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# THE DEVELOPMENT, SPECIAL TRAITS AND POTENTIAL OF HOLOGRAPHIC DISPLAY TECHNOLOGY

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# THE DEVELOPMENT, SPECIAL TRAITS AND POTENTIAL OF HOLOGRAPHIC DISPLAY TECHNOLOGY

Holographic Technology is a type of display technique created in the last century. The applications and usages of it have been developed and popularized rapidly in the recent years. However, to most common people this technique is still just a simple concept or impression.

Compared with the processing performances of CPU and GPU which are reaching their bottlenecks, the development of a new display technology is a new direction for the future of digital devices. At a certain level, the holographic display technology could be a new evolution for the industry and users are able to have a totally new type of experience of visual effects.

The main purpose of this thesis is to give a relatively more complete and clear image of this new-generation display technique, with the introduction of the background and history, and the analysis on the practical examples of applications, advantages and disadvantages as well as potential and challenges.

KEYWORDS:

holographic, filming, display, projection, 3D, simulating, visual effect, application, virtual character, performance, presentation, potential

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# LIST OF ABBREVIATIONS (OR) SYMBOLS

| | |
|---|---|
| CPU | Central Processing Unit |
| GPU | Graphics Processing Unit |
| BTH | British Thomson-Houston Company |
| 3D | Three - Dimensional |
| 2D | Two - Dimensional |
| TV | Television |
| BBMA | Billboard Music Award |
| LDS | Leia Display System |
| $m^2$ | Square meter |
| USD | U.S. Dollar |
| PC | Personal computer |
| OS | Operating System |

# 1 INTRODUCTION

The concept of “holographic display” could be easily confused in certain contexts, especially with the phrase “holographic displaying” which stands for a process in the work of holography, and the definition of it is also understood in multiple ways in the academic communities. In this thesis “holographic Display” is a general term for “holographic projection and display technique” if there is no specific definition introduced.

## 1.1 History

In the late 20th century, science-fiction movies popularized the concept of holographic technique, those virtual 3D images were the first impressions of hologram for many modern people.

In fact, the Hungarian-British Physicist Dennis Gabor accidentally discovered holography when he was conducting the research into improving electron microscope’s performance in BTH (British Thomson-Houston Company) , then the invention of this technique was officially filed as a patent in December 1947 (patent GB685286). Holography has been widely used in electron microscopy and named electron holography in this field, but the generally known optical holographic technique did not really progressed until the laser was well developed in 1960. In 1971, Gabor was awarded a Nobel Prize because of the invention of holography.

The first optical hologram photo with an object's 3D image recorded was filmed by Soviet scientist Yuri Denisyuk in 1962. Meanwhile, Juris Upatnieks and Emmett Leith conducted the same research at the University of Michigan, USA.

The mass production of low-cost solid laser devices was the key that brought significant progress in the development of holography. Devices like DVD players and the lasers in other common devices were cheap and small but their effects could still reach the same level of the expensive and large gas laser devices under certain conditions. In this way, researchers who only had limited budget, artists and even amateurs could all take part in the research of holography (Xuyan, 2011).

## 1.2 Holographic filming and displaying

Holography is the science of making holograms, which are designed for displaying three - dimensional images.

There are two main parts in the holography working process.

### Holographic Filming

The first step is the filming, implemented by the interference of lights. In the irradiation of laser light, the target object creates a diffusing image, the rest of the laser light shoots onto the holographic plate, overlaps with the image. Then it forms interference, which turns the phases and amplitudes in the object's light wave into the varying intensity. In this way all the information of about the

object's light wave can be recorded by knowing the differences and gaps of interference fringes.

After developing and fixation, the plate with the recorded information becomes a hologram.

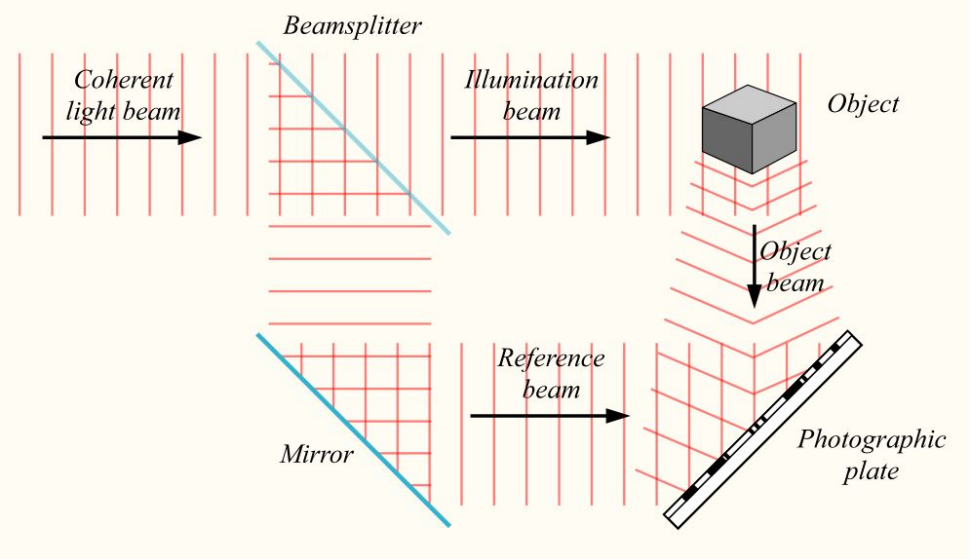


Figure 1. Recording a hologram (Mellish, 2007)

Holographic Displaying

The second step is displaying the hologram, based on the diffraction of light. The hologram is like a complicated optical grating, in the lights of coherent lasers and it will create two images: the original image and the conjugate image.

