular (cylindrical) arrays. He used either square-packed lens arrays or two, perpendicularly-crossed, lenticular lens arrays.

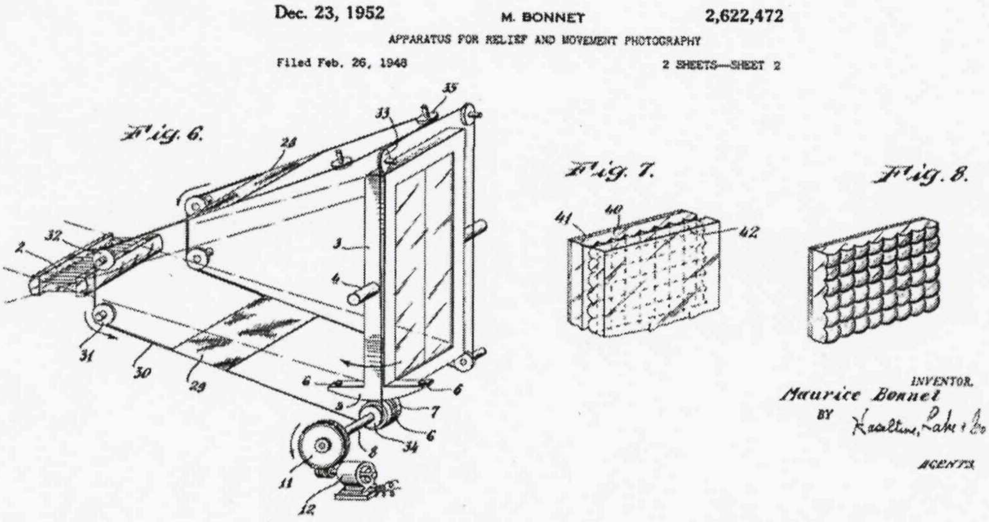

Figure 7: Illustration depicting an “Apparatus For Relief and Movement Photography” using integral lens arrays, U.S. Patent 2,622,472; Bonnet, 1952 (4).

In 1955, John T. Gruetzner of New Jersey experimented with a method of embossing the lens array into plastic photographic film stock, which was subsequently coated with a photographic emulsion; Fig. 8. He produced lens arrays with 40,000 lens per square inch (200 lenses per linear inch). The standard film thickness at the time was .007 inches. His patent included a consumer-level camera design.

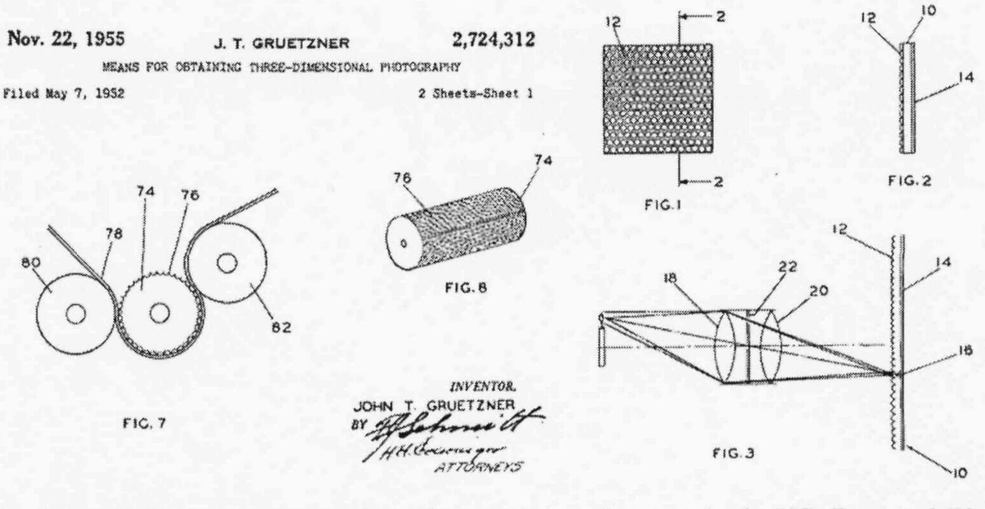

Figure 8: Integral lens array manufacturing and imaging method, US Patent 2,724,312; Gruetzner, 1955 (43).

The general optical principles of the indirect method, using a primary lens, is nearly identical to an ordinary camera, with three exceptions:

> First, the objective lens is typically much larger than a normal camera lens; so chosen to accept a wide field of view of an object.
>
> Second, a lens array is placed directly in front of, and often coated with, the light sensitive emulsion, with the lenslet side facing the objective lens.
>
> Third, the image formed by the lens is not brought into focus, instead it is *placed* relative to the lens screen/emulsion layer in such a manner as to recreate the appearance of the object at that position.

