Dynamic Stereograms with Oculus Rift*

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***Abstract*— Stereograms take advantage of quirks of the human vision to induce depth, and therefore offer a powerful pathway for psychologists and vision researchers to study and probe the human visual system. However, current methods for generating and viewing stereograms are outdated, and often require printing out the images, making them static and inflexible. In this paper, we explore the novel application of virtual reality hardware, specifically the Oculus Rift, for the display of stereograms. ultimately we describe a system to easily generate stereograms that can be dynamic changed on the fly.**

I. INTRODUCTION

Stereograms are pairs of two-dimensional images used to induce an illusion of three-dimensional depth. The usual way this is done is by taking an image and making a copy that is offset by a particular amount. Then the one image is shown to the corresponding eyes so that the brain perceives static depth cues and fuses the images via stereopsis. A sample stereogram is shown in 1.

Stereograms have a broad range of applications that make it worthy of study. For example, 3D movies and depth-tracking video game hardware are built on the principle of stereopsis, while random dot stereograms are used to screen children for various vision defects [3]. For psychologists, experiments with stereograms because they expose unexpected nuances to the human visual and perception systems that offer an opportunity to understand the low-level processes and mechanisms [1][2]. A better understanding of the human stereo-visual system has the potential to impact computer vision researchers, whom might use the knowledge, for example, to build better stereo vision systems for robots [4].

It is surprising then that despite the potential knowledge gained from studying stereograms that the equipment to view them are lacking. Gillam describes a typical setup for conducting an experiment using stereograms: ”The stereograms were generated and presented with a Power Macintosh...Stereoscopic presentation was achieved through mirrors configured to form a Wheatstone stereoscope” [1]. That researchers need to rely on arranging mirrors to induce stereopsis seems tedious and avoidable. There is other hardware dedicated to viewing stereoscopes, but these often require the stereogram to be physically printed out, and thus cannot be easily changed.

Fig. 1. A sample stereogram. Depth can be induced by crossing eyes so that the left eye sees the right image and the right eye sees the left image. Taken from Wikipedia page on stereograms.

The main contribution of this paper, then, is to demonstrate a modern system for creating, displaying, and tuning stereograms. To do this, we make use of the Oculus Rift [5]. The Oculus Rift is a head-mounted display originally intended for virtual reality applications. To create immerse virtual reality applications, it has two high resolution (960 x 1080) OLED displays for each eye that receives input from a computer to which it is connected. Because of its dual displays, the Oculus is easily made into a stereogram viewer, which we believe is a novel application for the device.

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II. Methodology

A. Stereograms

We choose three different stereograms from [1] and [2] to recreate, which are shown in 2.

The first stereogram we seek to create we refer to as the red sun stereogram. It consists of a large white cross between four black squares, and a smaller red cross inside the white cross. Despite the ground truth configuration, typically the embedded red cross is perceived to be a red disc occluded by the four black squares.

The second stereogram is simpler, and we refer to it as the black cross stereogram because it consists of two black crosses. The vertical bar in either image does not bisect the horizontal bar but rather is right and left of center for the left and right image respectively. This creates the illusion of binocular disparity so that when the two images are fused, the composite image is perceived to have depth.

Finally, we describe what we call the random forest stereogram, which consists of two halves, a forest and a plane. Both consists of a collection of sticks of varying length and orientation placed so that one endpoint from each stick in a series are perceived to be co-linear. However, while in the plane these sticks are all at the same stereoscopic depth, in the forest they are set at random different depths. When the two contours are placed next to each other so that the segment endpoints abut, as in 2, the contour is perceived to be much stronger despite not actually being present.