After these processes are done, the complete image can perform significant three–dimensional and realistic visual effects. Every part of the hologram records certain optical information at each point on the object. So theoretically, each one of these parts could display a complete image of the object separately.

This is the basic working mechanism of holography, and foundation of several derived techniques which have different theories and effects, they will be introduced in the following chapters.

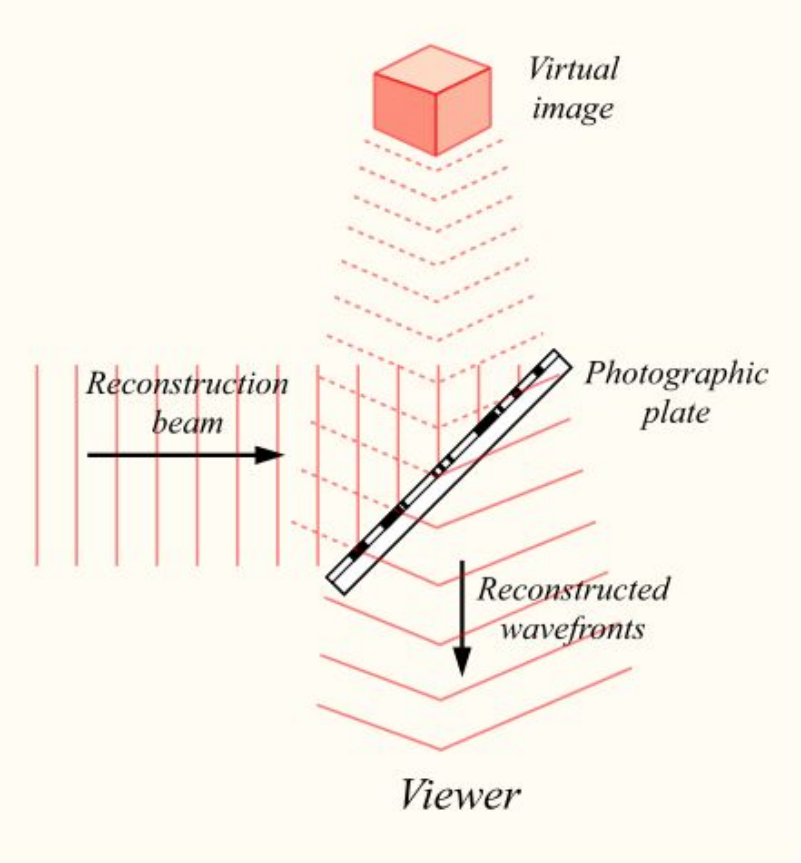


Figure 2. Reconstructing a hologram (Mellish, 2007)

# 2 DERIVED TYPES OF HOLOGRAPHY

Other than the original holography, there are several derived variations of this technology. The all have similar features and also differences, which will be introduced in this chapter.

## 2.1 Traditional Holography

Traditional holography is the original holography which was mentioned in the first chapter. It is the very foundation of all the holographic techniques that are in use nowadays.

The effect of holography is relatively simpler than other advanced new holographic techniques. The actual product of holography is a hologram picture which shows the image on different sides of the object when the viewer looks into it from different certain angles. However, the available range of angles is quite limited and the viewers will not be able to see a clear images once their sights are out of the available range. Due to this feature, the usage of traditional holography is limited, but the historical value of it is remarkable.

A typical example of traditional holography's application is an anti-false mark on a commodity's pack, cash and chip card, which has been used for decades and proofed reliable.

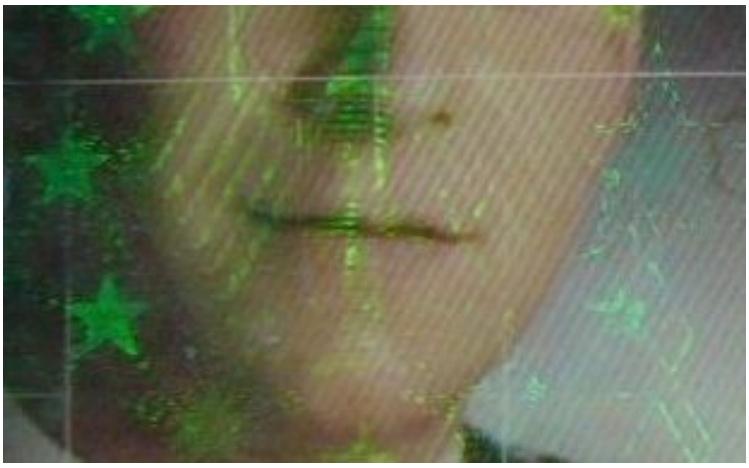

Figure 3. Identigram as a security element in a German Identity card (Mattes, 2004)

## 2.2 Holographic Projection

Holographic Projection, also known as Front-Projected Holographic Display is the most common used holographic technique in recent years, and has become the general concept of holography that people talk about.

The traditional projectors shoot the images onto a cloth or plastic white screen. Instead, holographic projector uses a transparent screen to display the object's image. This method makes the image look standing in the air, realistic and stereo.

However, even though the visual effect is close to 3D, and some industry insiders named this kind of effect '2.5D', it is actually still 2D since the platform for it is a simple planar screen. The viewers need to be in a strictly proper angle to have the best experience. This factor was the most serious problem for the

industry to consider ever since 360° Holographic Display came into people's sights.

### 2.2.1 Fourier Transform

The working theory behind holographic projection is Fourier Lens Transform. Fourier Transform is a type of linear combination which can transform a function into a trigonometric function or its integration under certain condition, it has many derived forms in different area.

A holographic projection works based on the Fraunhofer approximation in scalar diffraction theory, and the displayed image could be treated as the intensity distribution of Fraunhofer diffraction image generated by a purely phasic hologram.