As Winnek pointed out in 1936 (82), an important consideration for this camera method is to establish a relationship between the aperture of the primary lens and the field angle of the individual lenslets within the array, to ensure that adjacent sub-images in the image array are precisely abutting, and not appreciably overlapping or spaced apart. In general, the *f*-number of the primary lens must be numerically lower than that of the lenslets. In many instances an adjustable, opaque aperture plate was used to optimize this relationship for different optical arrangements. Lesley Dudley of Los Angeles pointed out that the shape of the aperture can also be adapted to correspond to different lens shapes and packings, such as square aperture for square-packed arrays or a circular aperture for hexagonally-packed arrays (Fig. 9). Both Dudley (25-28) and Takanori Okoshi (61-65) have provided exceptional studies of the optics of a variety of integral methods.

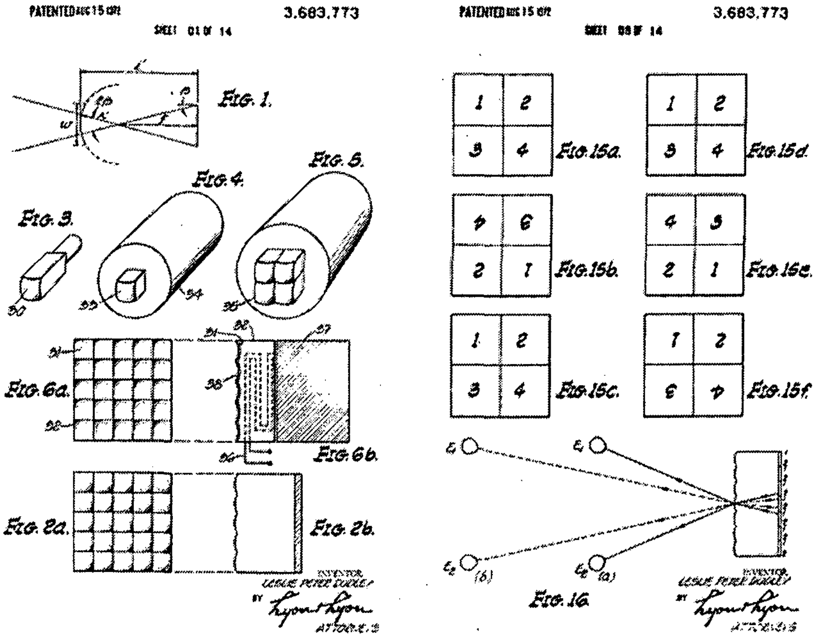

Figure 9: Integral lens array configurations, US Patent 3,683,773; Dudley, 1972 (26).

One key advantage of the indirect method, which often consisted of an compound optical assembly, is that the location of the aerial "real" image could be modified by either adjusting the location of the object, adjusting the position of the optics, or adjusting the proximity of the lens array within the focal plane of the camera, all along the z axis of the optical train. In other words, objects could be made to appear to be floating in front of, at the surface of, or inside the lens array, or a combination thereof; simply by making one of these adjustments in a precise manner.

Unfortunately, some form of spherical distortion artifacts were common by virtue of the requirement of a relatively large-aperture, wide-angle, primary lens, or concave mirror. Additionally, the cameras were still only capable of imaging relatively small actual objects.

The first one step imaging solution was proposed in 1968 by A. Chutjian and R. J. Collier of Bell Labs (12). This method presented a calculated, computer-generated pseudoscopic (reversed depth) image to the lens array, which naturally re-inverted the image to be orthoscopic (correct depth). The image was formed by moving a series of progressively-changing contours of an image, in layers, on a CRT screen, or by presenting a succession of computer-written transparency film masks behind which was placed a high-intensity light source, along the optical z axis; Fig. 10. The result was a fully volumetric, computer generated image. The image was recorded through a integral lens array to a light sensitive emulsion. Not only was this the first one step method proposed, it was also the first method to create computer-generated integral imagery and the first method to propose using a CRT or transparency masks to simulate a non-existing object.

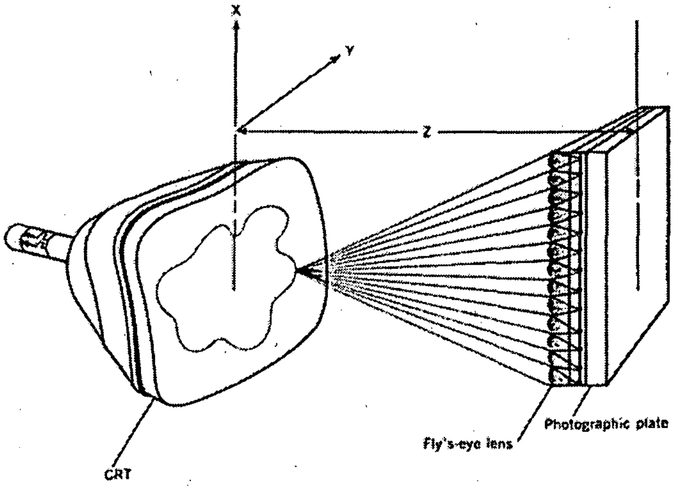

Figure 10: Illustration from Collier article in Physics Today, 1968 (11).

