SPAROGRAM: The Spatial Augmented Reality Holographic Display for 3D interactive visualization

Abstract— While augmented reality (AR) technology has become popular and been widely used in various fields, its usage is still limited to certain static circumstances. For instatnce, AR technology shows two-dimensional flat images which lack the information of depth. However, recent advances in display and computer graphics technology, fortunately, have minimized the barriers of the screen, causing closer relationship between physical and virtual space. In spite of this, there are still restrictions and difficulties to achieve representing pervasive information on the physical space which is the ultimate goal of AR. The central research question for my dissertation is how to present realistic spatial AR visualization with the tight integration of the three-dimensional visual forms and the real space. In this paper, I propose SPAROGRAM, the experimental prototype that is capable of visualizing augmented information by fully exploiting the space that takes in surroundings of the real object coherently. In order to present information effectively and to explore interaction issues by taking advantage of the new display capabilities, I will approach this topic with two methodologies: 3D Spatial Visualization and Interaction. In the early stage of the study, I solved basic problems. First, I designed SPAROGRAM prototype. Then, to express spatial visualization, stereoscopic image was applied in multi-layer, while spatial user interaction was applied in order to provide coherent spatial experience. My initial investigation suggests that the newly conceived spatial AR holographic display possesses the ability to create seamless 3D space perception and to express 3D AR visualization effectively.

Index Terms— spatial data visualization, augmented reality, holographic display, 3D visualization

1 Introduction

Augmented reality (AR) is a live direct or indirect view of overlapping three-dimensional virtual objects in the real world in new and enriched ways. It provides various kinds of virtual visual forms that are difficult to obtain from the real world offering the user a better chance to appreciate and experience the subject being presented. With the help of advanced technology (e.g. computer vision, object recognition, display technology), AR has been applied in diverse fields such as education, marketing, exhibition and medical applications [15]. Such advanced technology has led the boundary between the real and virtual world to become more obscure.

There exists diverse means to visualize and display augmented reality, utilizing special devices such as head-mounted and hand-held displays, and many others. Of those, transparent screen has the ability to reconstruct a complete and seamless space generating 3D information in the physical space more directly [7, 8]. Moreover, recent studies have implemented spatial AR visualization applying stereoscopic 3D images [6, 12]. However, it still has a problem to evoke physical depth cues and it has limits on displaying perfect 3D information because it uses only the frontal flat area.

The dissertation focuses on implementing and visualizing more realistic 3D spatial AR which calls for the tight integration of the 3D visual forms and the 3D real space. To implement this, there are several research questions as follows:

- How to produce three-dimensional information that makes the best use of the real 3D space?
- How to arrange and overlay the information in a real 3D physical space, going beyond the flat screen?
- What can help the user observe and manipulate diverse types of information on the three-dimensional space more easily and naturally?
- In which fields would this system be used in which forms?

In this study, I present Spatial AR Hologram (SPAROGRAM) which is capable of manifesting augmented three-dimensional information by making full use of the real 3D space that encompasses the surroundings of the real object comprehensively and simultaneously. I address the previously mentioned challenges in four ways: 1) Prototype the system by applying 2-layer display and stereoscopic image to provide stable depth perception. 2) After exploring the visualization problems that occurs from a multi-layer display, represent validated techniques and guidelines. 3) Investigate the interaction issues that occur when using the system from the viewpoints of both the audience and operator. 4) Select the environment that the system can be utilized sufficiently and present specific scenarios. This dissertation describes research questions, research methodology, the status quo of the research, and its future plan.