According to the quality of Fourier Lens Transform, the Fraunhofer diffraction of planer image in close range could be implemented with the use of Fourier Lens, and a simple instance of process is showed in Figure 4.

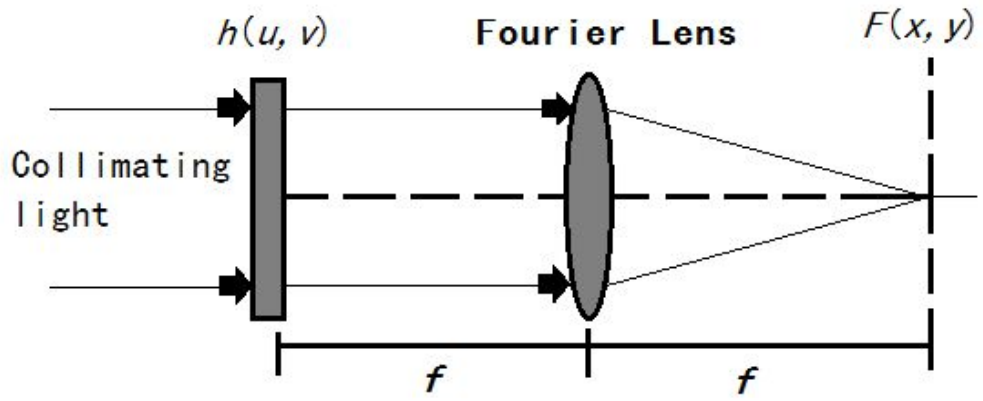


Figure 4. Fourier Lens Transform process (Burkley, 2011)

When the hologram $h(u,v) = exp(i\phi_n)$ is irradiated by the collimating laser light source whose rays are parallel and spreads minimally as it propagates, the amplitude distribution $F(x,y)$ on the rear focal plane of the Fourier lens equals to the 2-dimensional Fourier Transform of the hologram $h(u,v)$. In formula it could be understood as: $F(x,y) = Á\{h(u,v)\}$. (Xuyan, 2011)

This is the working theory of basic holographic projection. In other words, this method that records the coordinate of each point of the original image instead of rebuilding it in a new coordinates system.

## 2.3 360° Holographic Display

What makes the Front-Projected Holographic Display become the most common

used holography technique is an advanced application of it - 360° Holographic Display. This kind of display requires a four-sided pyramid glass projection screen set, instead of one simple transparent screen for the basic Front-Projected Holographic Display. The working theory remains unchanged, the difference is that the 360° display needs more complex hologram films which contain all sides of the target objects and projects them onto each side of the pyramid screen separately.

This advanced use of Front-Projected Holographic Display is the solution to the most critical shortcoming for all the previous holographic techniques: the limitation of the viewing angle. In the pyramid screen, viewers are able to have their visual effects of realistic stereo objects from all positions, and the holograms become 3D models instead of 2.5D (Xiang, 2014).

On the other hand, the application of the 360° Holographic Display is still not perfect. An obvious problem is the shape of the screen set; the displays on the edges of the pyramid always show incomplete or distorted images. As a solution to this problem, the practitioners usually make the object rotating or moving to minimize the visibility of distortions.

Another method for improving the performance is increasing the scale of the screen set and the complexity of the original holographic films. Theoretically if the scale of these sets is great enough, the visual effect could be incredibly close to perfect. However, this kind of perfection comes with extremely high costs and due to this reason, in the past it would be used only in top-level events.

Nowadays, when the 360° holographic display is relatively well developed and becoming more mature, and the problems and limitations are gradually eliminated, the use of this technique keeps being so popularized and expanded that it could be considered as the basic of advanced forms of holographic projection.

## 2.4 Air Holographic Display and Interaction

Air Holographic Display is the most common holographic technique in science-fiction movies such as <Star Wars> and <Back to The Future>. The purpose of this technique is just like its name, the complete hologram could be directly displayed in the air instead of any solid medium, which means there is almost no limitation for the viewers to have the ideal experience. On the other hand, it also allows the users to use gesture controls directly on the projection images, which makes the human-machine interaction more fluent and comfortable.

Unfortunately, at the present time the real air holographic display technology still only exists in movies and imagination. Due to the light brightness and air density, not all the colors of lights could be reflected by the air in natural conditions. This is the main barrier for the development of the air holographic display.

However, even though it seems a long way to complete this technique, the industry is making progress. For now the generally called air holographic display

is actually the concept of technology that could achieve relatively ideal effects by using steam or other forms of invisible gas instead of a solid screen as the rear projector. There are already successful products of this kind existing, and some of them are able to implement the direct interaction by using sets of sensors and special algorithms to read the gesture controls from the users (Sheng, 2013).

Currently, air holographic display is still newborn and barely developed. Literally, the air holographic display contains the future of digital equipment, it is no exaggeration to say that in the current phase this technology is the core of research on holography, and the companies who can research more and obtain more achievements earlier, will have a competitive advantage in the whole industry, especially at this time that computer technologies are almost in a bottleneck and people are eager to see a real evolution.

## 2.5 The Differences Between Holography and 3D Display

Other than Holography, the 3D display is also an emerging display technique which has been developed and used in the recent years. It is mainly applied in 3D movies and videos. Both of these two display techniques share the same goal: performing stereo and realistic visual effects. However, there are significant differences between them.

As introduced in previous chapters, holography could be understood as a technique of solid geometry mapping in the air. It separates the object to multiple

points and records their coordinates (phase position and amplitude), then presents them in another space coordinates system to reproduce the original object.

### 2.5.1 What is a 3D display?

The 3D display was invented in the end of 20th century, and now this technique is mature enough. Nowadays almost all of the large cinemas have advanced 3D movie halls, and 3D televisions also become more and more commonly used. Therefore, the 3D display technique is already a part of modern daily life.

