Analogous reconstruction of digital holograms

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When digital holograms are reconstructed optically by a spatial light modulator with a different pixel pitch compared to the recording camera, the size of the reconstruction changes. A method is proposed to compensate this difference by digitally processing the holograms. The impact on reconstruction quality is analyzed and optimization strategies are evaluated.

1 Introduction

The most common way to obtain the reconstructed amplitude or phase image in digital holography is by numerical reconstruction. The various algorithms developed for this task are well understood and in general fast enough to run on any computer. Sometimes however it might be useful to obtain these informations physically by reconstructing optically with laser light.

This is the case for digital comparative holography [1]. This method uses the digitally recorded hologram of a master object to illuminate a different test object in order to obtain information about surface deviations between both objects. However, this needs an accurate and high quality reconstruction of the hologram to work correctly.

2 Pixel pitch and hologram size

Both the recording camera and the spatial light modulator which is used to display the hologram have a discrete pixel structure. Unfortunately the pixel pitches of those two devices seldom match and can differ largely. While it may be possible to find a pair of devices with matching pitches, doing so imposes additional restrictions on the experimentator. Besides the financial aspect of aquiring new equipment, it limits the possible choices for choosing a camera or SLM.

When reconstructing the hologram with a spatial light modulator of different pixel size, the total area of the hologram changes. Using a camera with a pixel pitch of l_C, the recorded hologram will have a length of $n_{Cx}l_C \times n_{Cy}l_C$ in x- and y- direction respectively. Assuming the display device with the pixel pitch l_D is large enough, the unchanged hologram would have a size of $n_{Cx}l_D \times n_{Cy}l_D$. In other words, the hologram would be scaled by a factor of $\frac{l_D}{l_C}$. Hence, the size of the reconstructed image changes accordingly and makes it impossible to use the hologram for the aforementioned purpose.

3 Numerical compensation

To compensate this and to make the reconstruction accurate again, the hologram has to be scaled by the inverse factor $\frac{l_C}{l_D}$. Therefore the resolution of the hologram has to be changed to $n_{Cx}\frac{l_C}{l_D} \times n_{Cy}\frac{l_C}{l_D}$ to make it the same physical size as on the CCD chip of the camera. Because in general most cameras have smaller pixel sizes than the available SLMs, this will likely be a downsampling and therefore make the hologram smaller.

During our experiments we used an AVT Marlin F201 camera with a pixel pitch of 4.4 µm and a resolution of 1628×1236 pixel. The LCoS we used was a LC-R 1080 from holoeye with a resolution of 1920×1200 pixel. It has a pixel pitch of 8.1 µm, so the hologram has to be scaled by a factor of 0.54 to a resolution of 884×671 pixel. The maximum phase delay it could achieve was 0.85π, as seen in the phase curve in Fig. 1.

Since the scaled hologram only uses a quarter of the display area of the LCoS, smaller and cheaper display devices may be used. But since the reconstruction quality degrades and specle size increases because of the lower display resolution, a camera with a higher resolution might be prefered.

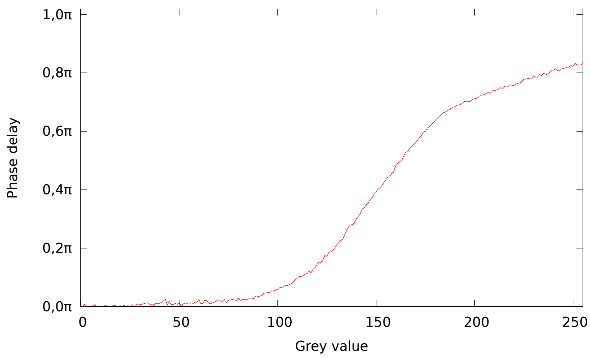

Fig. 1 *Measured phase delay of the LCoS as a function of the displayed grey value*

