James Dyson Foundation Undergraduate Bursary 2021/22 Project Report: Pixel-less Displays

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Introduction

TVs, mobile phones, smart watches, control panels, warning signs: displays are everywhere. As a result, there is always a need to develop better quality displays. Better quality displays are particularly important for virtual reality and augmented reality [1]. There currently exist many different display technologies such as LCDs and OLED displays which are already used in many applications and are being developed further [2]. These display technologies generally consist of a grid of small points called pixels, where each pixel emits light of a certain color and brightness. Since the pixels are packed closely together, this grid of pixels can be used to display quite a good quality image. Computer generated holography is a different technology which can be used to display images [3]. The aim of this project was to develop new methods of using computer generated holography with the hope of ultimately leading to better quality displays. This report will describe what computer generated holography is, and outline the results obtained by the new methods developed in this project.

Introduction to Computer Generated Holography

Holography refers to the following situation. When light shines through a hole and onto a screen behind the hole as shown in Figure 1, the light is diffracted by the hole and forms a pattern on the screen through constructive and destructive interference [3]. The pattern on the screen can be an image. The hole is called the hologram and the image on the screen is called the replay field [3].

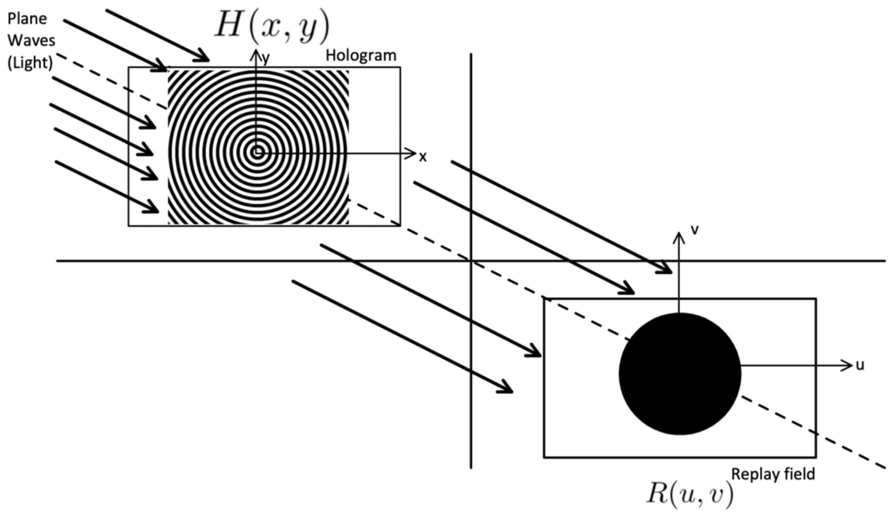


Figure 1 - Diagram illustrating holography

The relationship between the hologram and replay field is that the replay field is the Fourier transform of the hologram [4]. The Fourier transform is a mathematical operation which can be expressed by an equation. Therefore, for some simple images it is possible to calculate exactly an equation for the hologram that is required to display it [4]. For other, more complicated images the mathematics becomes either too difficult or impossible and so other methods must be used.

The scenario from Figure 1 can be setup experimentally as shown in Figure 2 [1]. A laser