### 2.5.2 Binocular parallax effect

The working theory behind the 3D display is mainly based on human's binocular parallax effect.

A human has a pair of eyes and the total visual angle of them is about 120°, but actually each of them has about 80° sight (slight differences exist among individuals). This means there is an area of about 40° that two sights overlap. Thus when people see things, two eyes will receive different images, and after these differences are processed by the brain, the viewer can feel the sense of distance, space, and stereoscopic effect of objects. 3D display works by simulating this binocular parallax effect.

Similar to holography, there are also two parts in the 3D display working process: filming and displaying.

### 2.5.3 3D filming and displaying

People who have tried watching 3D movies without wearing the 3D glasses share the experience that the videos became blurry with multiple-image fringes. The reason is that there are actually two images at different angles overlapping on the screen. When a cameraman is filming a 3D video, there are two 3D cameras working at the same time with slight deviations to the object's left and right side separately. Then these 2 films are combined by computer and become the original 3D film.

In the cinemas, the 3D videos need to be projected at certain angles, and wearing the 3D glasses is also necessary for audiences to experience the ideal effects. With careful observation, it is not hard to find there are intensive tiny streaks on the glasses, and they are in different directions, normally the streaks are vertical for the left eye and horizontal for the right eye. These streaks are synchronous with the directions of the projecting lights, in these ways the viewer can see separate images through each of the glasses, and the visual effects become stereo (Fan & Xianglin, 2006).

In recent years, an advanced technique of 3D display called glassesless 3D also

has been developed. With this upgrade, users can experience a similar effect from 3D images without wearing the specific glasses. However, shortcomings still exist: the limitation of viewing angel still remains unsolved, and there are strict requirements for the display size. Due to these reasons in current the phase this new technique could only be applied on certain portable devices, such as Nintendo 3DS game console series and several 3D cellphones.

Figure 5. 3D image's visual effect without glasses (Avatar, 2009)

### 2.5.4 Comparison of holographic and 3D display

With all their features taken into consideration, the differences between the holographic and the 3D display are clear. In other words, the holographic display records all the graphic information of the object and rebuilds it to present a stereo and realistic image with minimum limitation of viewing angle. The 3D

display records certain parts of the object's graphic information, and creates the sense of distance and space by simulating the human's binocular parallax effect.

As a simple analogy, the holographic display could be treated as a 3D printer, that is, it records the object and rebuilds a complete duplicate of it; the 3D display is like a general printer, that is, it records the information on certain sides of the object and presents them on separate papers. Thus it could be seen that the complexity of the holographic display is much higher than the 3D display.

Other than the technology content, the holographic display's quality of effects is also better in this comparison. After all, the 3D display needs a giant screen as the rear projector which is a planar platform, so no matter how strong the sense of space is, to the viewers, the visual effect would be no more than 2D with some special effects. Besides, because the 3D technique only records certain parts of the object, the image is not complete and only has about 120° available visual angle, so it is impossible for the viewers to see the flanks or even the back of the object. As to the holographic display, as preciously introduced, this technique uses a transparent or gaseous screen which could be almost invisible. The holographic display also records all the graphic information of the object, there is no dead angle, and the viewers can have the visual of every spot of the object (Tao, 2013).

In conclusion, the 3D display cannot really present 3D objects, most of the 3D perception come with the sense of distance and space. Therefore, even in the comparison with the simplest holographic projection using a single planar film as rear projector, 3D display's effect cannot reach that level of reality.

# 3 APPLICATIONS IN VARIOUS FIELDS

Due to the issues such as the high expense and immature technology, for now the usages of holographic devices are still not well developed and could only be applied in limited fields. There is a long way to go for the researchers and developers to use this new technology in every day life, just like the internet and the cell phone.

Even though the limitations exist, holography had already proved its value in certain fields.

## 3.1 Stage Shows and Concerts

### 3.1.1 The rising of virtual characters

On the 9th of March 2010, a Japanese entertainment company SEGA held a concert named “Hatsune Miku’s Day” where the virtual idol Hatsune Miku had her first show on the real stage. This event could be seen as a historical turning point for the application of holographic technology, and the beginning of a series of remarkable performances on the stage shows (Firth, 2010).

Figure 6. Virtual pop star performing on the stage (immersivetech, 2010)

At the beginning, Hatsune Miku was a human sound source pack published by Crypton Future Media, and the original voice was recorded from Fujita Saki and mixed by Yamaha's voice synthesis program Vocaloid. A famous illustrator, KEI, had designed a cute cartoon character and the image was printed on the product's pack. After the creation of this character, Hatsune Miku's concept was more like a lovely virtual singer, and the publisher also preferred to advertise it as an idol instead of a simple sound source, and this strategy was proved successful. Many amateurish and professional musicians kept creating songs for her. Soon she became one of the most popular idols on the internet and the number of fans increased day by day.

However, no matter how popular Miku is, after all she is still a virtual character and does not exist in the real world. It was a serious problem for the producers to consider how could she really perform on the stage instead of on the screen, so SEGA came up with the idea of using holographic technology, which

accomplished the first stage show of a virtual character in the whole world.

To implement this kind of event, the 360° holographic display is certainly the best option. With the holographic projection on the film set, all the audiences can feel that the character is actually singing and dancing in front of them on the stage.

On the other hand, the design of virtual characters for holographic display has strict requirements. When the animators and designers create the original holographic animations, there are three main features that need to be considered.

Firstly, because all the holographic techniques work are based on the interference and diffraction of lights, and the black colored parts will be displayed as transparent, the designers should try to minimize the use of black as much as possible. When it is unavoidable for certain parts such as hair, the quality of highlight reflection and texture need to be enhanced to make the image visible.