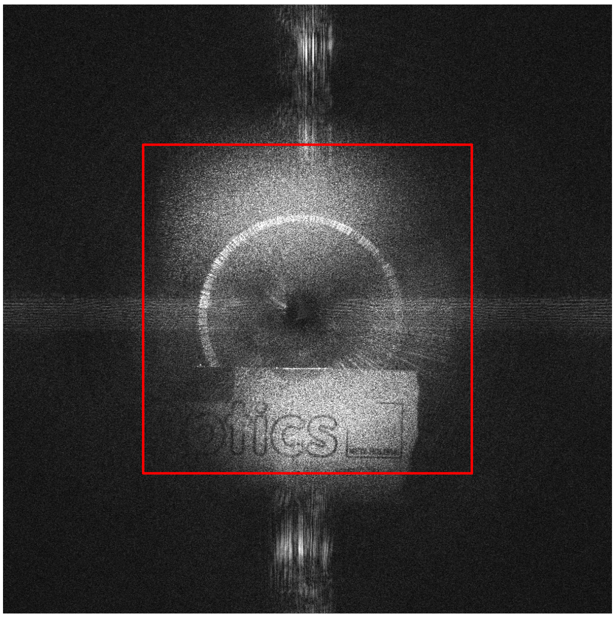

***Fig. 2** Recorded hologram with the reconstruction area of the LCoS highlighted*

4 Effects of the hologram scaling

According to the sampling theorem downsampling works like a lowpass filter and causes high frequencies to be lost. In digital holography in particular the downscaling causes high spatial frequencies to be cut from the reconstruction. Calculating the width of interference fringes and using the Nyquist theorem, it can be shown that the camera CCD chip is only able to record light waves with an incident angle smaller than $\frac{\lambda}{2l_C}$. Likewise, the microdisplay has a maximum reconstruction angle of $\frac{\lambda}{2l_D}$. Figure 2 shows a recorded hologram and the area of it that is possible to reconstruct with the LCoS. In our setup it was limited to an angle of 1.9° compared to a recording angle of 4.1°.

A detailed analysis of the influence of resampling holograms and a comparison of different resampling algorithms can be found in [2]. According to this, bilinear or bicubic algorithms are best suited for resampling holograms. Since the quality difference between both is rather small the bilinear algorithm was used as it is already implemented in many image libraries.

Nevertheless, even a bilinear resampling is an interpolation and therefore behaves like a lowpass filter by damping high spatial frequencies. The particular frequency response of a bilinear resampling operation with the parameters of our setup is shown in Fig. 3. It can be observed that higher frequencies are reduced in their intensity even though they can possibly be reconstructed with the used SLM. This makes reconstructed areas darker the further they are away from the center, an effect that could be easily observed in our experiments. Since resampling quality improves with more dense sampling points of the original image, using a camera with smaller pixel pitches can help reducing this effect.

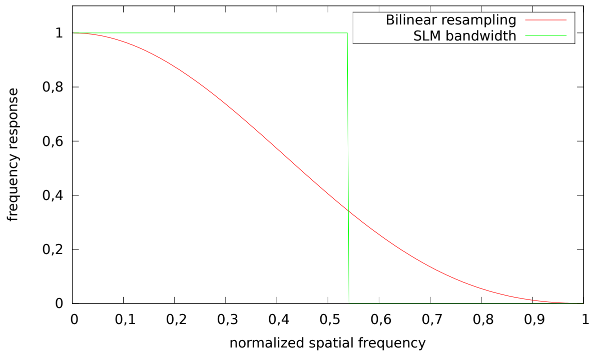

***Fig. 3** Frequency damping due to resampling in our experimental setup*

5 Conclusion

It has been shown that it is possible to reconstruct digital holograms with SLM devices that have a different pixel size as the camera that recorded it. Matching pitches should be preferred, but are not necessary since the reconstruction quality of scaled holograms is sufficiently high.

However this method is limited to small objects that are located near the center of the recorded area.

References

[1] T. Baumbach, “Investigations of Comparative Digital Holography with Active Wave Front Modification”, in *Strahltechnik, Bd. 35* (BIASVerlag, Bremen 2008)

[2] T. J. Naughton et al., “Compression of digital holograms for three-dimensional object recognition”, in *Proceedings of SPIE Vol. 4471 (2001)*