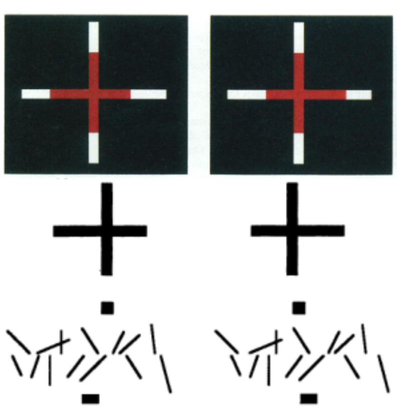

Fig. 2. From top to bottom: red sun stereogram, black cross stereogram, random forest stereogram from [1] and [2]

B. Framework

In order to create the stereograms, we use Unity [6], a comprehensive game creation tool and engine. Though Unity has a broad range of features, such as diverse lighting environments, textures, game logic, etc., for this application, we only use simple geometric features and different lighting environments. One complication is that Unity actually is designed for creating 3D scenes, so in order to generate pairs of 2D images, we actually create the scenes using flattened 3D shape, remove all shadow, and fix the camera in front of the configuration so that it is perceived to be 2D.

For example, for the red sun stereogram, we recreate the ground truth configuration by placing four flattened black rectangular prisms for the four black squares, in between which we embed an inner red cross also composed of flattened red rectangular prisms. We set the background to be white so that we do not need to create the larger white cross. For comparison, we also recreate the perceived geometric configuration: four squares in front of a floating red disc. Similarly, for the black cross stereogram, we not only create a black cross composed of two rectangles, but also a "cross" where the horizontal bar is not a planar surface, but rather a two rectangles bent to form a "V". When viewed directly, this "V" is perceived to be a planar surface.

However, creating the stereograms in this manner only gives us one geometric configuration, not two 2D images. Then in order to actually generate the two views, we use an Oculus integration library [7] for Unity. The package takes a scene and automatically generates the left view and right view with appropriate binocular disparity. The package uses average eye distance and adult height to calculate the offsets. We present some sample views from the Oculus in 7.

The package also allows user to look around the scene by rotating their head if they are wearing the Oculus, via mouse otherwise. We take advantage of this to display not only the ground truth configuration but also the perceived configuration of each stereogram. For example, in the red sun stereogram, on arrange the scene so that the user starts of seeing the ground truth configuration, but can rotate 90° to see the recreated perceived configuration. We depict the entire scene arrangement in 3.

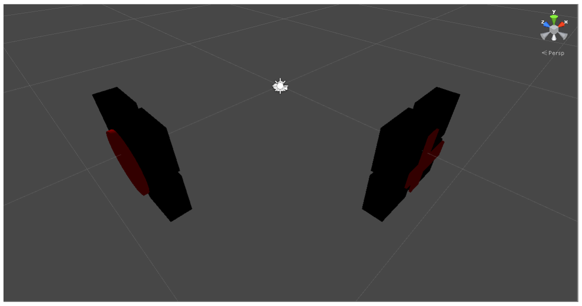

Fig. 3. Scene editor in Unity used to create the stereograms. On the left if the true perceived stereogram, with the red component a cricle. On the right, the red component is a cross but is still perceived as a red circle when viewed head on.

Then, to display the stereograms, the scene is published as an executable. When run, the application shows the left and right views to the corresponding display if the Oculus is attached. However, the program can also be run on any computer with sufficient processing power, but the user will need to fuse the images on their own.

As it stands, the work thus far only goes to show that stereograms can be replicated on the Oculus. The novel feature that we propose and implement is to allow these stereograms to be changed on the fly, via repositioning, resizing, rotating, etc. To do this, we take advantage of Unity's scripting framework. We write scripts so that the scene recognizes user input (currently keyboard input) and responds accordingly.

For the red sun stereogram, we allow users to reposition the images depthwise, in effect making the images larger or smaller. We also allow users to resize the red object, whether that is the cross or the disc, to explore the effects of different sizes. For the cross stereogram, we allow users to shift the position of the horizontal bar and move the entire configuration depthwise. We also allow the user to change the length of the horizontal bar. For the true black cross, this means simply stretching the bar lengthwise, and for the pseudo-cross, this is acheived by rotating the angle between the components of the "V". Finally, for the random forest stereogram, we allow users to shift either the forest or the plane up or down, backwards or forwards.

III. EXPERIMENTS

To verify that this system successfully recreates stereograms, we conduct two experiments.