Other than the colors, the scale and size of the character also influence the final effect. In some animation designs, the scale of the character's head is relatively larger and makes it hard to perform some movements. Then the display range of the character will be small, which makes the final effect stiff and unclear.

Related to the scale, the movement is another important issue. The arithmetic in this is quite simple, the larger movement range of the character requires larger holographic film, and of course it means higher expenses. The animators need

to design the character's movements based on the stage condition at the beginning to avoid reworks because of mismatches (Yi, 2013).

The holographic display can give people realistic face-to-face experiences of watching the virtual characters' stage shows. Besides live events and concerts, holographic techniques could also be applied on TV shows, and they work almost in the same way. The only difference is that the projection for TV shows simply uses a single holographic film instead of a pyramid film set for the 360° projection, because the cameras and viewing angles for the stages in TV shows are almost stationary and the audience does not need to view all sides of the object. Thus the holographic projection is also a great option for performing high-quality stage effects for TV shows.

### 3.1.2 Instances of extension

So far there are many practical cases of holographic display being applied in stage shows, and several of them are introduced here as examples.

After the success of "Hatsune Miku's Day", the event was held on every following birthday of this character - 9th of March. Besides Japan, this series of concerts was also spread in foreign cities such as Los Angeles, Bangkok, Hong Kong and Taipei. As the number of fans kept increasing, SEGA started to put other characters from its virtual idol family into the events. Since then, the Kagamine twins, Megurine Luka and other characters also keep attending in the form of

holographic images on the stages.

In July 2010, the same year of “Hatusne Miku’s Day”, holographic display had been applied in the Chinese singer’s Han Geng (Hankyung in Korean), solo concert to perform special stage effects.

On the 31st of December 2011, in the Jiangsu TV’s new year’s eve concert, the producers invited the special-effects team of the movie <Avatar> and the lighting team of English TV show <X-Factor> to implement the holographic effects in the show of the Chinese singer Zhou Bichang. She performed with late great singers Anita Mui, Leslie Cheung and Teresa Teng on the same stage together and accomplished that wonderful time-across show, and it achieved record audience rating at the same time (Dong, 2013).

In 2013, holographic effects appeared in the World Tour Concert of Jay Chou - one of the most famous Taiwanese singers.

In the BBMA(Billboard Music Award) held on the 17th of May 2014, a holographic show became the most impressive surprise for all the audiences. The show started with a dance from a group of dancers dressed in special force customs. When the curtain was open, it was the late greatest pop singer Micheal Jackson sitting in a throne singing a unpublished new song “Slave of the Rhythm”. The effects were significant and the performance was so realistic just like every show presented by the pop king himself (Ze, 2014).

Figure 7. Micheal Jackson comes back on the stage (Billboard, 2014)

Currently, stage show effects are an essential platform for holographic technology to express its value as it can make the effects able to break the limits and perform in diverse ways, and even make virtual characters look live and realistic.

## 3.2 Product Presentations and Exhibitions

### 3.2.1 Commodity model presentation

Nowadays, more and more companies, especially the manufacturers of digital devices choose to hold conferences to gain more awareness and influence for their new products. Usually, the actual physical models will not appear before the official releases, so in the conferences the companies prefer to choose to present their products by pictures and descriptions.

No doubt this traditional method is simple and easy to implement. A speech and a PowerPoint containing pictures are all the arrangements that need to be prepared. However, the effect of this kind of presentation is acceptable but also mediocre, the information that could be received from the pictures and texts is still relatively limited.

As a solution to this problem, a holographic model of the commodity can accomplish more ideal effects. One of the most valuable features of the holographic technique is the high-level completeness and reproduction of the original object. When the product is presented in the form of a holographic model, the audiences can have direct, stereo and realistic visual information of the product's virtual model, which definitely contains more details, such as the texture and overall shape, than the simple pictures do.

On the other hand, the holographic display can even perform better in the presentations of large-size products. For instance, in the exhibitions of vehicles, the holders could present not only the complete products, but also the separate parts such as the engine, cylinders and wheels of them. At higher expense, more details could be seen on the holographic models, make them look more close to the real products (Yihan & Fangjun & Chengfen, 2014).

Moreover, in the exhibitions of rare precious goods such as works of art, antiques and jewelry, the holographic display could even be a security measure. Usually, due to the security issues, replicas of the valuable objects are presented instead of the genuine ones. However, the manufacturing of high-quality

imitations could be complicated and costly. As the replacement method, the holographic model could meet both the security and the presentation effect requirements.

### 3.2.2 Room Simulation

In the business of real estate, other than the outside appearance, the inside space is another a crucial feature for the buyers to know before they make decisions. In the past, normally the estate agents prepared separate sample rooms for different house types, and eventually many of them would be refitted to sell or even dismantled directly. This kind of arrangement was necessary but absolutely wasteful.

Today, with the use of holographic technique, the inside rooms of buildings can be simulated and presented by virtual models, and the buyers can know what the rooms look like without the preparation of physical samples which are considered wasteful. The room simulation works for the sellers themselves as well, they can check the final effects of the designs in advance, and minimize the repetitive works of adjustments and refits.

In a similar way, this kind of application could also be implemented in landscape design, environment design and even city planning.

Thinking about the inside space, which is also important for vehicles. Basically,

the automobile manufacturers will prepare finished cars in their exhibitions for customers to experience the feeling of sitting inside, and unlike the sample rooms, the sample cars are still going to be sold without much rework. Thus this type of presentation is effective and rational for cars, but what about larger vehicles?

