Demodulation of Holographically Reconstructed 2-D Signals with Spatial Quadrature Amplitude Modulation

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Abstract: Demodulation of holographically recorded and retrieved signal beams, whose intensities and phases are spatially modulated with multiple values, is experimentally demonstrated to increase the storage capacity of holographic data storage. The intensity and phase modulated signal beams are generated by serially arranged two liquid crystal spatial light modulators and recorded in the holographic material. The intensity and the phase of the reconstructed signal are demodulated by the phase-shifting interferometry. Feasibility and potential of this kind of modulation are discussed with the constellation plots of the demodulated signals.

1. Introduction

Recent years, spatial quadrature amplitude modulation (SQAM) has been expected as one of the signal modulation methods to increase the capacity of holographic data storage (HDS).[1] Although two-dimensional intensity distribution of the signal beam is modulated merely in two brightness levels in the conventional modulation method, both the intensity and the phase of the signal beam are spatially modulated with multiple values in SQAM. To detect the SQAM signals, phase-shifting interferometry (PSI) which requires plural interferograms having the different spatial phase from each other is generally employed.[2] However, this technique decreases the data transfer rate of HDS because multiple interferograms should be captured per a datapage. To improve the data transfer rate, we have proposed the novel detection technique for SQAM-based holographic data storage system referred to as phase-shift embedding method.[3] In ref.3, only the spatial phase of the signal beam was modulated in order to simply confirm the basic operation principle of our proposing method.

In this paper, we experimentally demonstrate the demodulation of holographically recorded and retrieved SQAM signals in which both the intensity and the phase are fully modulated with multiple values. The SQAM signal beams are generated by serially arranged two liquid crystal spatial light modulators and recorded in the holographic material. The intensity and the phase of the reconstructed signal are demodulated by the PSI. Note that the demodulation is implemented by conventional four-step PSI in this paper because the main purpose of the experiment is experimental realization of modulation and demodulation of fully intensity- and phase-modulated SQAM signal. Feasibility and potential of this kind of modulation are discussed with the constellation plots of the demodulated signals.

2. Spatial Quadrature Amplitude Modulation and Phase-shifting Interferometry

Figure 1 shows the conceptual diagram of the holographic data storage system with SQAM. Both the intensity and the phase of the signal beam are modulated with multiple values. At the moment, the combination of the intensity-type and the phase-type spatial light modulators (SLMs) is used to generate the SQAM signal. In this paper, we adopt conventional four-step phase-sifting interferometry to demodulate the SQAM signal where the intensity and the phase of the signal beam is calculated by the following well-known equations.[2]

$$I(x,y) \propto \{I_4(x,y) - I_2(x,y)\}^2 + \{I_1(x,y) - I_3(x,y)\}^2 \quad (1)$$

$$\phi(x,y) = \tan^{-1}\left[\{I_4(x,y) - I_2(x,y)\}/\{I_1(x,y) - I_3(x,y)\}\right] \quad (2)$$

$I_j(x,y)$ denotes the intensity distribution of the interferogram of the signal beam recalled from the hologram and the reference beam with the phase retardations of 0 (j=1), π/2 (j=2), π (j=3) and 3π/2 (j=4).