Experiment 1: First we recreate an experiment centered around the random forest stereogram, from [1]. In this experiment, Gilliam presented four scenes: the forest alone, the plane alone, the forest and plane together with the forest far, and the forest and plane together with the forest near. We encourage readers to consult [1] for more precise details. For each scene, the subject was then asked to rate the clarity of the perceived contour located along the co-linear endpoints on a scale of 0-8 where 0 denoted no contour, 1 denoted a fuzzy contour, and 8 denoted a very strong contour. A sample scene is shown in 4

Experiment 2: In our second experiment, we test whether users are able to distinguish between the ground truth configuration and the recreated perceived configuration for the red sun and cross stereograms. For each scene and subject, we ask the subject to identify which configuration matches their perception.

We present both experiments to a single body of subjects. One notable difference from Gilliam's procedure is that our subject pool has 50% less females and 50% more males than Gilliam's original experiments. Our subjects consist of three males and one female, as opposed to Gilliam's two males and two females, but we don't expect this to significantly affect results. All subjects had normal or corrected-to-normal vision and two were naive with respect to the stimuli and experimental aims.

We display our stereograms on an Oculus Rift Development Kit 2 run from an Alienware x51 r2 computer.

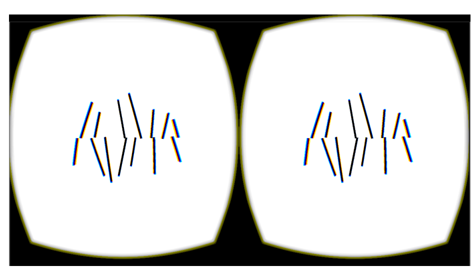

Fig. 4. Random forest stereogram as shown to subjects, with configuration forest far. In between the two halves of the stereogram, there is a clear subjective contour.

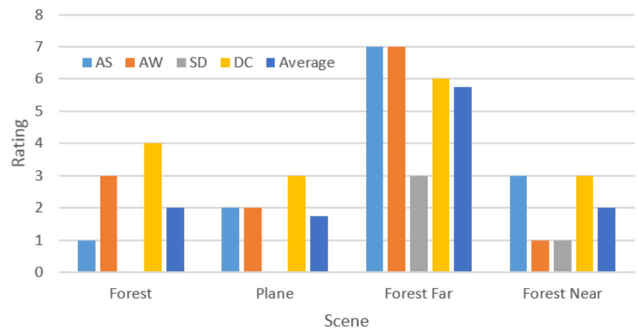

Fig. 5. Rating of subjective contour strength for all configurations over all subjects and average. These results successfully replicated those of [1]

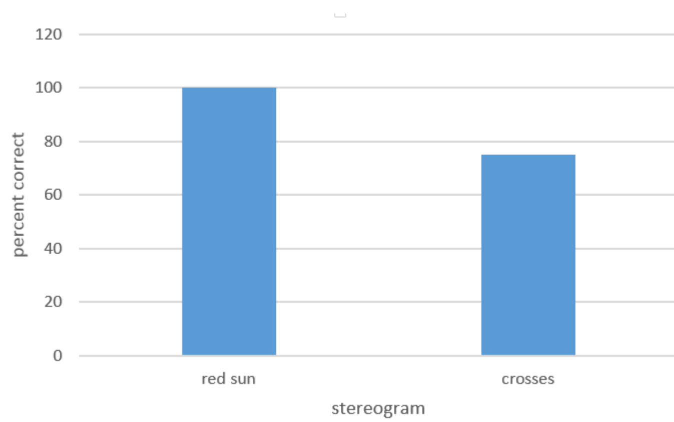

Fig. 6. Percentage of users that correctly determined recreated perceived stereogram

We present the results of experiment 1 in 5 and of experiment 2 in 6. Our results for experiment 1 largely replicate those of Gilliam. The contour between the forest and the plane was strongest when the forest was far. When either the forest or plane was presented alone, their was almost no contour perceived.

For experiment 2, subjects were largely able to guess which image was which correctly, though numerous subjects reported that they weren't sure for the cross stereogram. We attribute the high success rate to some small visual defects in the stereogram, such as slightly rounded edges of the red component of the red sun stereogram that were clues to which was the actual disc. We speculate that with additional tuning, the two images could be nearly indistinguishable.