A similar one-step integral method was later designed by David Roberts and Ivars Villums in 1989 for Three Design Company in Wisconsin which introduced the use of color transparency masks and an objective lens camera, which Bell labs had not contemplated. The method used a dual primary lens camera, that resulted in color objects that appeared to float above or below the lens array. In one experiment an image of a credit card was produced to appear to float several inches off the lens screen. This work was done as an extension to US Patent 4,878,735; Villums, 1989 (81).

A number of researchers advanced the process of Integral Photography in the sixties and seventies including, most prominently, Roger de Montebello (21-24) who produced hundreds of striking images using his patented Integram system (Fig. 11). He was the first to offer the technology, along with lens arrays, to the general public through his company MDH Products of Ann Arbor, Michigan. De Montebello went on to describe methods of manufacturing his lens arrays "comprising a large number of closely adjacent or contiguous lenslets, closely packed in either a square, or preferably a hexagonal array, formed of transparent moldable or castable plastic material" in 1971 (22).

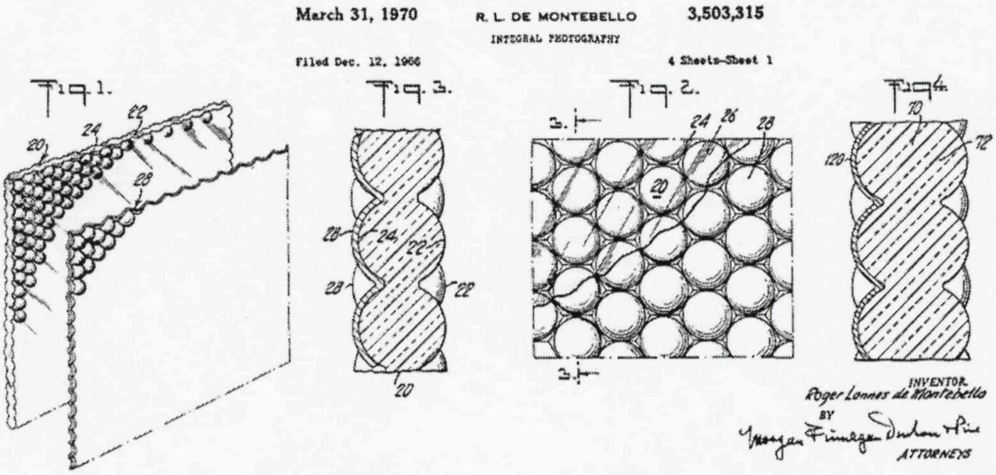

Figure 11: Integram method, U.S. Patent 3,503,315; de Montebello 1970 (21) .

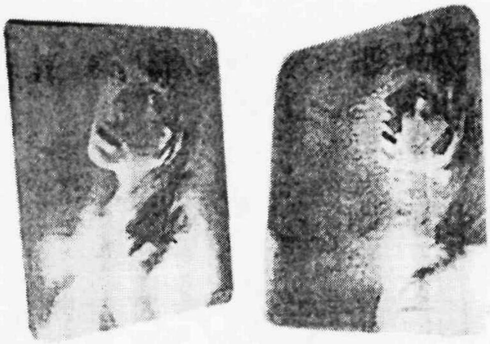

Figure 12: Two views of a single 11" x 14" Integram photograph; Roger de Montebello, 1977 (23).

From 1970 through 1987 a group of researchers in the Soviet Union produced an impressive body of work that was documented in over twenty technical papers published in the Soviet Journal of Optical Technology ((1)(3)(31-38)(48-49)(70-74)). Certainly the most thorough investigation of the technology up to that time, their work still stands as some of the best reference material on the subject. The researchers included Yu. A. Dudnikov, B.K. Rozhkov, E.N. Antipova, N.K. Ignat'ev, I.M. Chaykina, N.P. Samusenko and M.D. Khukhrina.