3. Experiment

We experimentally demonstrate holographic recording, retrieving, and demodulation of the SQAM signal with PSI. Figure 2 shows the experimental setup. The diode-pumped solid state laser of the wavelength of 532nm is used as the light source. The SAQM signal beams are generated by serially arranged two liquid crystal spatial light modulators. Here LC-2002 (Holoeye) and LCOS-SLM x10468 (Hamamatsu Photonics) are used as the intensity and the phase spatial modulators, respectively. The spatial distributions of the intensity and the phase of the signal beam are two-dimensionally modulated according to the patterns with 8×8 pixels as shown in Fig.3. In Fig.3 (b), the gray-level indicates the depth of the phase modulation, and the black (0) and the white (255) correspond to 0 deg. and 360 deg., respectively. The SQAM signal is demodulated by the four-step PSI in which the phase retardation of the reference beam 2 in Fig.2 is sequentially changed by the piezo-driven mirror, and the four interferograms with the phase-shifts of 0, π/2, π and 3π/2 are captured. In the following, we denote the number of the intensity modulation level N_I and that of the phase modulation level N_P as (N_I, N_P). The demodulated symbols of the SQAM signals are plotted in the constellation diagrams in Fig.4. It is shown that the constellation points of (2, 4), (2, 8) and (3, 4) can be separably recognized, although discrimination of the symbols of (2, 16), (3, 8) and (3, 16) are relatively difficult. Increase of the dispersion in the constellation plots is considered to be caused by the error in the shift amount of the piezo-driven mirror, aberration of the lenses and so on.

4. Conclusions

Holographically recorded and retrieved signal beams, whose intensities and the phases are spatially modulated with multiple values, have been successfully demodulated by the phase-shifting interferometry. Increasing the number of pixels and intensity/phase levels are future subjects as well as the quantitative evaluation of the demodulated signals.

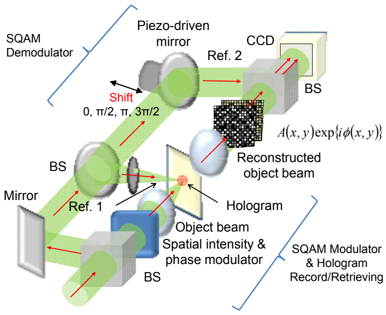


Fig. 1: Conceptual diagram of holographic data storage system with SQAM signal.

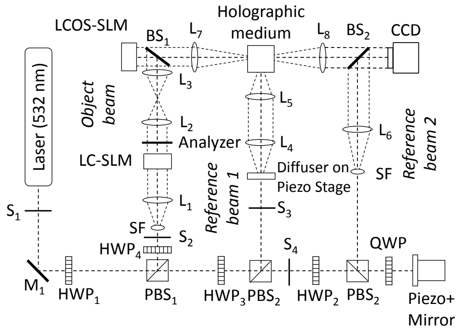
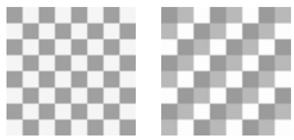
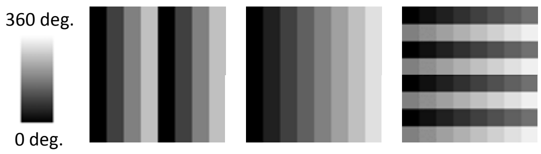


Fig. 2: Experimental Setup.

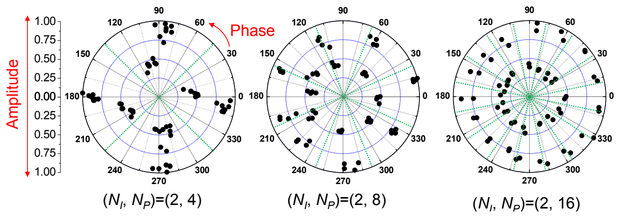


(a) 2- and 3-valued intensity modulation patterns

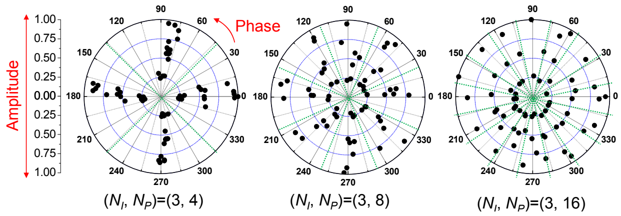


(b) 4-, 8- and 16-valued phase modulation patterns

Fig. 3: Intensity and phase modulation patterns.



(a) 2-valued intensity modulation with 4-, 8- and 16-valued phase modulations from left to right



(b) 3-valued intensity modulation with 4-, 8- and 16-valued phase modulations from left to right

Fig. 4: Constellation plots of demodulated SQAM signals.

References

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