In the marketing of large vehicles such as trains, vessels, aircrafts and even space ships, the sample models are quite hard to be placed in the halls of general exhibitions. This requires the manufacturers to use outdoor showgrounds or the customers have to see the products only in the factories or warehouses; either way the process is complicated.

Again, the holographic display stands out as a more scientific option to solve this problem. Holographic models are capable for most types of exhibitions, even though the customers always prefer to see the full scale models in the sizes of the real products. With the holographic technique, it is possible to build and present a large room partially and the customers can see all the details of these parts one after another, and all the process can be done in almost any regular-sized exhibition hall.

With all the mentioned factors taken into consideration, it can be concluded that the application of holographic technology is a new direction for commercial exhibitions. There are more and more companies using this novel, efficient, and attractive method of presentation to promote their product, and for the customers it is also more convenient and perspicuous than traditional media, like pictures. It can be estimated that with the continuous improvement of techniques and

decrease of cost, the holographic display has a good chance to become the mainstream of commercial demonstration.

## 3.3 Holographic applications for medical use

Since 2014, an application of holography for medical use has been developed in Israel. With this new technique, doctors can use 3D holographic models to implement surgery simulations. This development has created a new platform for surgical treatment and remote medicine.

The simulation of human's body and organs sounds like a science-fiction movies, but this kind of technique does not just look impressive but it could be a practical assistant for surgeons to save people's life. An Israeli doctor, Elchanan Bruckheimer, mentioned that with the use of this technique, the successful rate of surgery could be significantly increased. "This new system can simulate a complete 3D model of human anatomy, it looks realistic. Doctors can have a clear visual on every detail of the body tissue including the positions of organs and the working condition. With this, the operation can be done more fluently." says Bruckheimer (Realview, 2014).

This medical application was developed jointly by Philips and the Israeli company RealView. Shaul Gelman - the president of RealView indicates that this system works based on data analysis and light projection.

The holographic 3D system can present realistic images without the necessity for doctors to wear specific extra devices. This technique shows its high value also in minimally invasive surgery, and it is being applied in the repair or exchange of the heart valve.

Dr. Einat Birk of the Heart Institute at Schneider Children's Medical Center said that this new system gives a visible model of heart to surgeons and it can display all the information of the organ in real time. So far most computers are still only able to provide 2D images to doctors, but now this new technique can build 3D models which could be much more perspicuous to observe and analyze. "Enlightening" was the term Dr. Birk used to describe the experience (CBS News, 2014).

With constantly improvement, this holographic system could be really well-used in surgical and remote treatment areas and it has significant value for the development of modern medicine.

# 4 THE FUTURE

On the basic of these practical applications that people are using nowadays, it can be concluded that holographic technology has great value in various fields. In fact, at present the development of holographic technology is still in the start-up stage and there are many possibilities existing in the future, and some of them are already even coming soon.

## 4.1 Imminent Products

Since there are already various types of holographic devices exist in the market, based on the continues improvement of techniques, it could be expected that more applications and products of holographic technology are coming closer and closer.

### 4.1.1 Holographic Cellphone

On the 17th of July 2014, the Chinese technology company Estar announced its new holographic cellphone project “Takee”. In the presentation, the holder indicated that this brand new cellphone can perform realistic holographic display effects and air interaction.


Figure 8. The concept demonstration of the Takee phone (Estar-Takee, 2014)

After the conference, the industry, the media and even amateurs started analyzing and guessing the possibilities. “Holographic chat”, “holographic games” and other elements could be seen in scientific-fiction movies were never this close to becoming reality.

Meanwhile, a group of users showed the least faith in this new device as they believe “holographic” is just a gimmicky title that the company uses to advertise, and it could not reach the same effects in movies. Unfortunately, this estimation was quite close to the result.

When the product was released, the reality dawned with users sharing their experience and test videos on the internet, and most of the opinions were frustrating. It turned out that the 3D effects that the Takee Phone can perform are implemented by a set of sensors tracing the user’s eye movements and sight line and displaying different angles of the 3D models in real time. The application does not contain the holographic display process, so technically it is just a

complicated form of regular screen display which can present relatively more stereo 3D models (Shangmei, 2014).

In 2015, the similar technique was applied in Amazon's Fire Phone, but by that time no one would consider it as holographic technology anymore. Obviously, this application does not meet the user's expectation.

However, everything has two sides. Through this new product concept, even though it did not make the dream came true, at least it is a direction of developments for the industry and the companies can start having views on more advanced technical evaluation instead of reducing the weights or enlarging the screen sizes of devices.

Ostendo Technologies in California is working on the development of their holographic device - a holographic projection chip which could be small enough to be installed inside a portable device. In their vision, that single tiny chip will be able to project a 48-inch image on any platform. This basic 2D version works well in the tests, and with multiple chips connecting together and special techniques, an advanced 3D image of larger size and higher resolution could be projected directly into the air. Currently Ostendo already showed their concept demonstration, and according to their estimation, They are very hopeful that the complete device could be put on the production line by late 2015 (Boxall, 2014).

After all, the holographic cellphone is a brand new area that no one has achieved success before, and the fact of all the rumors or estimations could not be told until an actual working product is presented in front of the users. However,

it is still worth expecting and there is the possibility that this kind of technology could come even sooner than anyone has imagined.

### 4.1.2 Air Holographic Projector

As it was mentioned in previous chapter, the air holographic projection is the core of the development of all holography applications, and there are products in the market to purchase already. As one of the most typical and representative device, the LDS series has been in use since 2014 and gained considerably positive evaluations. According to the introduction on Leia's official site, currently they have two models for sale. S-95 is a TV-sized holographic projector to display virtual characters, 3D models or even games, and the image is fully interactive and could be useful for museums, promotions and virtual control panels. X-300 is a device hanged from the ceiling which could cover a 3 $m^2$ area and simulate larger objects such as cars by its projection. It could also be well used for both business and entertainment.