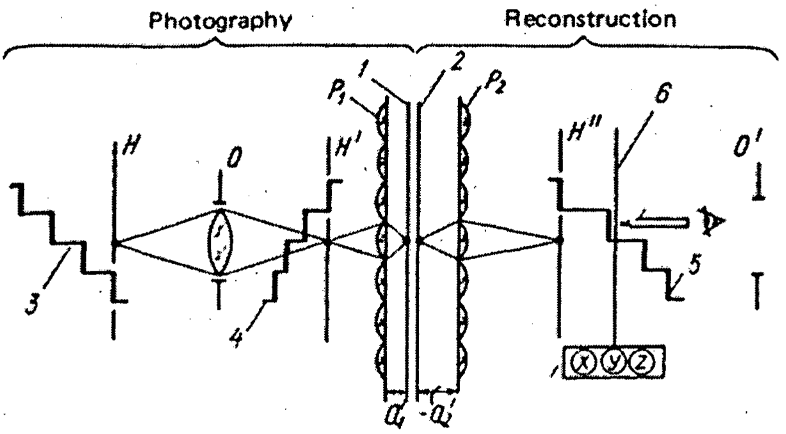

Figure 13: Scheme for photographing and reconstructing integral image: **P_1** - photographic lens array, **P_2** - projection array, ***O*** - objective lens, ***O'*** - integral image of the exit pupil of the object lens, **1** - object, **2** - image of the object beyond the objective lens, **3** - integral image of the object, **4** - ground glass plate, **5** - measurement mechanism, **6** - microscope; Rozhkov 1979 (70).

A group of researchers at the University of Sheffield UK also began investigating the process in 1988, and continue to this day. They are principally Neil Davis, Malcolm McCormick, Mike Hutley and Li Yang ((13-20)(58)(83)). They have likely done more work in the area over the last fifteen years than any other group, including developing a number of elegant pseudoscopic reversal methods including retro-reflective solutions, novel camera and lens designs, computer generated images and image reproduction methods. They now reside at the De Montfort University in Leicester under the name Imaging Technology Group.

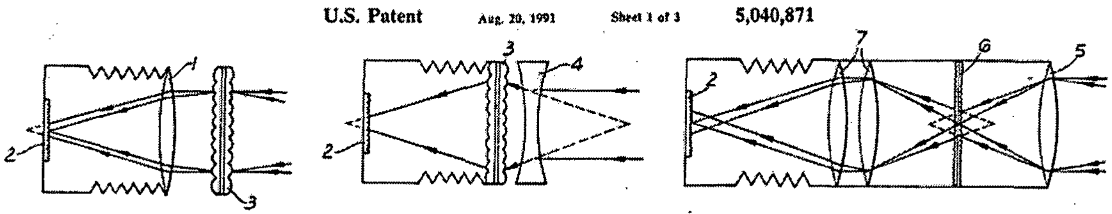

Fig. 1 Fig. 2 Fig. 3

Figure 14: Pseudoscopic reversal method, U.S. Patent 5,040,871; Davis 1991 (14).

In the 1970's lens arrays were still very difficult to fabricate, and prohibitively costly, limiting the wide spread commercial potential of the method. One elegant solution was to use tiny glass beads (typically with a diameter of 50 microns) embedded in photographic emulsions. The first to propose the concept was John Alofs of Grand Rapid Michigan in 1970 (2), closely followed in 1972 by C. B. Burckhardt and E.T. Doherty of Bell Labs in New Jersey (9). 3M continued this area of research in 1987 using the glass bead arrays to create animation effects (66) and animation effects on curved surfaces (5).

In 2001, 3M developed a three-dimensional product and method using beaded screens to form "floating" virtual objects using a high intensity laser that is scanned by a galvanometer directly to the beaded lens screen through a series of optics (40). In this approach the primary lens or lens screen is moved along the optical z axis as the image is drawn to achieve a fully volumetric image. This is recorded through the glass bead lens array to a metal-based material layer that is generally ablated, or altered thermally, to form an image. Also proposed was again the use of a mask, containing a transparency of a logo for instance, that would be made to appear to float above, within or behind the screen.

One major drawback to the use of glass beads is the focal point of a sphere actually lies well beyond its back surface, meaning the imagery produced from them was not as sharp and detailed as it could have otherwise been using a more traditional lenslet design that focused on a flat back surface (called a *plano convex* lens). Further, a simple spherical shape is not an optimal lens shape. In the early days, plano convex lenslet designs, for both integral arrays and lenticular arrays, were largely limited to spherical lens shapes. Use of such designs in imaging and image viewing can be limiting however as distortions from spherical aberration, astigmatism and coma are unavoidable. This is described by Snell's Law of refraction. Optical designers have long known the performance improvements possible by incorporating non-spherical surfaces, or aspheres, into their designs. Most lenticular designs have incorporated aspheric correction since the eighties, as have many integral lenslet designs. As the methods to master optical lens arrays improve, so does their performance by improved surface quality and precise control over shape. Today lens arrays are typically either diamond tooled into copper or nickel, or produced in photo resists by lithographic methods

Early on integral lens arrays found some interesting photographic uses that were unrelated to three dimensional imaging. The use of the arrays in creating traditional cinematic animations was suggested as early as 1932 by Eliot Keen of New York (52). His method utilized each individual lenslet to record a scene, one at a time, over a short period. These views would be played back individually in rapid sequence to show a ten or fifteen second animation sequence, all on one piece of film ordinarily used for a single exposure. The camera was used both for taking the animation and as a projector to play it back. Similar approaches were later refined by Edwin Land of Polaroid in 1960 (53), Goodbar in 1963; Fig. 15 (42), and Browning in 1966 (6). Another novel use was described by V.C. Ernest in 1935, that used lens arrays to produce lithographic halftones (39).