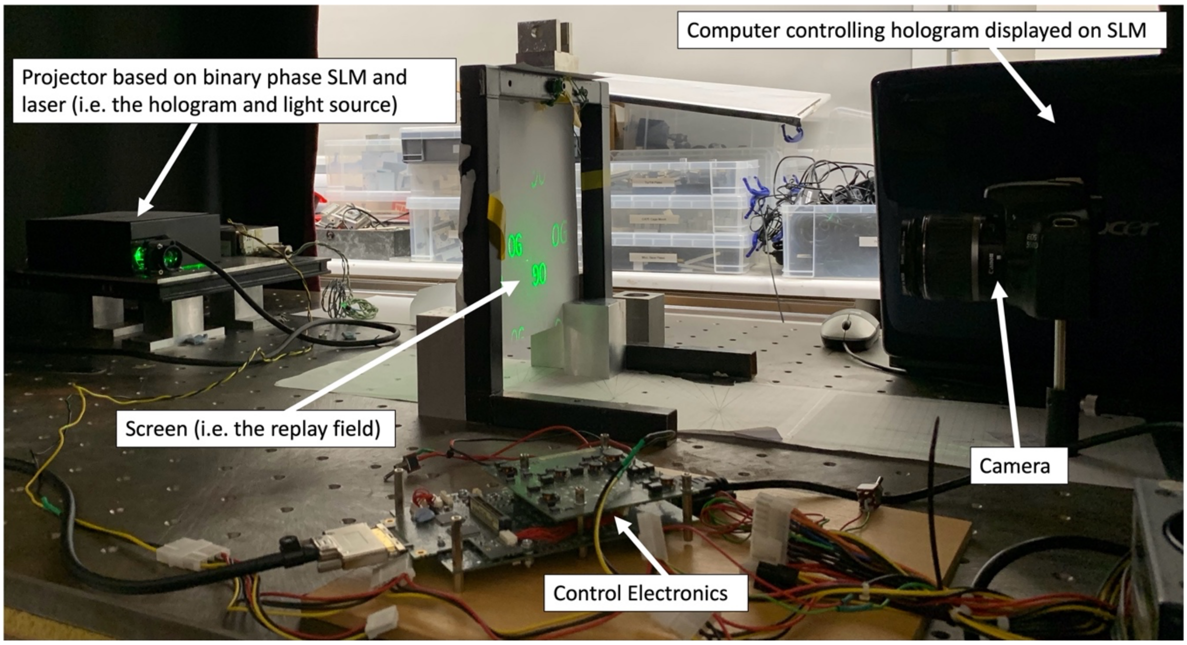


Figure 2 - Experimental setup of holographic projector

shines light through the hologram and some lenses focus it onto the screen to form the image in the replay field. A camera can be used to record the replay fields obtained.

The hologram needs to be implemented using some form of technology. One popular technology which can be used to implement holograms is the binary phase spatial light modulator (BP-SLM) [3]. A diagram of a BP-SLM is shown in Figure 3. The BP-SLM is a grid of small squares called pixels, where each pixel can take a value of +1 or -1 [3]. This value affects how the pixel affects the light than shines through it: it applies a phase shift to the light meaning that depending on if the value is +1 or -1 it slows down the light by a different amount [3]. The diagram in Figure 3 shows a 10 by 10 pixel BP-SLM, real BP-SLMs are much larger than this. For example, the one used in this project has 1024 by 1280 pixels [1].

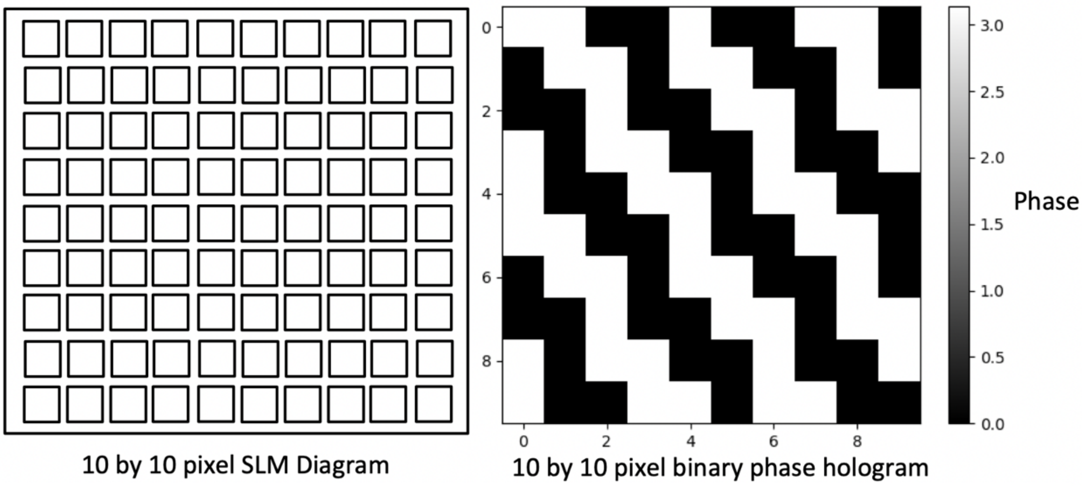
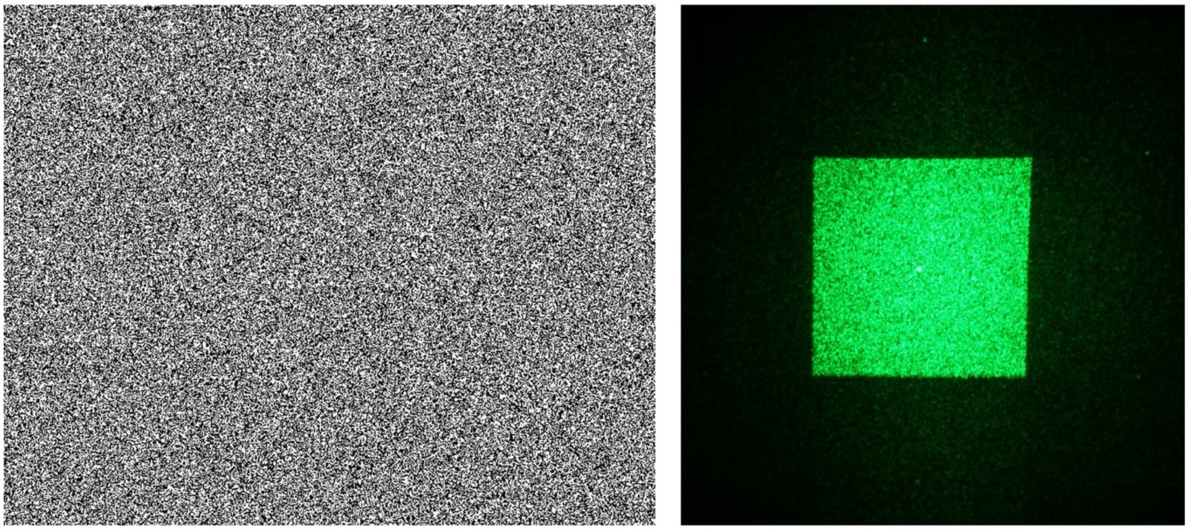