The work of LEIA's system is based on the use of streams of barely visible fog generated by a part of the projector, which is the image carrier, and LEIA's technology allows the laminar airflow to be generated in a long range continuously, which makes this series the most steady air holographic projector in the market for now (LEIA, 2015).

Figure 9. 3D plane displayed by LDS (LEIA, 2015)

Other than LEIA's products, there are also many companies working on their holographic projects since this is a development trend for the industry. At present, air holography still relies on the generation of gas, so the goal for the next phase could probably be the simplification of device complexity and size which could influence the extension of this new technology's applications.

## 4.2 Potential and challenges

Even though there are many actual products in the market already for this start-up technology, undoubtedly there could be many imaginable possibilities and potential applications to be developed, and even more that people cannot see at this time.

What kind of holography applications could be expected in the near future, and

what problems and limitations still need to be solved? The answers to these questions are analyzed in the following sections.

### 4.2.1 Household equipment

Nowadays holographic devices are mainly used in commercial exhibitions, business conferences and large-scale entertainment. They could be considered well-known by many users, especially the insiders of the industry and tech enthusiasts.

However, to really popularize the use of this technology, it needs to be accepted by the general public besides customers in several certain fields. Thus, the household equipment area could be an important battleground for the development in the next phase.

Just like TVs, computers, phones and any other technological products everyone is using every day, one standard to judge if a new product is well-spread and widely accepted is the popularization rate in the general user group. Since there are already products in the size of a normal TV which could be set in almost any room, the expansion of use in home entertainment is actually not that far from now for people to implement.

Holographic TV will probably be an option for average families to choose as one of their entertainment terminals in the living room. It could be able to project large-size and high-resolution 3D images in mid-air without a huge solid screen,

and this factor could be considered as an efficient method to save space while performing advanced visual effects.

The motion-sensing game console is another potential application for holographic display. Nowadays all the mainstream video game consoles have many motion-sensing games. This type of games was once considered a new style of gaming and became popular for more and more players. It can easily be seen in the market that all those consoles implement the interaction between player and the virtual world by using special controllers with motion sensors, or cameras capturing player's movements and calculate the distance. Other than these factors, the most obvious limitation for this kind of interaction is the solid screen which is like a block on the border line between the realistic and virtual world. With the use of holographic display and interaction, players can communicate with objects in games more directly; they could be able to walk in the game scenes, interact with virtual characters, and control objects by their own movements instead of the traditional controllers. This is another direction of gaming device development besides the VR equipment for enhancing player experience of human-computer interaction.

There are still more possibilities that holography could be applied in general users' homes. Since the concept of the smart home has becomes a popular topic recently, there could be many household devices using digital control and display, so it is reasonable to believe that the popularization of holographic display and interaction has the potential to provide people with a new high-tech life style.

### 4.2.2 Mobile devices

During the last decade, mobile devices have been developed at an impressive speed and become an indispensable part for modern daily life. Mobile phones, portable music players and portable game consoles now have very diverse functions and significant performance; they are people's outdoor information terminals and in some way they can even be perfect substitutions of PCs.

The application of holography on mobile devices is not really a foreign concept because it can be seen in many movies and fiction set in the future. In these artistic works, holographic mobile devices mainly appear without any physical solid screen. Holograms are projected instead when they are activated, and users can communicate with simulated 3D avatars or control the devices directly by gestures. The range could cover mobile phones, watches or even business cards.

Since the release of the first model of Apple's iPhone, which came with the touch screen technique, it has been a long while that mobile devices have made any qualitative leaps in their display and interaction method. So the development of this brand new style of technology could definitely be a direct excitement for the industry and users, especially when the current devices' processing speed and performance already had passed far beyond the need of general use for common customers.

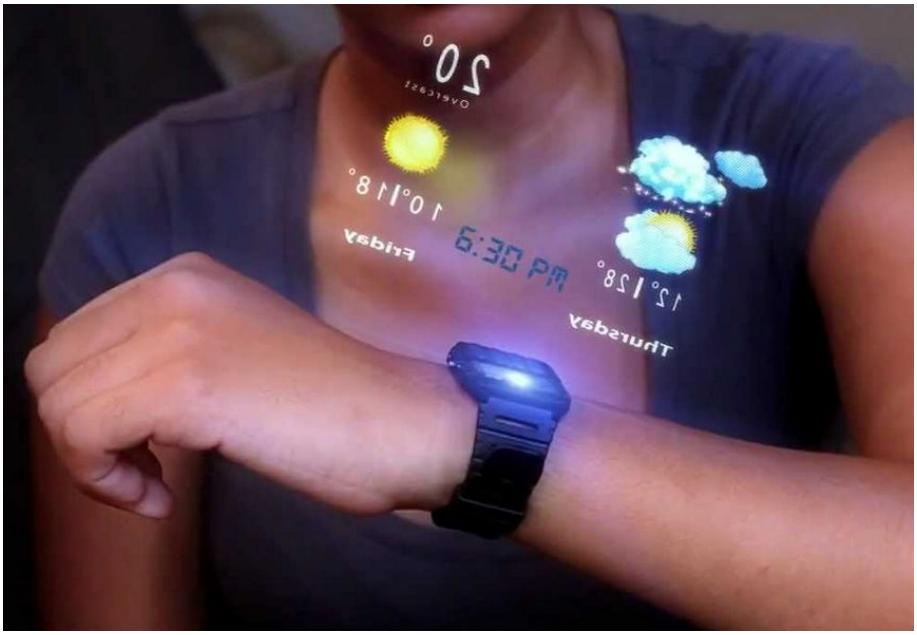


Figure 10. Fan's concept design of holographic wrist watch (Dreamers Awaken Studio, 2011)

Thus it can be seen that the development of holographic mobile device has already attracted considerable attention, and manufacturers are also having a fierce competition to be the first to open the new market. Therefore, maybe this kind of technology will really come into people's life in the near future instead of only existing in their imagination.