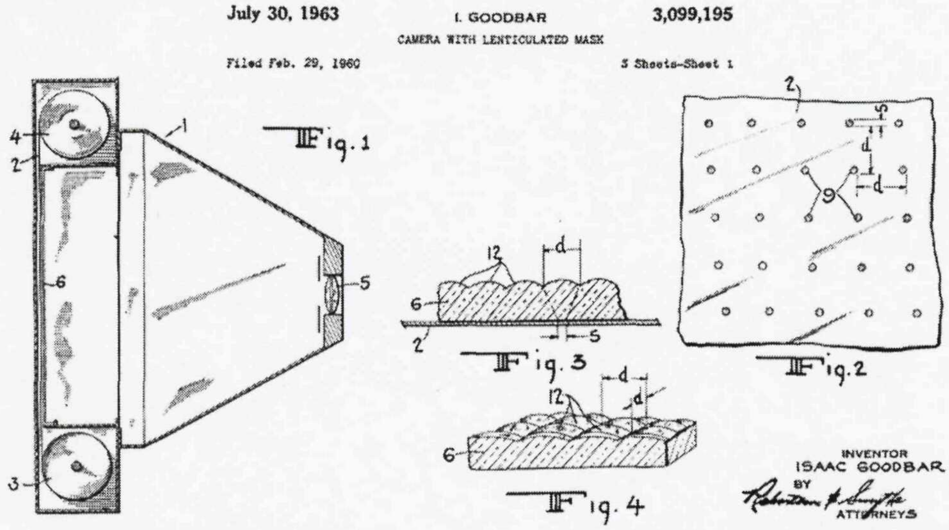

Figure 15: Camera with lenticulated mask, U.S. Patent 3,099,195; Goodbar 1963 (42).

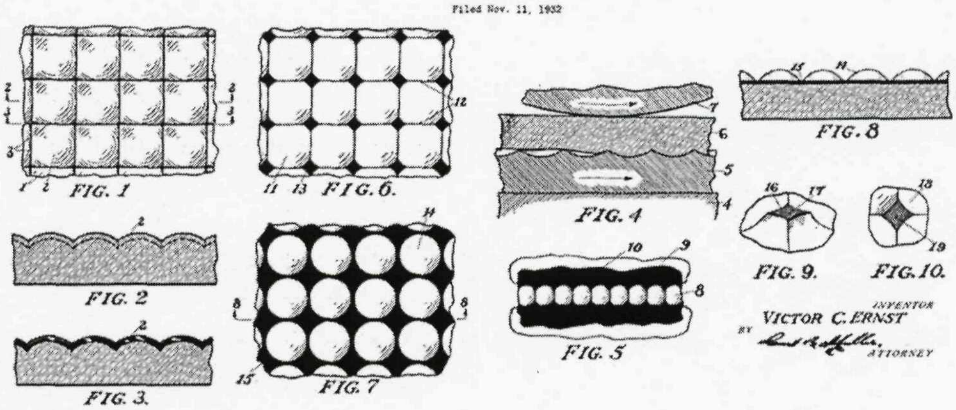

Figure 16: Full tone reproducing screen , U.S. Patent 1,991,888; Ernst 1935 (39).

The first in depth study of lithographic printing of auto-stereo imagery was described in 1936 by Carl Percy and Ernest Draper of the Perser Corporation; Fig 16. It included methods of mass producing integral imagery, either using a lens array or aperture array, what they referred to as *diclinic* imagery, and lenticular or barrier, what they called *monoclinic* imagery.

Along with describing methods to form the lens arrays in celluloid or glass, they point out the problem of objectionable moiré artifacts that resulted when using traditional halftone printing methods to reproduce the images. Two general solutions to the moiré problem were proposed. The first solution was to use halftone screening, but at non-standard screen angles. They wrote,"It is best to avoid angles whose tangents are equal, or nearly equal, to the ratio of any two integers (considering zero as an integer)". "That is, it is best to avoid the following angles: Arc tan 0/1 = 0°, Arc tan 1/1 = 45°, Arc tan 1/2 = 26-1/2°, Arc tan 1/3 = 17°, Arc tan 2/3 = 34°". They further recognized that auto-stereo imagery required higher definition than traditional printing, and thereby suggested using line screens with frequencies as high as 400 lines per inch, over four times the norm of the period.