2 Previous Work

2.1 AR Visualization with Holographic Display

Augmented reality is the technology that integrates graphical augmentations into the real environment. Many approaches have expressed AR using special devices, such as head-mounted and hand-held displays. Among them, transparent screen, or hologram, by reconstructing a complete and seamless media space, it enables viewers to see virtual images more realistically by presenting them as if they appear to coexist in the same space as the real world [5]. Starting with the hologram performance, Peppers Ghost (1869), it has been expanding its application into telepresence, presentation, medical training, and desktop workspace for a long time [14, 11, 4, 7, 8]. Even though it is regarded as 3D by providing greater spatial flexibility, image is displayed on a 2D single layer offering a limited depth effect. Accordingly, recent research has shown that applying stereoscopic 3D images creates AR representation more naturally by blending virtual and real objects in the 3D space [6, 12]. However, the area where the virtual forms are presented is limited to the frontal area of the real object, so there are limits to sufficiently use the surrounding area of the physical object as a display area.

2.2 Multi-Layer Display Visualization

The Multi-Layered Display (MLD) is a display technology that is comprised of physically separated display layers. The physical distance between the two displays can bring real depth into the digital display world. Information presented on the rear screen is viewable through the front screen [16]. The physical construction not only supports a sense of depth queues, but also presents us with opportunities for increasing the quantity of information presentable within the visual field of view [9]. Therefore MLD is useful in information intensive environments such as command and control [2, 13]. In addition, MLD is utilized in various environments such as exhibition, advertisement, performance by placing the physical objects between the two displays and displaying related information at each layer display with the flavor of augmented reality. But still, validated techniques and guidelines for visualization and interaction are needed for taking advantage of the physical depth feature to create layers of information.

To expand the existing research, my dissertation focuses on how augmented visualization space can be better designed with the tight integration of the 3D visual forms and the real space.

3 Method and Application

In order to overcome the limitations of conventional AR visualization, we propose a new visualization system, SPAROGRAM that can help the creation of three-dimensional augmented information effectively (Fig 1). This system uses both front and back space surrounding the physical object and the object itself as a display area, so it allows reproducing real three-dimensional information through taking advantage of the real space possible. To achieve this, I need to design the system configuration and solve the spatial visualization and the spatial exploration problems.

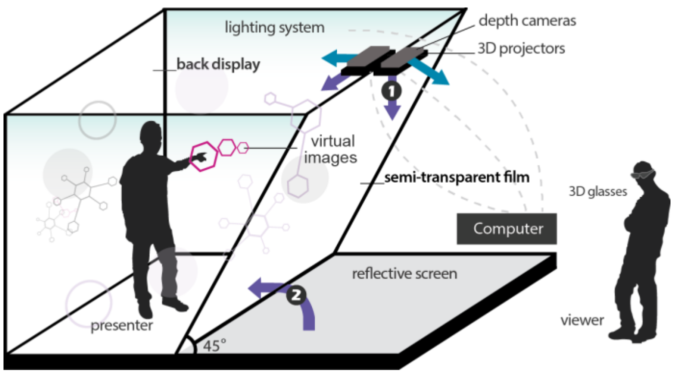

Fig. 1. Prototype of SPAROGRAM.

3.1 SPAROGRAM System Configuration

In order to express stable spatial representation, I need to expand the display area to seamless 3D space. This can be implemented with two methodologies: installing 2-layer display and applying stereoscopic images. Multiple layer displays offer spatial impression by increasing the number of displays and arranging them separately in the physical space [10]. Stereoscopic technologies make the creation of the continuous space between two layers to be possible by adding the third dimension. It allows the virtual information to be merged around the physical object naturally and accurately. After this process, it is required to do a user study on how effective the system is in terms of creating 3D spatial perception and spatial awareness. Also, it is essential to investigate the level of visual fatigue which is caused by multiple stereoscopic images.