Figure 3 - Diagram showing a binary phase spatial light modulator (BP-SLM)

Current Approaches to Computer Generated Holography

If a BP-SLM is being used to implement a hologram, the main question to answer becomes the following: given an image to be displayed in the replay field, how do we set the values of the pixels of the BP-SLM to best display this image? Traditionally, we would generate the hologram by inputting the desired image into an algorithm, and the algorithm would then repeat a series of steps to produce the hologram [5]. These algorithms usually change the values of the pixels of the BP-SLM several times and try to improve the quality of the replay field obtained with each iteration [5]. One popular algorithm for generating holograms is the Gerchberg-Saxton algorithm [5]. The Gerchberg-Saxton algorithm was used to generate a hologram of an image showing a square, and the resulting hologram and replay field are shown in Figure 4.



Binary Phase Hologram for Square **Photograph of Replay Field for Square**

Figure 4 - Hologram and replay field showing a square generated by the Gerchberg-Saxton algorithm

The hologram on the left is divided into many small black or white pixels, corresponding to values of +1 or -1. When light shines through this hologram, the square shown on the right is produced in the replay field. The square is green because that is the color of the light used. The square is a bit grainy. There are some more complicated algorithms which can produce better results [5].

New Approaches to Computer Generated Holography

The previous section showed how current approaches to holography use an algorithm which repeats a series of steps a number of times to generate a hologram. It is sometimes possible to calculate exactly what hologram is required to display a certain image in the replay field using the Fourier transform, which is a mathematical operation [4]. In this project this idea was used to generate holograms by calculating the exact hologram required to display a certain image, and then manipulating the hologram so that it could be implemented on a BP-SLM. Manipulating the hologram is necessary because the BP-SLM can only take values of +1 and -1 but the ideal hologram has a much greater range of different values than this.

This new method was also used to generate a hologram for displaying a square in the replay field. The resulting hologram and replay field are shown in Figure 5.

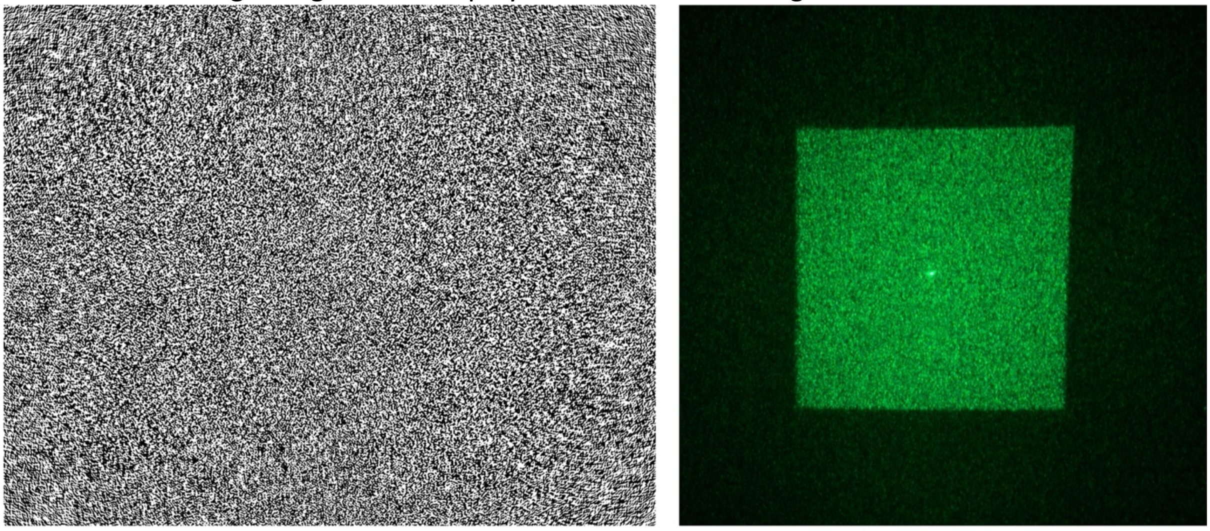


Figure 5 - Hologram and replay field displaying a square generated by the new method