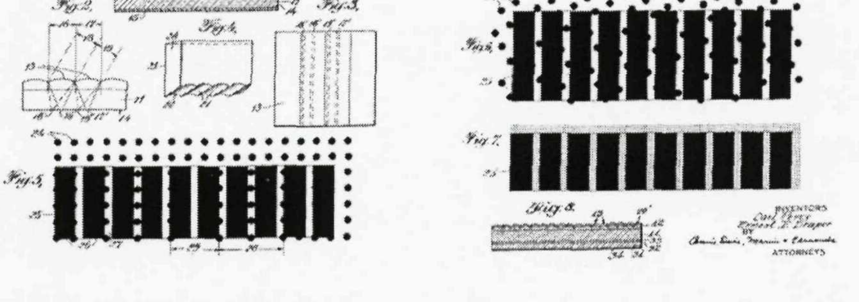

Figure 16: Percy and Draper demonstrate the advantages of rotating halftone screen angles to avoid moiré patterning, U.S. Patent 2,151,301; 1936 (69).

The second solution was to use a continuous tone printing method of the era called collotype, which was a gelatin plate process, exposed through photographic film, that did not posses a mechanical dot structure, and therefore avoided moiré effects altogether. The method had it's drawbacks however, as the gelatin plates were fragile, which resulted in very short press runs of typically only a few hundred sheets, and required very skilled and specialized pressman.

The Perser corporation of New York was apparently the first company to mass produce backlit barrier strip novelty images in the thirties called Depth-O-Graph's. Their insight at the time however was remarkable, as rotated halftone screen angles, higher frequency line screens, and continuous tone (stochastic) methods are all still essential tools in lens-array printing today.

A motorized retro-reflective animation display incorporating a fly's eye lens array was proposed in 1947 by Fred Hotchner of Los Angeles; Fig. 17. In his design, an "interlaced" patterned screen, which was printed to a retro-reflective surface, was moved precisely under a lens array to create a dynamic animation effect.

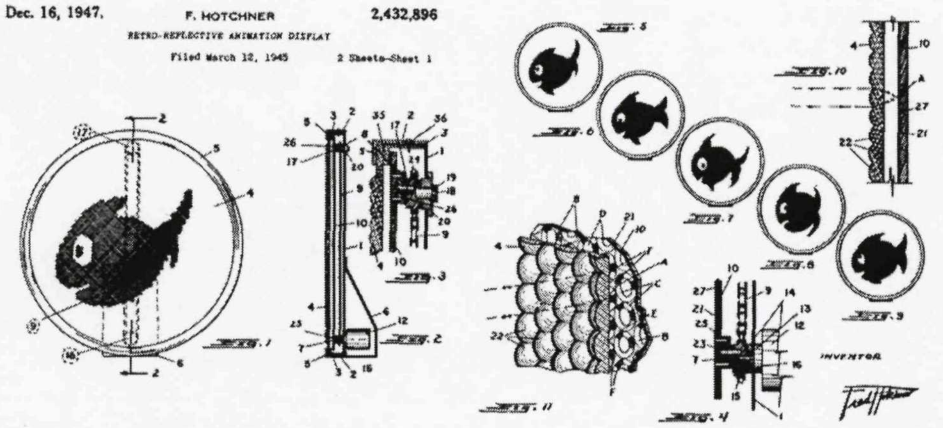

Figure 17: Retro-reflective animation display, U.S. Patent 2,432,896; Hotchner 1947 (46).

The first traditional integral animation effect method was proposed in 1958 by Juan Luis Ossoinak of Argentina who described using square-packed lens arrays or lenticular screens to produce animation flip and motion effects; Fig. 18. He suggests using the animation of "legends, mottos, photographs, cinematographic pictures or animated drawings, etc." His work was certainly synchronous with Victor Anderson's around that same period that produced flip and animated lenticular images in the millions (beginning with the famous "I Like Ike" button), but went further to consider the advantages of using an integral screen. Interestingly, Ossoinak only describes a method of arrangement of sub-images behind the lens array and the resulting animation effects, not any specific method to produce the arrangement.