3.2 Spatial Visualization

With the system configuration, it is necessary to study how to arrange visual forms effectively and naturally across the two layers in order to get the full benefit of the depth information. At this stage, there might be two research questions. The first research question is figuring out the depth range of each layer. To make a seamless 3D space using both front and back displays, I need to make a clear definition of the range of depth area that each display layer covers. Especially, when the real object is in the real world space, it should be explored how to make proper use of foreground and background surrounding of the physical object. How both layers will be integrated seamlessly is an open question and challenging issue. Further research regarding layering displays and arranging information in both effective and efficient ways in the space is required. The other research issue is how to present information on the physically distinct display layers. After comprehensive understanding of the system, clear guidance and framework to create layer of information needs to be presented through empirical and theoretical approach [16]. By combining form of data, color, and transparency, I can create new ways of presenting information such as focus+context, visual form linking, and information layering. For example, it is possible to present details on the front screen, while still retaining a context for the details on the back screen in the same field of view. Also, text of other visual artifacts such as diagram or objects, can exist on the different layers and overlap with one another within the same visual field of view (Fig2. (left)).

3.3 Spatial Interaction

In the future generation of the system, it is expected to be used in dynamic environments such as interactive exhibition, stage performances, and presentations by incorporating moving objects or actors [5]. Through computer vision techniques, the system could expand the boundary of visualization subjects to dynamic objects. With such point of view, I expect the following two interaction issues. The first interaction issue is the interaction of the active object who lies between the two displays in the system. The active object, also can be referred as the active presenter, is the one who handles the information inside the system by understanding the structure well enough and taking certain action with purposes. In order to present information along the users' movements the position of the presenter and operation behaviors such as 3D transition, rotation, zooming, and many others should be identified. An elaborate multi-tracking enables information and moving object to be registered correctly and naturally. Computer vision field also considers this as a challenging issue. The other interaction type is a passive subject, the audience, who observes the information outside the system. Even though the audience is unaware of the system architecture and does not interact with it actively, it is still important to present the virtual visual forms as their attention is correctly registered on the physical information consistently. One way to solve this problem is facing the user and tracking his or her head to enable motion parallax in order to increase the interactivity between the audience and information. In addition, it is necessary to consider multiple user interactions to provide an enhanced user experience (Fig2. (right)).

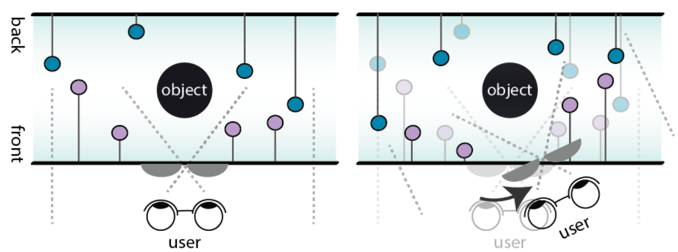

Fig. 2. Spatial visualization (left) and spatial exploration (right).

3.4 Application Scenarios

SPAROGRAM provides immersive viewing experience and is suitable for many augmented reality applications. It is crucial to develop specific scenarios as well as to explore ongoing issues and suggestions for visualization and interaction techniques persistently. Moreover, after applying the system in the real environment, user study is needed to verify the effectiveness of the system in creating seamless 3D AR visualization. In this paper, I briefly explain museum and presentation scenarios.

Museum environment

Today, most interfaces in museums have dead presentation and computer-look-and-feel explanations. Therefore, interesting scenario development that makes full use of museum space and exhibits while consequentially evoking audiences' deeper experience and understanding is required. For example, in the case of additional exhibit's information, SPAROGRAM includes indirect background information and foreground information which explain exhibits directly on each layer display. Also, for the interaction subject, it is not only the audience but also the presenter (or the docent) who can take the advantage of the interactive nature of the display system.

Interactive information presentation
The other scenario is information presentation scenario. When giving presentation, integrating with graphical aids, such as texts, images, and sound, is effective and helpful. In current situation, most of presentation materials are located at the back of the speaker, so there are limits to make full use of those elements. By utilizing SPAROGRAM, presenter may describe information directly which is floating in front of him or her, as well as even surrounding the speaker. Moreover, it is possible for the speaker to manipulate virtual visual forms directly in real time, while helping people explore and navigate data easily and effectively.

4 WORK IN PROGRESS

The dissertation is yet at an early stage and I have conducted basic research problems as follows. I have focused on designing SPAROGRAM system and implementing the system by applying spatial visualization and interaction. Also, I tested the system focusing on how effective the system is in presenting the 3D spatial realism and created example application contents for exhibition.