### 4.2.3 Online Shopping

In this age of computers, internet and digital devices make all kinds of information reachable from almost anywhere. In the recent years, online shopping has become more and more common and useful for everyone. However, besides its high efficient and convenience, disadvantages have come

with this new form of shopping.

One important negative feature of online shopping is that the buyers can only make their decisions based on the pictures and descriptions on the websites, and sometimes they find that not all of the provided information is reliable.

According to the result of a survey held by students from Harbin Institute of Technology, over 90% online shopping users experienced disappointment when they found that the received product did not really meet their expectations based on the descriptions and pictures (Yuehua et al., 2009).

What if online shopping could be combined with the use of holographic display devices? Just like its usage in any kind of product presentation and commercial exhibition, holography could also be able to present a better form of images that and be used by general customers in their online shopping in everyday life. The 3D model in high completeness of simulation could be the second most reliable reference only after the actual real product when the customers make judgments.

However, the popularization of this kind of application is based on the popularization of devices and this technology itself. For now certain problems still exist and need to be solved for holography to be wide-spread and developed fully.

## 4.3 Challenges

### 4.3.1 High cost

Like any other technology in its start-up phase, considering that the technology is not mature enough and the complexity of design still remains high, for now the price of holographic projectors are definitely too high for general users to accept.

According to the comparison between several online shopping websites, the cost of a holographic projector which only has the very basic function of projecting planar images is mainly between 600 and 1000 USD, and most of the 3D versions are not even available for retail, they are only available for customization for certain events or business uses. Therefore it is not hard to imagine that the price tends to be set especially for enterprises and authorities instead of personal use. On the other hand, the cost of making a real-scale and detailed model of real people could be at least 100,000 USD, and cartoon style characters could be cheaper in certain rates based on the complexity of the model. Obviously this level of expense is out of general customers' consideration for private or family daily use.

The high expense could be considered as the most crucial obstacle which blocks the development of this new technology and leads to a series of other problems. So far, since there are successful designs already in mass production, the next step for the industry and companies to consider could be simplifying the complexity of design and manufacturing process, and reducing the expense which increases the cost performance to higher level that would be accepted by

more general users.

### 4.3.2 Application chain

One standard to evaluate a successful digital product is the complete life circle around it. For instance, the popularization of Android which is nowadays the most commonly used smart phone OS in the whole world relies on its giant base of applications and accessibility of development; on the contrary, the Windows phone OS has a limited number of applications and it could only attract the loyal core users and some curious users. Therefore, the audience group is quite limited so the developers would rather choose other more popular platforms to develop and publish their products. These features finally generate a vicious circle which greatly influences the market share of Windows phones.

For the same reason, the popularization of holographic devices also needs a complete “ecosystem” and application chain to support it, because if no one is making the holographic models, videos, and other special-customized applications, the device would become worthless, just like a TV without shows or a game console without software.

Unfortunately, there are only certain companies, such as LEIA and Ostendo focusing on the development of the device and application of holography, and the number is still too small for building a complete chain. This is also a problem caused by the high expense. Under financial pressure, many developers and small-scale companies would not consider this area until the cost becomes more acceptable for them and also the users.

In other words, the building of the application chain is a key to making holographic devices really valuable and practical for customers instead of good-looking toys but of no use. Hopefully with the improvement of technology and decrease of cost, more developers can join in and help with the popularization of this new technology.

### 4.3.3 Energy consumption

When looking back at the development of electronic products, the hardware scale, processing speed and using experience have all been significantly improved in the past years. However, there is one factor of electronic devices that has barely been upgraded in the process of development in many years, the battery capacity.

Energy consumption is a considerable issue not only for holographic mobile devices but also for any other kinds of portable electronics. At present, the physical energy density of general lithium battery is quite stable, which means that there is a strict limitation for the capacity of battery in certain sizes. Normally, the manufacturers have two methods to extend the battery life of a device. A simple way to improve it is enlarging the size of battery, but considering that the portability is also an crucial feature for mobile devices, the battery size is then limited with the size of device. Another method is the optimization of software and OS which makes the device capable of better performance in higher efficiency, but this improvement requires the developers to fully understand the

application and system and implement a series of research and tests.

According to the working mechanism holographic display, if the ideal effect is to be projected in mid-air, then the energy consumption of this kind of display could be much greater than for a general screen even though it is already a serious problem for some mobile and wearable devices.

The demand for lower energy consumption and longer battery life could be treated as one of the most obvious barrier for the further development of mobile devices, and there are people who believe that when the new forms of energy carrier come into use, the whole mobile device field can make a great step forward immediately. (Yuanwei, 2014)

For now the development of advanced holographic display has just started and there is no doubt that there is a long way to go for the existing problems to be solved and the use of this technology becomes really universal for everyone to use in daily life. However, with the intelligence of researchers and developers, these exciting potentials might be realized even sooner than expected.

# 5 CONCLUSION

In this digital age, smart devices have becomes an essential part of modern life. Display technology can be considered as the last frontier of the development of digital devices.

Holographic display technology was invented in the last century and has developed fast in the recent years. It aims to create stereo and realistic 3D images and provide a new style of visual effect and human-machine interaction.

So far this new technology has already attracted much attention from the industry and tech fans, and there are already practical successful instances of its application in various fields. With the improvement of technology and solutions to certain problems, the use of this magical technology which once only existed in science fiction artistic works is coming closer to the real world in the near future.

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