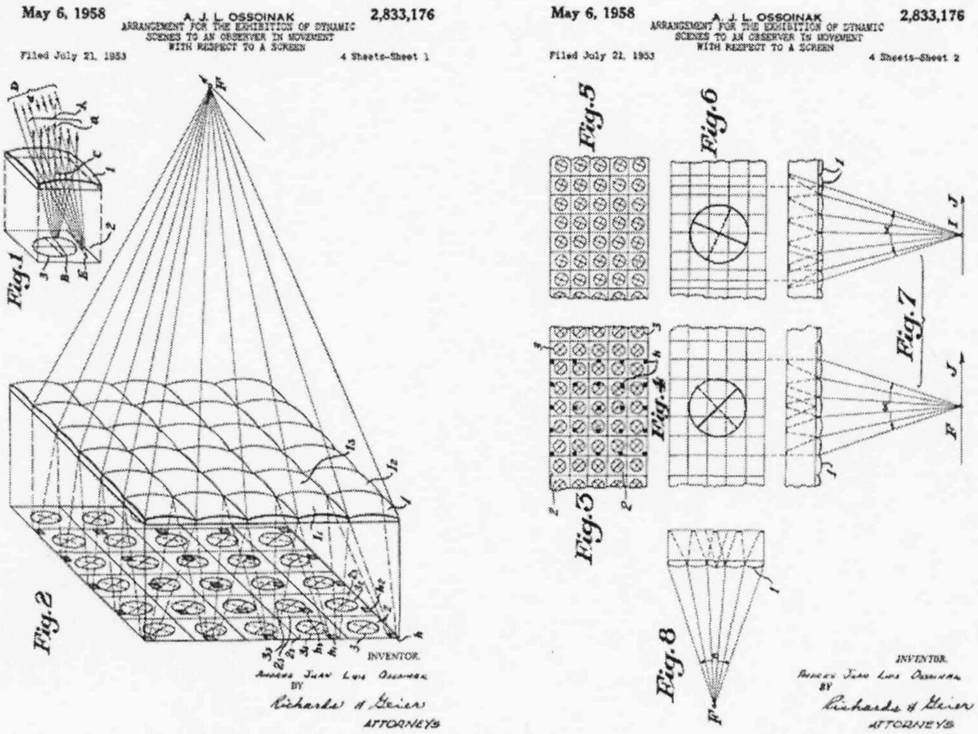

Figure 18: Integral lens array animation effects, U.S. Patent 2,833,176; Ossoinak 1958 (67).

Creating 3-D integral imagery of purely computer generated objects, by digitally calculating and interlacing image points was first demonstrated in 1978 by Yutaka Igarashi, Hiroshi Murata and Mitsuhiro of the Tokyo Institute of Technology in Japan; Fig. 19. They displayed their computer generated images on a CRT monitor, with a square packed lens array fitted to the front of the screen. The experiment used an array consisting of 53 x 53 lenses. Certainly one big advantage of computer-interlaced imagery is eliminating the need for complicated pseudoscopic-inversion methods, by simply arranging the micro images in proper orientation.

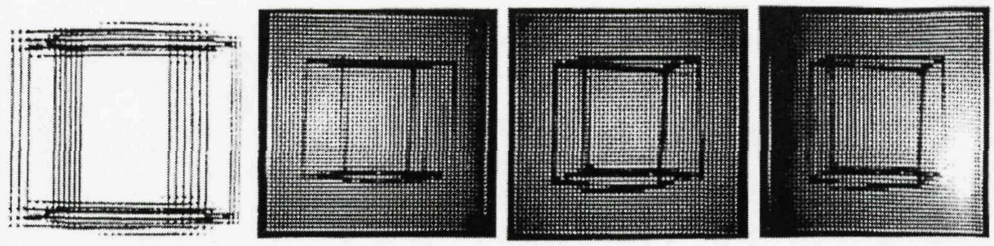

Figure 19: Digitally interlaced integral image (far left), various views of subsequent integral print (right); Japan Journal of Applied Physics, 1978 (47).

As photo-mechanical techniques were replaced by digital solutions in the late eighties and nineties, researchers naturally shifted their focus from photographic reproduction methods to digital methods. Digitally interlacing high-resolution integral imagery for output on printing devices was first proposed by Ivars Villums in 1989; Fig 20. Villums describes a method of integral imaging using diffraction-based lens arrays. Villums and David Roberts explored a variety of reproduction methods from 1988 through 1992, including x-ray imaging, photographic methods, projection methods and lithographic printing. The use of diffractive lens arrays for integral imaging continues to be explored today by Mathias Hain et al. (44).

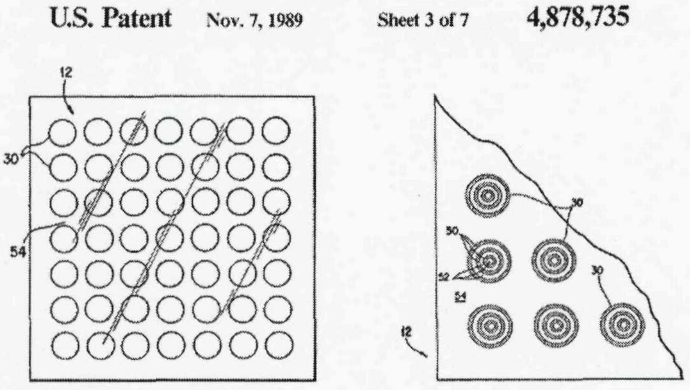

FIG.4 FIG.5

Figure 20: Diffractive integral lens array, U.S. Patent 4,878,735; Villums 1989 (81).