4.1 SPAROGRAM Design and Prototype

4.1.1 System Design

In order to express spatial visualization, SPAROGRAM uses two displays, a semi-transparent film and a normal projection screen. In early stage, I placed the two displays in parallel with 1 meter of empty space between them. Recently, I expanded the range of the empty space to 2 meters where an actual person can fit it. The semi-transparent film reflects the virtual image, manifesting a virtual image on the mid-air. Moreover, the system can present spatial information visualization by allowing viewers to look at the physical objects as well as the displayed digital information on the front and back displays at the same time. Our physical configuration for SPAROGRAM is illustrated in Fig.1 and Fig.3.

Fig. 3. SPAROGRAM configuration: front view of the system (left), side view of the system (right).

For the front display, I use Musion Eyeliner 42 inch semi-transparent display with 50% light transmission [3]. This front display reflects light toward the viewer from a thin reflective surface under the system. The projector displays a 1024x768 pixels images at 4000 ANSI LUMEN. I installed the controllable lights inside the system that switch the scene between virtual reality and augmented reality information naturally and improve the visibility of the real object. The lighting system is controlled by using ARDUINO [1]. A depth camera which is installed in front of the system faces the viewer and tracks their movements in real time. To block the light and enhance usability, we covered the entire system with a black cloth except for the front which serves as the interaction space with the viewer.

4.1.2 Spatial Visualization and Interaction

To visualize 3D spatial images, I applied a stereoscopic image at the front and back display. Polarized 3D system, one of the 3D representation methods, is not applicable in this case because of the diffused reflection properties. Accordingly, I applied the anaglyph 3D image which can be implemented easily. As an experimental approach, although I currently use an anaglyph 3D image system, active shutter 3D system is preferable for that it is much better at three-dimensional representation and high resolution implementation.

One depth camera (Microsoft Kinect) placed in front of the system faces the viewer and tracks the head to enable the motion parallax. It tracks the position of the viewer head and links it with the two cameras which render graphical elements in the virtual three-dimensional space. This allows the viewer to see the digitalized additional information as their attention is correctly registered on the physical information consistently. Therefore, it ensures the continuity of the spatial experience, increasing the interactivity between the information and the viewer (Fig. 2).

4.2 Feasibility Study

I conducted a user test to evaluate the efficiency of the system in creating the 3D spatial perception and to examine the potential of 3D AR visualization (Fig.4). At first, for the spatial perception issue, I operated only single front display, and evaluated 12 participants (age 20-32, 4 male and 8 female) with three physical variants of the SPAROGRAM: 1) the system applying 2D image, 2) the system applying 3D stereoscopic image, 3) the system applying 3D stereoscopic image and user interaction. Users were asked to arrange a virtual ring image spatially aligned with the physical sphere model which is located in the middle of the system. Then I formally evaluated the error value (the difference of the position between the two objects in space), and task completion time. The results highlight that the system produce not only continuous 3D space perception, but also the better spatial awareness and realism.

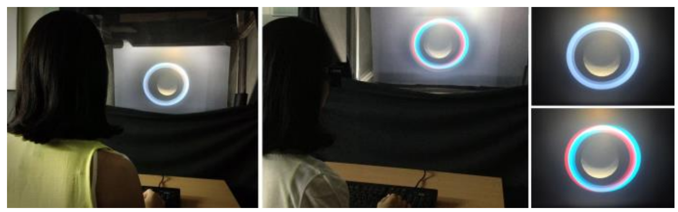
Fig. 4. User evaluation setup: evaluation task applying 2D (left) and 3D (right). 2D AR Hologram-virtual 2D ring image and physical sphere (top), 3D AR Hologram-virtual 3D ring image and physical sphere (bottom)

