Gamma Correction in Holographic Projection

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In a computer-generated holographic projection system, the image is generated via diffraction of light from spatial light modulators. In this process, several factors contribute to non-linearities between the replay field and the target image. This article evaluates the gamma response of the overall system experimentally, and then applies a gamma correction method, with the aim of increasing the image quality of a holographic projection system. Both a notable increase in replay field quality alongside a significant reduction in mean squared error were observed, demonstrating the effectiveness of gamma correction in holographic projection.

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1. INTRODUCTION

Holographic projection is an exciting way of generating both two-dimensional (2D) and three-dimensional (3D) images through the controlled diffraction of coherent light. In computer-generated holography (CGH), a given hologram can be calculated through various algorithmic approaches and then displayed on a spatial light modulator (SLM) in order to create an image in the replay field through diffraction [1–4]. Digital holography has a variety of applications in measurements [5, 6], imaging [7, 8] and 2D and 3D displays [9, 10]. One of the major challenges faced by researchers is the image fidelity of the subsequent replay field, being affected by shot noise [11, 12], additive noise [13] and speckle noise [14, 15]. These types of noise present in the replay field decrease the signal-to-noise ratio (SNR) and hence, the overall image quality [16]. Researchers have utilised several digital image processing methods to reduce the noise by implementing median filters [17–19], introducing wavelet-based transformations [20] or reconstructing multiple holograms and later averaging the intensity [21].

In order to improve image quality of holographic projection, the idea of the gamma correction method arose to improve the contrast of the replay field. Every display has an inherent property known as the gamma value $\gamma$, which essentially describes the transfer function between input pixel value and output pixel energy [22]. Gamma correction is normally done via a look up table or correction curve which allows the relationship between the input and output to be adjusted. A gamma correction method was developed for the replay field of holographic projection by measuring the gamma response and applying the inverse of the response to target images.

2. EXPERIMENTAL SETUP

The holographic projector used in this experiment was a Fourier projection system developed by Freeman [23]. The laser source was a diode-pumped solid-state (DPSS) 532nm 50mW laser, with a collimator and beam expander used to achieve near-uniform illumination of the SLM. The SLM was a binary phase SXGA-R2 ForthDD ferroelectric Liquid crystal on silicon (LCOS) micro-display with a refresh rate of 1440Hz, and a resolution of 1280x1024, and a pixel pitch of 13.6 µm.

The holograms uploaded to the SLM were generated using the one-step phase retrieval (OSPR) algorithm [4]. Each group of 24 individual, binary-phase holograms are encoded as the 8-bit reg, green, blue (RGB) channels of a 24-bit image to interface with the SLM driver electronics. The SLM displays each bit plane sequentially, with ones and zeros mapping to opposing phase modulations of each pixel. The images were captured using a Canon 550D camera with an EFS 18-55mm lens. The images captured were in 24-bit RGB colour, which were subsequently converted to grey-scale in 8-bit depth when calculating mean squared error (MSE).

3. DETERMINING THE GAMMA CORRECTION CURVE

To determine the gamma correction curve of the holographic projection system, the gamma response needs to be measured first. A hologram was generated to form a linear grey-scale ramp of brightness from 0% to 100% as shown in Fig. 1(a), along with a single pixel white (100%) strip at the left end as a fiducial marker to demonstrate the beginning of the grey-scale region [4].

The projection output of the linear grey-scale ramp was captured as shown in Fig. 1(b). From this the gamma response curve was determined, by averaging each column of pixels and normalising to a percentage scale, forming the blue line in Fig. 1(c). A three-degree polynomial fit was applied, generating a smoothed gamma response curve (yellow line in Fig. 1(c)).
Fig. 1. Gamma response characterisation and correction. (a) Input linear grey-scale ramp, (b) Holographic projection replay field of (a), (c) Original gamma response curve and according correction curve, (d) Gamma corrected grey-scale ramp, (e) Holographic projection replay field of (d), (f) Gamma response curve after correction.

The resultant gamma response curve exhibits a high degree of non-linearity. By taking the mean of the square of the error between the measured output (blue line) and the linear reference (green dashed line), the MSE of the measured output was calculated to be 0.023773. To correct the gamma response, the gamma correction curve (red line) was formed by inverting the gamma response curve.

Subsequently the gamma correction curve was implemented to adjust the grey-scale ramp, achieving the gamma corrected grey-scale ramp as shown in Fig. 1(d). The gamma corrected projection output was captured as shown in Fig. 1(e). By using the same method of averaging columns of pixels, the gamma corrected output was measured and plotted in Fig. 1(f). It can be seen that the corrected gamma response was much closer to linear comparing to the original gamma response, and the MSE was calculated to be 0.001484.

|                        | MSE     | Normalised Error |
|------------------------|---------|------------------|
| Native gamma response  | 0.023773| 100%             |
| Gamma corrected response | 0.001484| 6.24%           |

Table 1. Gamma response results before and after gamma correction

Hence, as demonstrated in Tab. 1, gamma correction achieved a 93.76% reduction in MSE, which was a significant improvement, proving the effectiveness of gamma correction method on the grey-scale ramp.

4. APPLICATION OF GAMMA CORRECTION TO REAL-WORLD TEST IMAGES

The gamma correction curve obtained in Section 3 was then applied to the two sample images as shown in Fig. 2.

The replay fields of the holographic projection of uncorrected images are shown in Fig. 3 (a) and (c), and the replay fields of the holographic projection of images after gamma correction are shown in Fig. 3 (b) and (d) respectively.

As shown in Fig. 3 (a), it can be seen that, before gamma correction, the edges between the buildings and the sky were quite ambiguous, with most detail of the sky being lost. In comparison, after gamma correction, the replay field (in Fig. 3 (b)) provided not only sharper edges between buildings and the sky, but also more detail of clouds in the sky. The MSE of the replay field for sample image 1 decreased from 0.06139 to 0.04920, which was a 19.86% reduction.

In Fig. 3 (c), before gamma correction, the horse was difficult to distinguish from the background, especially around the horse’s back area. But after gamma correction, as shown in Fig.
3 (d), contrast has been significantly boosted and the fine detail around this part of the horse is more evident. The MSE of the replay field for sample image 2 decreased from 0.04309 to 0.03635, which was a 15.64% reduction.

| Sample image 1 | MSE     | Normalised Error |
|----------------|---------|------------------|
| Before gamma correction | 0.06139 | 100%             |
| After gamma correction  | 0.04920 | 80.14%           |

| Sample image 2 | MSE     | Normalised Error |
|----------------|---------|------------------|
| Before gamma correction | 0.04309 | 100%             |
| After gamma correction  | 0.03635 | 84.36%           |

Table 2. Gamma correction results for sample images

Hence, as summarised in Tab. 2, gamma correction achieved a 19.86% reduction in MSE for sample image 1 and a 15.64% reduction in MSE for sample image 2, proving the effectiveness of gamma correction method on real-world test images.

5. CONCLUSION

The gamma response of holographic projection can exhibit a high degree of non-linearity. By projecting a linear grey-scale ramp, the gamma response of the holographic projection system was measured. The gamma correction curve, which was simply the inverse of gamma response, was applied to the grey-scale ramp and successfully reduced the MSE by 93.76%. And then the gamma correction method was applied on two sample images, it was observed that more details were shown in the replay field after gamma correction, and the MSE’s of the two example images were reduced by 19.86% and 15.64%. Hence, we have demonstrated the effectiveness of gamma correction method to boost image quality for a holographic projection system.

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