Following the success of mass-produced lenticular products, mass-production of integral-based products was explored by a number of companies. In 2000, Lenticular Corporation of Wisconsin began exploring the engraving of integral lens embossing extrusion cylinders via laser-ablation with the hope of mass producing the product. To support this product Satori Vision of Virginia developed FlyCom, an integral interlacing software program, Fig 21. Bringing Bonnet's groundbreaking work in the 1950's with Relief and Movement Photography (4) into the digital realm, FlyCom enabled the combination of full X/Y parallax and animation effects within digitally interlaced, integral images.

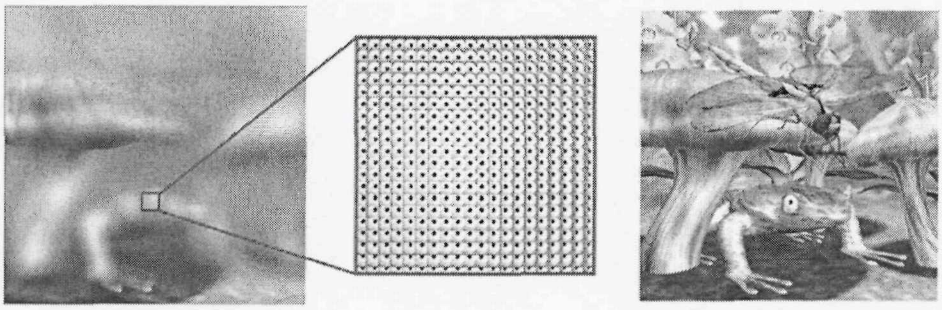

Figure 21: Digitally rendered, integral image; FlyCom, 2000. Image rendered using 100 views per lenslet (10x10); Left: interlaced integral image, Center: enlargement, Right, single de-interlaced view of 3D/Animation scene.

Since the late 1980's, Ken Conley of Microlens Technologies has been producing experimental integral-array master embossing cylinders, with numerous material runs utilizing UV resin casting at Rexham Corporation of New York, and plastic extrusion runs at Eastman Chemical in Tennessee.

Work in lithographic integral image reproduction continues with the work of Phil Gottfried of Texas in 2002 (41), and Davies and McCormick of the De Montfort University in Leicester. Dr. Daniel L. Lau of the University of Kentucky-Lexington and Trebor Smith of ThreeFlow, Inc., have also developed a number of patent-pending lenticular and integral-specific digital halftoning methods, Fig. 22.

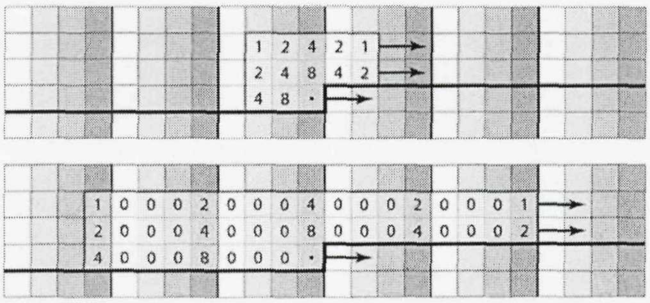

Figure 22: The (top) traditional and (bottom) lenticular Stucki error-diffusion filters for a four component, lenticular image where halftoning can now be done after the spatial multiplexing of images but with the same results as if done prior to; Dr. Daniel L. Lau, Optics Express, 2006 (54).

Integral Imaging holds great promise. While the mass production of integral lens arrays remains difficult, they will likely become widely accessible in the near future as the relevant replication technologies continue to evolve. Once available, these lenses, when coupled with readily-available digital interlacing and effects generation software, will enable lithographic integral imagery to develop as an important advertising medium.

Many thousands of experimental images have been produced throughout the last century, by a wide variety of methods, exhibiting 3-D, animation and other impressive effects. Research and commercialization of integral methods remains very active today including a wide body of work in integral television and other electronic displays. Although integral imaging has not yet achieved significant commercial success, its widespread use is inevitable.

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Appendix VII: Video clips of Simulations in DVD

Video clip 1

This video clip is a simulation of the effect I was aiming to create through the research. A girl's floral dress changes its pattern and colour when viewed from different angles.

Video clip 2

This is a short video record of 3D Integral Imaging Technique experiments. In the beginning of the video you can see an experiment with a material that has similar characteristics to the Spherical Micro-Convex Lens array as shown previously in Fig.26. Here you can see the interaction between the movement of the microlens array and the particular configuration of the image which is related to the 3D Integral Imaging Technique. In the second experiment, the video clip shows the advantages in combining the Lenticular technique with the 3D Integral Imaging Technique using Fresnel Lens array. The experimental works of the two combined techniques allows the viewer to experience the floating 3D image in unlimited directions of viewing angles. The experimental work consisting of these combined techniques demonstrates a potential to achieve the original aim of the research.