The second experiment was conducted in order to verify the ability of the system to provide a coherent and seamless 3D space with multiple layers of stereoscopic images. Similar to the previous setting, physical sphere was placed in the middle of the system and four virtual spheres were presented in various sizes and depths. Then, the users were asked to array objects based on the distance between each object and themselves placing the closest one as the first. Results show that using multiple layers of stereoscopic images in AR visualization provides the user with not only more accurate 3D spatial perception but also with more seamless spatial realism (depth sense). This means that the system is different from the general AR visualization method in a way that I used both the real space surrounding the physical object and the object itself as a display area at the same time. After I presented the results of the study at the associated conferences, technical details and the possibility of the system have been proven by international communities. Currently, I am working on the research extending the range of the study further through the collaboration with other researchers.

4.3 Application Contents

As further experiment, example applications were created by using static real object and SPAROGRAM. One prototype contents is data visualization in medical environments (Fig.5). The system produces augmented medical information in the space surrounding the physical human model. For example, through the frontal semi-transparent display, virtual images such as human skeleton, structure of organs, and related information are augmented on each position of the human body model. At the same time, images describing contextual information is displayed in back layer display. Therefore, the audience can focus attention on targeting information, while retaining the ability to see the context of the information. Furthermore, the system enable the audience to explore human organs at various angle, so it helps him or her understand exhibition contents easier and better.

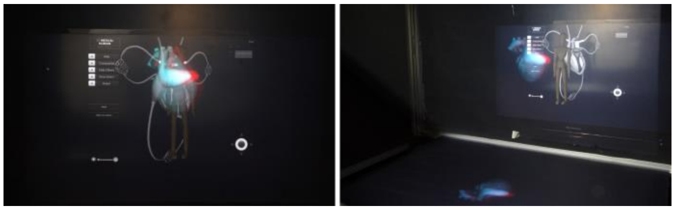

Fig. 5. Prototype of SPAROGRAM content: medical data visualization.

As I mentioned earlier, I expect the system to be useful in diverse fields such as exhibition, education, medical and biological applications, and interactive presentations and performances, where a real person acts as a physical object while manipulating the information on front and back displays.

5 FURTHER DISCUSSION

I believe that the newly proposed SPAROGRAM is the beginning of an exploration of three-dimensional AR visualization. Regarding my research issues, I still have several questions and insatiable curiosities as listed below and further study will be needed. I expect helpful feedback and fresh perspectives on my research topics from DC panellists.

System issue

The current system places display in parallel. If I were to take one step further, would it be possible to compose the space in other different ways such as placing four-sided display that surrounds physical object? Then, will it help create seamless space? Will it increase the sense of 3D space?

Application issues

Since the front display is semi-transparent, image is partially reflected producing a less vivid image than that of the back layer display. Accordingly, will it be possible to ensure the high quality of image, even if I use multiple displays simultaneously? If not, what should I take into considerations in terms of user interface design?
In addition, the current system matches the physical object and the 3D information exactly, but the process is limited to one viewer. Unfortunately, in most of performances and exhibitions, not one but multiple users watch the contents together at the same time. Even though such limitation is not apparent in situations that do not require exact matching, will it be still possible to provide all the audience with an enhanced user experience by applying multiple user interactions?

Human perception issue

Due to the multiple vergence planes caused by multiple stereoscopic imaging, visual fatigue factor becomes an issue to consider. The main concern about it is whether the multiple vergence planes will worsen the visual fatigue problems or not. Then I also need to consider how to offer the audience comfortable viewing experience when they see the real physical and virtual objects located in various position and depths.

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May 1, 2015

To whom it may concern,

I, as the dissertation advisor, am writing this letter to ensure that Minju Kim, who is submitting to the doctoral colloquium, is a Ph.D. student at Graduate School of Culture Technology, KAIST. She has been enrolling at KAIST as a regular doctoral student, pursuing her doctoral degree. Her research topic is concerned with a novel method to explore the holoscopic projection in 3D spaces. I hope that she will be given an opportunity to present her work at IEEE Vis.

Sincerely,

Kwangyun Wohn

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