The results from these experiments are encouraging as they suggest that the stereograms displayed on the Oculus are largely faithful to the original stereograms. This provides some evidence for the validity of our approach.

IV. RELATED WORK

Our work is primarily inspired by the work of Nakayama and associates on stereograms [1] [2]. Although our work does not directly interact with their research, we discuss their results to highlight the potential areas of application of this project.

In [1], Gillam argues that because the contour is only perceived when the forest and plane abut and not when either is viewed alone, the subjective contour is perceived on a scene analysis level, rather than image processing, as previously believed. Understanding this mechanism in human vision can guide future computer vision research.

In [2], Nakayama uses stereograms to argue that human perception is based on the principle of generic image sampling. In other words, when faced with a visual ambiguity in a scene, humans perceive the scene to be the most generic possible configuration that would generate the ambiguity. This type of conclusion has powerful implication not only for psychology and neuroscience, but also for computer vision and robotics researchers that also must deal with ambiguous visual cues when designing robot vision systems.

Where are our contribution stands to make the most impact are studies that seek to understand the limits of perceiving stereograms. For example, Erkelens conducted an experiment to find the fusional limits of random dot stereograms [8]. Crucial to his experiment was the ability to quickly and easily change the parameters of his stereograms. However, to display the stereograms, Erkelens used a system of mirrors, projectors, and colored spectacles. To change the stereograms, a computer was used to rotate the mirrors. Though the experiment was conducted successfully, it is clear that the apparatus for displaying the stereograms could be simplified to facilitate further study into the limits of stereograms.

We were unable to locate any other academic papers that incorporated the Oculus Rift. We attribute this to the fact that Oculus Rift and other virtual reality hardware is not yet released to the public or is otherwise hard to acquire. However, we were able to find some user created stereo photo viewers [9], but none that featured dynamically changing the image or were specifically created for the Oculus.

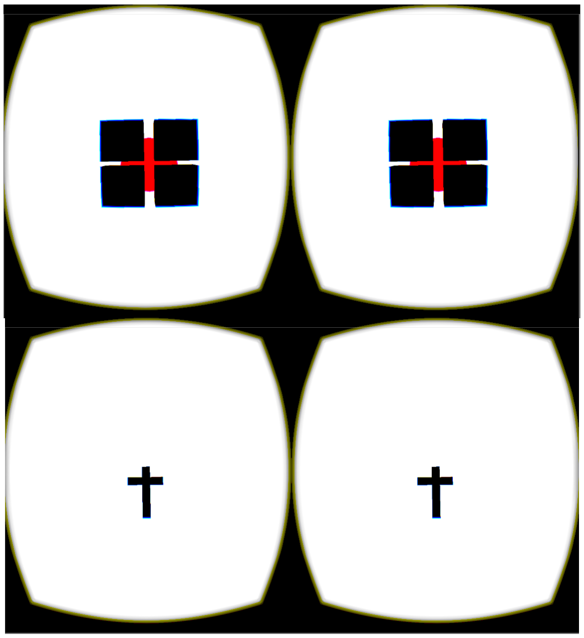

Fig. 7. Views of the sun (top) and cross (bottom) stereograms, as seen from the Oculus Rift.

V. CONCLUSIONS

In this paper, we present a novel application for the Oculus Rift: dynamic stereogram display. We walked through a system for creating new stereograms that change via user input, and through two experiments verify that they successfully replicate the stereograms.

This paper was a proof-of-concept and an exploratory step on using virtual reality hardware for displaying stereograms. There are lot of possible extensions of this project, such as creating more complex stereograms in Unity, such as random dot stereograms, or creating more controls for the stereograms we have created already. In a larger sense, we hope that these experiments will spur further research into the application of cutting edge devices, such as the Oculus Rift or other virtual reality devices, for various academic purposes, be it psychology or computer vision.

All code and relevant files will either be bundled with this report or can be found at `https://github.com/W4ngatang/cs283-final-project`.

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