We can see that the replay field produced in this way is quite similar to that produced by the Gerchberg-Saxton algorithm in Figure 4. Perhaps the quality is slightly lower as the square is less bright and perhaps appears to be a tiny bit grainier. Therefore, the new method seems to give similar although slightly inferior performance to the Gerchberg-Saxton algorithm.

However, it should be noted that it is easy for the Gerchberg-Saxton algorithm to display more complicated images such as that of the initials “OG” shown in Figure 6, but it is difficult for the new method to display more complicated images due to the required calculations becoming quite difficult or even impossible.

Figure 6 - Replay field showing the initials "OG" produced using the Gerchberg-Saxton algorithm

Further work will be required to enable the new method to display more complicated images in the replay field. In this project some initial methods of displaying more complicated images were explored. The idea behind these methods was to add together a combination of circles and squares to form more complex images. Examples of replay fields formed through this method showing a no entry sign and a cartoon robot are shown in Figures 7 and 8.

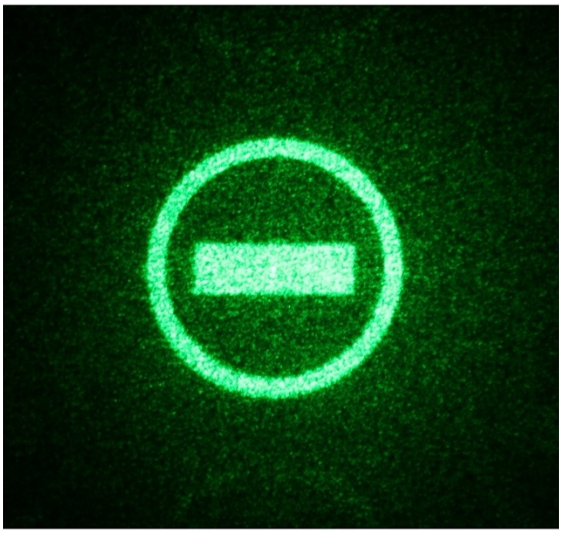


Figure 7 - Replay field showing a no-entry sign

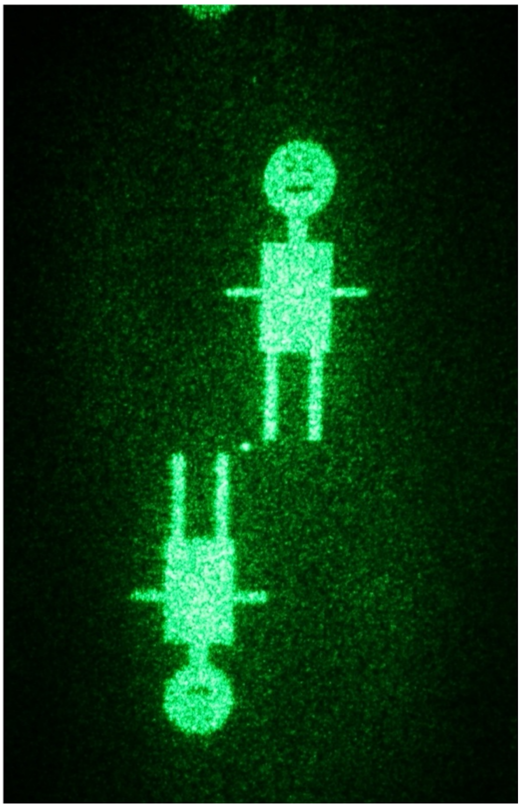


Figure 8 - Replay field showing a cartoon robot

These images are still quite simple and further work would be required to figure out how to display more complex images and improve the quality of images displayed.

Conclusion

The aim of this project was to develop new methods of generating holograms. These methods were based on the idea that if there is an image that is to be displayed in the replay field, then it can be possible to directly calculate the required hologram. This is done using the mathematical operation called the Fourier transform. The new methods performed slightly worse than the conventional Gerchberg-Saxton algorithm, and it is difficult to use them to display more complex images. Therefore, these methods need significant future work if they are to lead to better quality images produced by holography.

References

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